UNDERWATER INSPECTION OF BRIDGES

DEMONSTRATION PROJECTS
DIVISION

FEDERAL HIGHWAY ADMINISTRATION
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WASHINGTON, D.C. 20590

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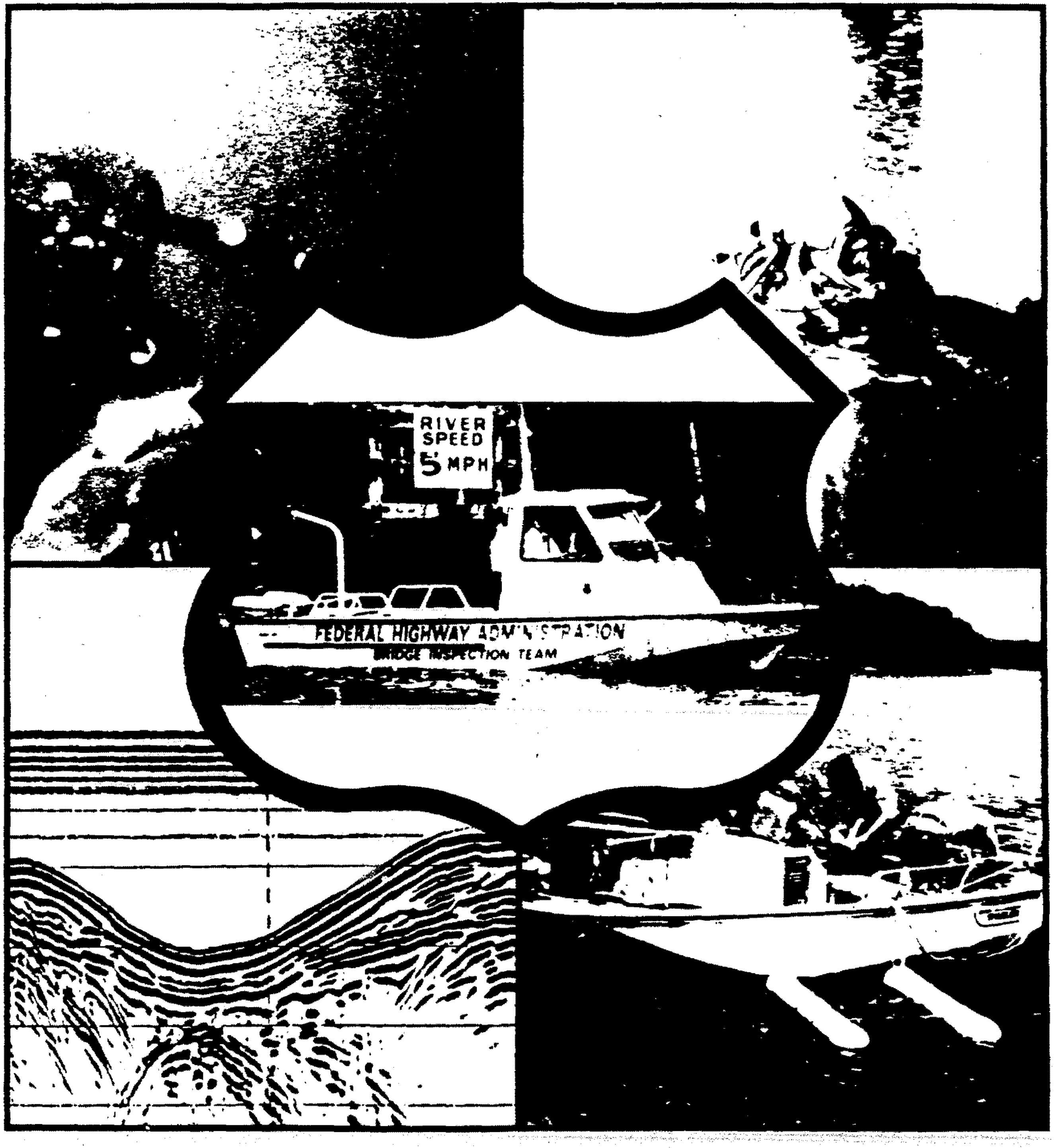

Underwater Inspection of Bridges

Report No. FHWA-DP-80-1

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16. Abstract

To ensure public safety and to protect the capital investment in bridges over water, underwater members must be inspected to the extent necessary to determine their structural condition with certainty. Underwater inspections must also include the streambed. In shallow water, underwater inspections may be accomplished visually or tactilely from above the water surface; in deep water, however, inspections will generally require diving or other appropriate techniques to determine conditions. Underwater diving, inspection, and documentation equipment has improved in quality in recent years, and the underwater inspector has a wide range of equipment and techniques available to him.

The purpose of this manual is to provide guidelines for underwater bridge inspection; acquaint those responsible for bridge safety with underwater inspection techniques and equipment; and briefly present methods of repair for commonly found defects. It should be of interest to bridge and maintenance engineers, technicians and inspectors. This manual is a stand alone supplement to the Bridge Inspector's Training Manual and was prepared in accordance with its procedures and rating systems.

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PREFACE

The bridge structures of today reflect technological advances in design, and construction that have evolved over the years. Nevertheless, these advances have not precluded unfortunate and, in some instances, tragic occurrences. The collapse of the Silver Bridge in 1967, aroused increased interest in the inspection and maintenance of bridges and prompted the United States Congress to add a section to the Federal-Aid Highway Act of 1968 requiring the Secretary of Transportation to establish a national bridge inspection standard and to develop a program to train bridge inspectors.

In April 1985, the collapse of the U.S. Route 43 Bridge over Chickasawbogue Creek near Mobile, Alabama prompted the Chief of the Bridge Division of the Federal Highway Administration (FHWA) to issue a memorandum to FHWA regional offices stressing the importance of underwater inspection, and ordering steps to ensure that each state has a well-founded underwater inspection program.

The tragic collapse of the New York State Thruway Bridge over Schoharie Creek in April, 1987 in which ten persons died and the U.S. Route 51 Bridge over the Hatchie River near Covington, Tennessee in April, 1989 in which eight persons died again illustrate the critical importance not only of underwater investigations but also appropriate correction of deficiencies discovered.

In October 1988, revisions to the National Bridge Inspection Standards (NBIS) became effective which, among other stipulations, mandate that a master list be developed of all bridges which require underwater inspection; that procedures be determined for the underwater inspections, and that the frequency of inspection for each bridge, not to exceed five years, be determined. In 1988, to assist bridge owners in complying with these new requirements, FHWA issued two Technical Advisories, "Revisions to the National Bridge Inspection Standards (NBIS)" and "Scour at Bridges", which included guidelines for underwater inspections and scour investigations. The procedures in the FHWA Technical Advisories are not regulatory or policy but rather the best FHWA technical advice.

This manual was prepared as part of the FHWA's Demonstration Project 80, Bridge Inspection Techniques and Equipment, which included presentation of a 2-1/2 day course for state highway organizations throughout the country. Many organizations and individuals have contributed photographs, slides, and other graphic materials which have been used in the class presentation and this manual; many others have offered suggestions for both the course and the manual. Their assistance is acknowledged and appreciated.

Although it is intended that this manual reflect current NBIS requirements at the time of its publication, it may not in all instances reflect current FHWA interpretation of underwater inspection requirements. Readers are urged to refer to the NBIS and the American Association of State Highway Transportation (AASHTO) Manual for the Maintenance Inspection of Bridges.

To facilitate use of this manual and in the interest of clarity and brevity, single-gender pronouns are used. "He" is to be read as "he or she" and so on.

METRIC (SI*) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

LENGTH

Symbol	When You Know	Multiply By	To Find	Symbol
in	inches	2.54	millimetres	mm
ft	feet	0.3048	metres	m
yd	yards	0.914	metres	m
mi	miles	1.61	kilometres	km

AREA

Symbol	When You Know	Multiply By	To Find	Symbol
in^2	square inches	645.2	millimetres squared	mm^2
ft^2	square feet	0.0929	metres squared	m^2
yd^2	square yards	0.836	metres squared	m^2
mi^2	square miles	2.59	kilometres squared	km^2
ac	acres	0.395	hectares	ha

MASS (weight)

Symbol	When You Know	Multiply By	To Find	Symbol
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg

VOLUME

Symbol	When You Know	Multiply By	To Find	Symbol
fl oz	fluid ounces	29.57	millilitres	mL
gal	gallons	3.785	litres	L
ft^3	cubic feet	0.0328	metres cubed	m^3
yd^3	cubic yards	0.0765	metres cubed	m^3

NOTE: Volumes greater than 1000 L shall be shown in m^3.

TEMPERATURE (exact)

Symbol	When You Know	Multiply By	To Find	Symbol
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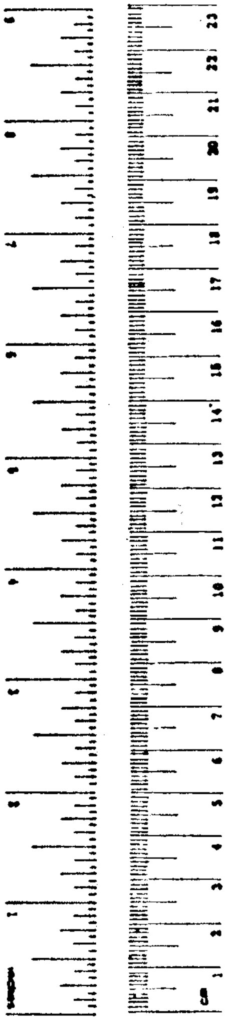

APPROXIMATE CONVERSIONS TO SI UNITS

LENGTH

Symbol	When You Know	Multiply By	To Find	Symbol
mm	millimetres	0.039	inches	in
m	metres	3.28	feet	ft
m	metres	1.09	yards	yd
km	kilometres	0.621	miles	mi

AREA

Symbol	When You Know	Multiply By	To Find	Symbol
mm^2	millimetres squared	0.0016	square inches	in^2
m^2	metres squared	10.764	square feet	ft^2
km^2	kilometres squared	0.39	square miles	mi^2
ha	hectores (10 000 m^2)	2.53	acres	ac

MASS (weight)

Symbol	When You Know	Multiply By	To Find	Symbol
g	grams	0.0353	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams (1 000 kg)	1.103	short tons	T

VOLUME

Symbol	When You Know	Multiply By	To Find	Symbol
mL	millilitres	0.034	fluid ounces	fl oz
L	litres	0.264	gallons	gal
m^3	metres cubed	35.315	cubic feet	ft^3
m^3	metres cubed	1.308	cubic yards	yd^3

TEMPERATURE (exact)

Symbol	When You Know	Multiply By	To Find	Symbol
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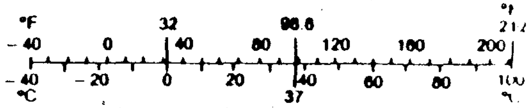

These factors conform to the requirement of FHWA Order 5190 1A

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* SI is the symbol for the International System of Measurements

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CHAPTER I

ESTABLISHING AN UNDERWATER INSPECTION PROGRAM

SECTION 1. IDENTIFICATION OF BRIDGES FOR UNDERWATER INSPECTIONS

1-1.1 Need for Underwater Inspections

Approximately 86 percent of the bridges in the National Bridge Inventory (NBI) are built over waterways and most bridge failures occur because of underwater problems. Underwater members must be inspected to the extent necessary to determine with certainty that their condition has not compromised the structural safety of the bridge. To achieve that certainty, bridge owners may have to employ one or more specialized underwater inspection techniques. These techniques may include visual and tactile inspections during periods of low water by wading, diving inspections, remotely operated vehicles and underwater cameras, radar and sonar, sounding equipment, sampling equipment, and other specialized inspection equipment as needed to determine underwater structural and streambed conditions.

Bridges that cross waterways often have foundation elements located in water to provide the most economical total design. Where these elements are continuously submerged, underwater inspection and management techniques must be used to establish their condition so that failures can be avoided. (Figs. 1-1 and 1-2).

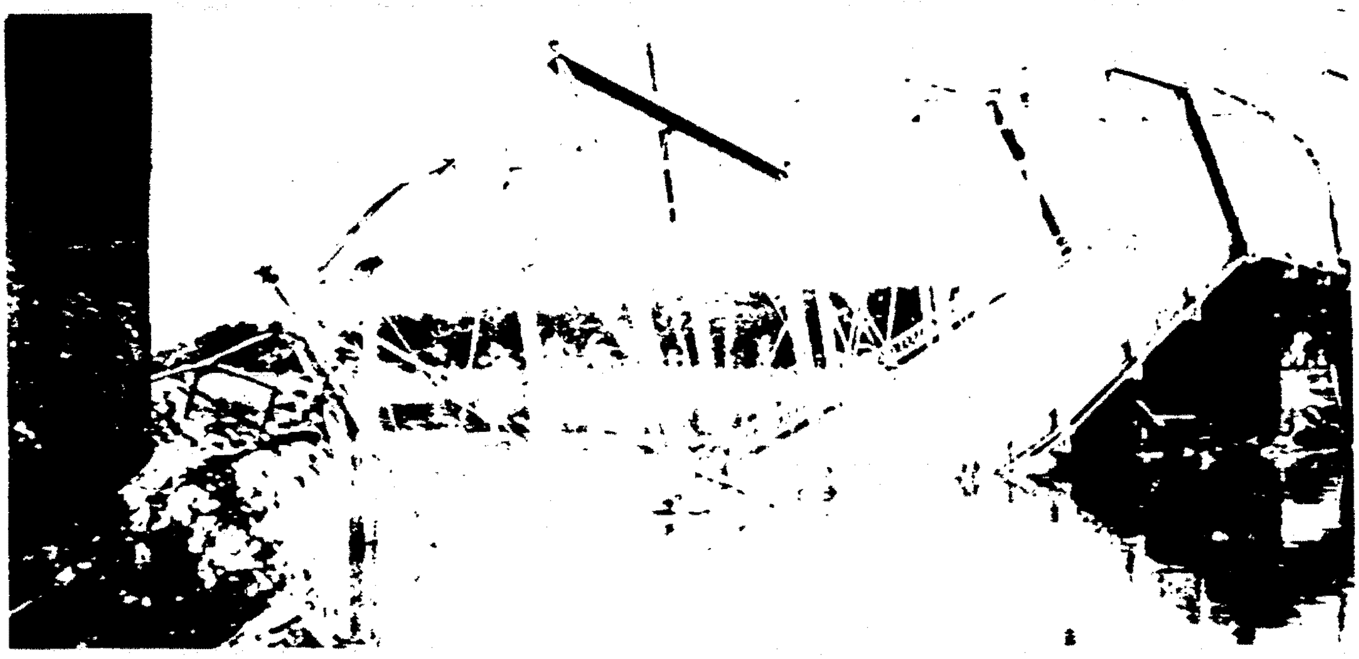


Figure 1-1 Bridge failure.

Underwater inspection, including the streambed, is only the first step in the investigation of a bridge. The inspection results must be evaluated by qualified engineers. In many cases, a bridge located over water must be evaluated by a multi-disciplinary team including structural, hydraulic, and geotechnical engineers.

Figure 1-2 Bridge failure.

1-1.2 Bridge Selection Criteria

The National Bridge Inspection Standards (NBIS) require that all bridges with substructures located in water receive periodic inspections of the submerged elements. A comprehensive review must be made of all bridges contained in an agency's inventory to determine which bridges require underwater inspection. Many combinations of waterway conditions and bridge substructures exist. For any given bridge, the combination of environmental conditions and structure configuration can significantly affect the requirements of the inspection. Those bridges which require underwater inspection must be noted on individual inspection and inventory records as well as be compiled in a master list. For each bridge requiring underwater inspection, the following information should be included as a minimum:

(a) Type and location of the bridge.
(b) Type and frequency of required inspection.
(c) Location of members to be inspected.
(d) Inspection procedures to be used.
(e) Dates of previous inspections.
(f) Special equipment requirements.
(g) Findings of the last inspection.
(h) Follow-up actions taken on findings of the last inspection.

Water depth, clarity and current influence the selection of methods of inspection. In waterways with slow currents and maximum depths of a few feet, an underwater inspection might be conducted by wading and probing provided that the structural condition of the underwater elements can be determined with certainty. Wading inspections can often be performed by regular bridge inspection teams with waders and a life preserver. For greater depths, diving or other specialized methods or equipment are typically required. In determining whether a bridge can be inspected by wading or whether it requires the use of diving equipment, water depth can not be the sole criteria. Channel bottom conditions such as softness, mud, "quick" conditions and slippery rocks; current; debris; water visibility; and structure configuration affect the ability of a wading inspector to determine structural safety with certainty. Even in water less than three feet deep, it may not be safe for an inspector in waders to inspect a structural element below water. Bridge owners should have a written rationale and criteria for determining which bridges require underwater inspection; the inspection procedures to be employed for various situations; and the maximum inspection frequency for each specific bridge.

a. <u>Scheduled Inspections</u>. Routine inspections of substructures in water must be conducted at least every five years. Five years is a maximum interval which is only appropriate for a structure in excellent condition. Structures having underwater members which are partially deteriorated or which are in unstable channels require shorter inspection intervals. The American Association of State Highway and Transportation Officials' (AASHTO) Manual for Maintenance Inspection of Bridges requires that steel substructure elements located in corrosive environments be inspected at least once every two years.

b. <u>Non-scheduled Inspections</u>. Certain conditions and events affecting a bridge may require more frequent inspections. These include, but are not limited to the following:

(1) Unusual Floods. Bridge elements located in streams, rivers, and other waterways with known or suspected scour potential should be inspected after every major runoff event to the extent necessary to ensure bridge foundation integrity.

(2) Vessel Impact. Bridges should be inspected underwater if there is visible damage above water. This should be done in order to determine the extent of damage and to establish the extent of liability of the vessel owner for damages (Fig. 1-3). It is especially important to inspect vessel damage in busy channels in a timely manner so that damage can be attributed to the proper vessel.

Figure 1-3 Bridge pier struck by a ship.

(3) Unusual Ice Floes. Ice floes can damage substructure elements, and accumulations of ice on the elements can cause scouring currents or increase the depth of scour.

(4) Prop Wash From Vessels. Prop wash, i.e., turbulence caused by the propellers of marine vessels, can cause scouring currents and may propel coarse-grained bottom materials against substructure elements in a manner similar to that of blast cleaning operations.

(5) Build-Up of Debris at Piers or Abutments. This material build-up effectively widens the element and may cause scouring currents or increase the depth of scour.

(6) Evidence of Deterioration or Movement. Many underwater deficiencies only become apparent above water when the distress extends above the waterline or is manifested by lateral movement or settlement. Bridges should also be inspected underwater following significant earthquakes.

(7) Adverse Environmental Conditions. Brackish water, polluted water, and water with high concentrations of chemicals may cause rapid and severe deterioration of materials.

(8) Critical Location in Highway System. Structures whose loss would cause significant economic damage to the community may warrant more frequent inspections even though the structure is generally in good condition.

SECTION 2. UNDERWATER INSPECTION

1-2.1 Levels of Inspection

Underwater inspection practices developed by offshore certification agencies, such as Lloyds of London, and the U.S. Naval Facilities Engineering Command have led to widespread acceptance of standard "levels of inspection". The levels of inspection, as defined below, are indicative of the level of effort required for various inspections and provide a system for standardization of inspection terminology. Three levels of inspection have been adopted by the Federal Highway Administration (FHWA). These levels, as defined more fully below, may be summarized as:

Level I: Visual, tactile inspection
Level II: Detailed inspection with partial cleaning
Level III: Highly detailed inspection with Non-Destructive Testing (NDT)

a. <u>Level I Inspection</u>. A Level I inspection includes a close visual examination, or a tactile examination using large sweeping motions of the hands where visibility is limited. Although the Level I inspection is often referred to as a "swim-by" inspection, it must be detailed enough to detect obvious major damage or deterioration due to over-stress, or severe deterioration or corrosion. It should confirm the continuity of the full length of all members, and detect undermining or exposure of normally buried elements. A Level I inspection is normally conducted over the total exterior surface of each underwater structure element, whether it be a pier, abutment, retaining wall, bulkhead, or pile bent. A Level I inspection may also include limited probing of the substructure and adjacent streambed.

The results of the Level I inspection provide a general overview of the substructure condition and verification of the as-built drawings. The Level I inspection can also indicate the need for Level II or Level III inspections, and aid in determining the extent and selecting the location of more detailed inspections.

Figure 1-4 Level II cleaning of a pile.

b. Level II Inspection. A Level II inspection is a detailed inspection which requires that portions of the structure be cleaned of marine growth. Cleaning is time-consuming and should be restricted to critical areas of the structure. For pile type structures, a 10-inch high band should be cleaned at designated locations, generally near the low waterline, near the mudline and midway between the low waterline and the mudline. On a rectangular pile, the cleaning should include at least three sides; on an octagon pile, at least six sides; on a round pile, at least three-fourths of the perimeter; on an H-pile, at least the outside faces of the flanges and one side of the web. On large solid faced elements such as piers and abutments, 1 foot by 1 foot areas should be cleaned at three levels on each face of the element. The selection of the locations for cleaning should be made so as to minimize the potential for damage to the structure. Damaged areas should be measured, and the extent and severity of the damage documented.

The Level II inspection is intended to detect and identify damaged and deteriorated areas which may be hidden by surface biofouling. The thoroughness of cleaning should be governed by what is necessary to discern the condition of the underlying material. Removal of all biofouling staining is generally not needed.

c. Level III Inspection. A Level III inspection is a highly detailed inspection of a critical structure or structural element, or a member where extensive repair or possible replacement is contemplated. The purpose of this type of inspection is to detect hidden or interior damage, or loss in cross-sectional area, and to evaluate material homogeneity. This level of inspection includes extensive cleaning, detailed measurements, and selected non-destructive and partially destructive testing techniques such as ultrasonics, sample coring or boring, physical material sampling and in-situ hardness testing. The use of testing techniques is

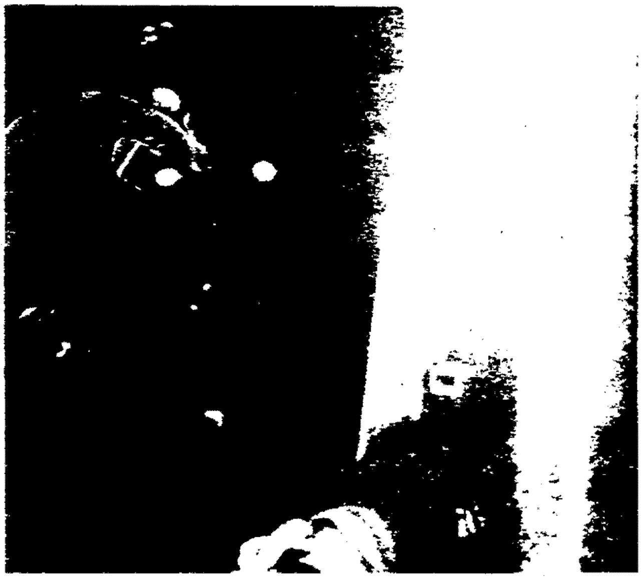


Figure 1-5 Level III inspection. Ultrasonic measurement of steel thickness.

generally limited to key structural areas, areas which are suspect, or areas which may be representative of the underwater structure.

1-2.2 Frequency and Types of Inspection

a. General Various factors influence the selection of the frequency, type, and level of inspection for a particular structure. As a minimum, all structures must receive routine underwater inspections at intervals not to exceed 5 years. This is the maximum interval permitted between underwater inspections for bridges which are both in excellent condition underwater and which are located in passive, non-threatening environments. More frequent routine and in-depth inspections may be desirable for many structures and necessary for critical structures. The bridge owner must determine the inspection interval that is appropriate for each individual bridge. Factors to consider in establishing the inspection frequency and levels of inspection include:

(1) Age.
(2) Type of construction materials.
(3) Configuration of the substructure.
(4) Adjacent waterway features such as dams, dikes, or marinas.
(5) Susceptibility of streambed materials to scour.
(6) Maintenance history.
(7) Saltwater environment.
(8) Waterway pollution.
(9) Damage due to waterborne traffic, debris, or ice.

b. Routine Inspection. As a minimum, routine inspections, which must be conducted at maximum intervals of 5 years or less, should include a Level I inspection of the complete underwater structure; a Level II inspection of at least ten percent of the substructure elements; and a basic scour investigation. The Level II inspection should be conducted on representative areas of the structure and in areas of apparent distress as determined by the Level I inspection. The initial routine inspection may indicate that additional Level II or Level III inspections must be performed in some areas to confirm the Level I and Level II findings, or to gain additional data so that the structural conditions can be evaluated with certainty. A basic scour investigation should include probing the channel bottom adjacent to the structure, and determining channel cross sections in the area of the bridge.

c. In-Depth Inspection. One or more of the following conditions may dictate the need for an in-depth inspection:

(1) Inconclusive results from a routine inspection.
(2) Critical structures, whose loss would have significant impact on life or property.
(3) Unique structures whose structural performance is uncertain.
(4) Prior evidence of distress.
(5) Consideration of reuse of an existing substructure to support a new superstructure, or planned major rehabilitation of the superstructure.

The in-depth inspection typically includes Level II inspection over extensive areas and Level III inspection of limited areas. Non-destructive testing is normally performed and the inspection may include partially destructive testing methods such as extracting samples for laboratory analysis and testing, and boring and probing.

SUMMARY OF GUIDELINES
FOR
ROUTINE UNDERWATER INSPECTION

Level I inspection: (Visual, tactile, "swim-by" overview)	100% of all underwater elements.
Level II inspection: (Limited measurements and cleaning in bands at designated areas)	10% of all underwater elements.
Scour investigation:	Cross sections of channel. Probe bottom near underwater elements.
Frequency:	Maximum of every 5 years.

Figure 1-6 Summary of minimum routine underwater inspection procedures.

The distinction between routine and in-depth inspections is not always clearly defined. For some bridges, such as steel pile supported structures in an actively corrosive environment, it may be necessary to include Level III, non-destructive testing, inspection techniques as part of routine inspections.

CHAPTER II

THE UNDERWATER INSPECTOR

SECTION 1. INTRODUCTION

2-1.1 General

The person in charge of a state bridge inspection program is responsible for establishing minimum qualifications for the diver-inspectors who will be conducting underwater bridge inspections. This chapter suggests attributes desirable in the underwater inspector and discusses the environmental conditions under which he must operate. The underwater bridge inspector not only needs to have a thorough knowledge of bridges and inspection techniques, but must apply these skills while working in an unnatural and often adverse underwater environment.

2-1.2 Qualifications

a. General. The success of any inspection program depends on the training and dedication of those persons charged with the actual inspection, whether for an underwater or an above-water inspection. An appreciation of the importance of the work to the safety of lives and property, and dedication to do a good job are essential prerequisites.

Good intentions alone, however, are not sufficient qualifications for the underwater inspector. He must be trained both as a diver and a bridge inspector. Training in only one of these areas will not suffice. Comprehensive training of underwater inspectors is even more important than training of above-water inspectors since the underwater inspector is often the only person who can or will see a structure underwater. He must have the ability to recognize the structural significance of conditions he encounters underwater; the judgment to expend inspection effort commensurate with the indicators of defects he perceives; and the technical competence and vocabulary to relate his findings to someone on the surface.

The underwater inspector must also be an experienced and accomplished diver. Diving conditions are usually adverse at bridge sites. Bridges are often built at the narrowest point in a channel where velocity is greatest, and in areas where water may be dark and polluted. Marine traffic, floating logs, and construction debris are among commonly found underwater hazards.

b. Technical Competence and Experience. The competence and experience required by the inspector-diver depends on the bridge complexity, substructure and superstructure interaction, water depth, current, and other site conditions. All underwater inspections should be conducted under the direct supervision of a fully qualified bridge inspection team leader. Some bridges are of such complexity that they require the actual diving inspection to be conducted by a fully qualified team leader. In fact, in some cases, only a professional engineer experienced in underwater bridge inspections would be considered qualified. In other cases, a diver fully trained and experienced in the inspection and evaluation of substructure and streambed conditions will meet inspection and safety requirements.

A diver not fully qualified as a bridge inspector or bridge inspection team leader must be used only with care and under close supervision. His work should be limited to tasks such as simple measurements, verbal descriptions, underwater photography, etc., which can provide conclusive evidence for evaluation by an on-site, fully qualified bridge inspection team leader.

c. Physical Condition. The underwater inspector is subjected to hyperbaric conditions and must be in good physical and psychological condition. Divers are required to have an annual medical examination to comply with Occupational Safety and Health Administration (OSHA) Standards, and a copy of the examination findings must be kept on file by the diver's employer. Refer to the OSHA regulations in the Appendix for details of the medical examination requirements. Because of the polluted waters in which some inspections must be made, all divers' immunizations should be current.

d. Attitude. A determined diver with a resilient spirit is essential, since the inspector often is isolated under adverse conditions. He must realize the importance of his work and his responsibility in ensuring overall bridge safety.

2-1.3 Training

a. Bridge Inspection. The National Bridge Inspection Standards (NBIS) recognize four avenues for achieving certification as a bridge inspection team leader. These are:

(1) Registration as a professional engineer

(2) Eligibility for registration as a professional engineer

(3) Completion of a comprehensive course in bridge inspection (generally, a two to three week course depending on the educational background of the inspector); and a minimum of 5 years of bridge inspection experience

(4) Level III or Level IV certification under the National Society of Professional Engineers' National Institute for Certification of Engineering Technologies (NICET) program.

The NBIS do not specify minimum requirements necessary for a diver to be considered fully trained and experienced in the inspection and evaluation of substructure and streambed condition so that he would meet FHWA inspection and safety requirements. These minimum requirements must be established by the person in charge of the state bridge inspection program. Factors to consider in evaluating the credentials of a diving-inspector working under a team leader include technician certifications, associate degrees in related technologies, engineering degrees, bridge inspection training courses, and experience in bridge inspection.

Because bridge inspectors, including inspector-divers, must have a basic knowledge of how loads are distributed throughout the bridge, the importance of the various components of bridges to safety, and a general understanding of the effects of deterioration upon the safe load capacity, each bridge inspector should participate in a continuing training program including a comprehensive bridge inspection training course with a minimum course duration of two weeks for engineers not experienced in bridge inspection and three weeks for technicians. All bridge inspectors' training should be supplemented periodically, preferably annually, by a short refresher course or updated training sessions.

b. Diving. At present, there is no single, nationally recognized dive certification agency. Three types of formal diving training are commonly available: certification from a nationally recognized diver training program, (e.g.; YMCA; PADI, i.e., Professional Association of Diving Instructors; and NAUI, i.e., the National Association of Underwater Instructors), certification from a commercial diving school, and military training. In addition, organizations specializing in marine studies, such as NOAA, the National Oceanographic and Aeronautical Administration, offer diving training. Many divers also receive initial or advanced training on the job.

Programs conducted by organizations such as the YMCA, PADI, and NAUI are oriented toward the recreational diver. Generally, these organizations offer a basic type of certification; and may offer advanced training and certifications such as Deep Diver, Wreck Diver, Rescue Diver, Underwater Photography, Divemaster and others. These courses alone, however, may not prepare an individual for diving in the severe conditions encountered at bridges (poor visibility, strong current, and underwater obstructions); nor do they teach the use of surface supplied air equipment, or the use of testing equipment. A recreational diver having advanced through a number of certification levels or having dived for a number of years can gain, but may not necessarily have gained, the diving competence necessary to cope with the conditions commonly encountered during bridge inspections.

Graduates of commercial diving schools are generally better prepared initially for the diving conditions encountered in underwater inspections. They are taught various types of diving methods, equipment maintenance, and how to perform mechanical tasks underwater. Some schools also provide specialty courses in Nondestructive Testing (NDT). When students graduate from a commercial diving school, they often join a diving company as a tender or tender-diver gaining experience before they are considered fully qualified commercial divers.

Military divers complete extensive courses in various types of diving systems, and normally receive extensive on-the-job training and experience in diving operations.

None of the training alternatives described above fully prepares a diver for the conditions typically encountered during underwater bridge inspections, either from a diving or a technical perspective. A novice bridge inspector-diver, regardless of type of dive training he has received, should receive additional on-the-job training under the supervision of an experienced bridge inspector-diver. Additional training can include familiarization with diving under bridge site conditions, recognition of structural distress, underwater photography and video, and NDT.

Diver training, like bridge inspection training, should be supplemented periodically by refresher training. Divers can only maintain their competency through continued practice. Divers who have not had regular and recent in-water experience can pose a threat to themselves and others if placed in a hazardous situation without sufficient time to acclimate themselves.

SECTION 2. SAFETY

2-2.1 Occupational Safety and Health Administration (OSHA)

In 1976, the revised Occupational Safety and Health Administration established Subpart T - Commercial Diving Standards for diving and related operations conducted in connection with all types of work and employments. All divers, regardless of their training, if receiving renumeration for their diving services are considered commercial divers. A copy of the OSHA Commercial Diving Standards is included in the Appendix. The standard delineates minimum personnel requirements, general operations procedures, specific operations procedures, equipment procedures and requirements, and recordkeeping requirements.

Many of the provisions of the standard are described in following sections of this manual. Some of the key provisions are:

Personnel Requirements:

(1) All divers must be trained in their duties, including dive physiology, first aid and cardiopulmonary resuscitation (CPR).

General and Specific Operating Procedures:

(1) All employers must develop a safe diving practices manual for their diving operations.

(2) An employer designated person-in-charge of the operation, who is qualified by training and experience, must conduct pre-dive and post-dive briefings.

(3) The use of scuba diving is not allowed at depths greater than 130 feet sea water (fsw).

(4) The use of scuba is not allowed in currents exceeding 1 knot unless the diver is line tended.

(5) The use of surface-supplied air is not allowed at depths greater than 220 fsw.

(6) For dives to depths deeper than 100 fsw or for dives outside the no-decompression limits, a recompression chamber must be on-site ready for use.

Equipment Procedures:

The standard specifies minimum equipment requirements for the diver and diving operations; and equipment testing and maintenance requirements.

Recordkeeping:

> Records of all dives and all diving accidents must be maintained.

In general, the OSHA standards provide a good basis for ensuring safe diving operations during an underwater bridge inspection, but compliance with the standards, in themselves, may not be sufficient. A company or agency diving safety program, coupled with competent, experienced divers and dive managers, is essential to preventing serious diving accidents. Many commercial organizations and governmental agencies, have developed comprehensive policies to govern their specific diving operations.

The U.S. Navy, for example, conducts operations in accordance with the U.S. Navy Dive Manual, and the U.S. Army Corps of Engineers Safety Manual contains a chapter on diving. Both these manuals were written for specific situations. They are more restrictive in some instances than OSHA standards, and what is commonly referred to as "Commercial Practice". If applied to all underwater bridge inspections, the Navy and Corps of Engineers guidelines may be too restrictive. Specifying these or other standards without being fully cognizant of their individual provisions may result in unnecessary expense.

SECTION 3. MANAGEMENT OF DIVING PERSONNEL

The management of diving personnel, whether by a governmental agency, a contractor or a consultant, poses special problems because of the hazardous nature of the work.

Diving work is very strenuous. As a result, divers generally cannot spend an entire day working underwater. A great amount of time and energy is often expended in preparation for a dive of short duration. It must be remembered that this is not lost time, but rather part of the total work effort.

Bridge inspector-divers must move from dive site to dive site. Often divers must enter waters of unknown quality. Local water quality monitoring agencies should be contacted to determine the degree of hazard the water presents, and appropriate precautions must be taken. These may include additional immunizations and the employment of special diving equipment to provide complete diver encapsulation. In some cases it may be necessary to obtain water samples and have the samples tested prior to diving. Diving managers must ensure that proper precautions are observed (Fig. 2-1). The long term effects on the diver of these and other occupational hazards may result in future liabilities.

Figure 2-1 Conducting a pre-dive briefing.

CHAPTER III

IDENTIFICATION OF UNDERWATER STRUCTURAL DEFECTS

SECTION 1. INTRODUCTION

3-1.1 General

In order to completely inspect and evaluate the condition of bridges located in the water, the inspector must be able to recognize various types of substructure configurations, materials, types of defects commonly encountered, likely locations of defects, and causes of deterioration. The principal causes of underwater bridge distress are deterioration of the structural material, vessel damage, and undermining and loss of lateral and vertical soil support due to scour.

Deterioration of the structural material is caused by environmental factors and the quality of the material itself. For example, timber piles in water will eventually decay or be attacked by marine borers. How quickly this will happen depends on how well the pile has been protected with preservative or other measures, and the environmental conditions in which it is located. The type of deterioration that will occur in a structure is dependent upon the properties and characteristics of the material, and the location of the material within the structure. There are, however, indicators of the condition of the material which the diver-inspector can look for in any part of a structure and which can be used to evaluate the structural condition.

On navigable waterways, bridges are also subject to damage by marine vessel impact. When damage is caused by marine traffic, the damage may be visible above water. An underwater inspection, however, is often the only way to determine the overall condition of the structure and evaluate its structural adequacy.

Scour of streambeds has been a major cause of bridge failure, primarily, because there are usually no early warning signs visible above water. Problems of loss of lateral support and undermining normally are not detected until they are extremely serious or disastrous. Even if scour does not reach catastrophic proportions, it can manifest itself in less spectacular, but still costly, symptoms such as settlement of piers, misalignment of joints and bearings, and binding of movable spans. There are, however, several ways to check the condition of the streambed. The most common methods are taking soundings and underwater inspections. More sophisticated geophysical equipment and techniques, as described in Chapter VI, are also available which, although not commonly in use at this time, are gaining wider acceptance as a part of comprehensive bridge safety programs.

SECTION 2. TYPES OF SUBSTRUCTURES LOCATED IN WATER

3-2.1 Pile Bents

Pile bents are structural supports consisting of piles and pile caps. Superstructure loads are distributed to the piles by the pile cap. Pile bents, which can be constructed of timber, concrete, steel, or a combination of these, are used both as intermediate supports and abutments (Fig. 3-1). Often, bracing is used to increase lateral stability (Fig. 3-2).

Piles can also be used as supports for piers and abutments where soil conditions are such that the piers

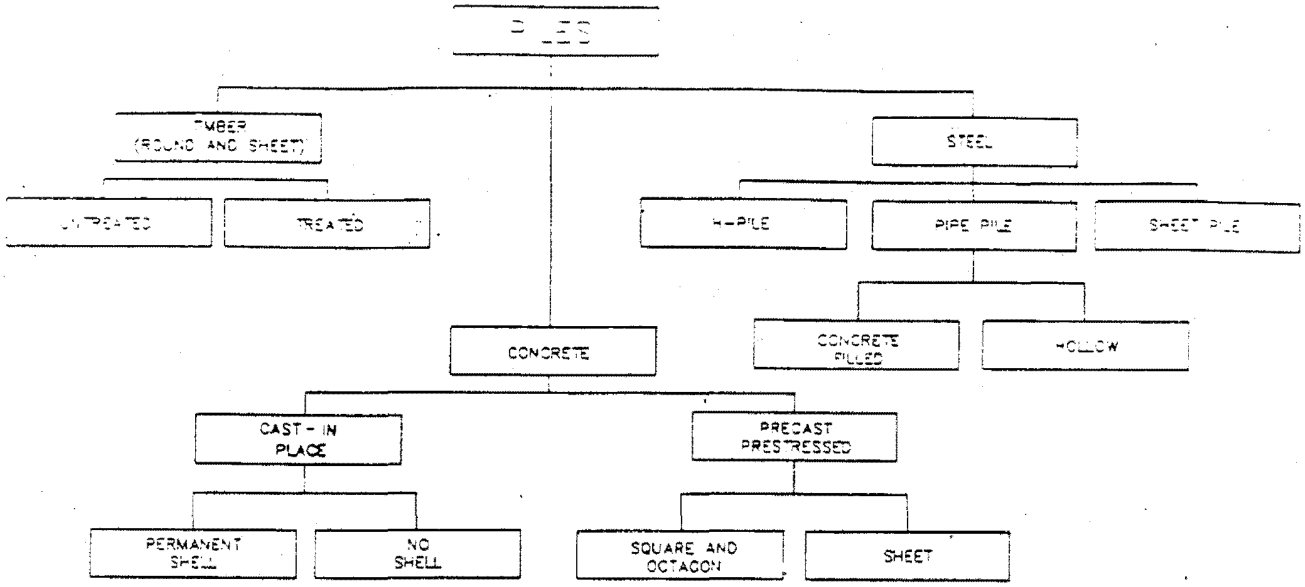


Figure 3-1 Types of piles.

and abutments cannot be supported by spread footings on the upper soil strata.

Timber piles may be untreated or may be pressure treated with preservatives such as creosote, creosote-coal tar, pentachlorophenol or arsenate solutions. Timber piles generally have butt diameters in the range of 12 to 18 inches, and maximum lengths of about 40 to 50 feet, although longer piles are sometimes used.

Concrete piles can be cast-in-place, with or without a permanent shell; precast concrete; or prestressed concrete. Cast-in-place concrete piles can be constructed by driving a metal casing into the ground and using the casing as a form for the concrete. There are many types of proprietary shell piles available.

Usually the shell is thin and not considered to add to the structural capacity of the pile. Reinforcing steel is normally added within the concrete, especially near the top of the pile, where it may be subject to lateral loads.

Uncased, cast-in-place concrete piles can be constructed by driving a casing into the soil, and removing the casing as the concrete is placed. In very firm soils, concrete may also be placed in augered holes without any casing.

Large diameter, cast-in-place concrete piles, called drilled shafts, may be used to support massive bridge elements. These shafts may also support formed columns from the channel bottom to the underside of the bridge deck (Fig. 3-3).

Precast and prestressed concrete piles, which may be solid or hollow, are generally square, rectangular, or octagonal shafts with a tapered end for driving. They commonly range in size from about 8 inches to 30

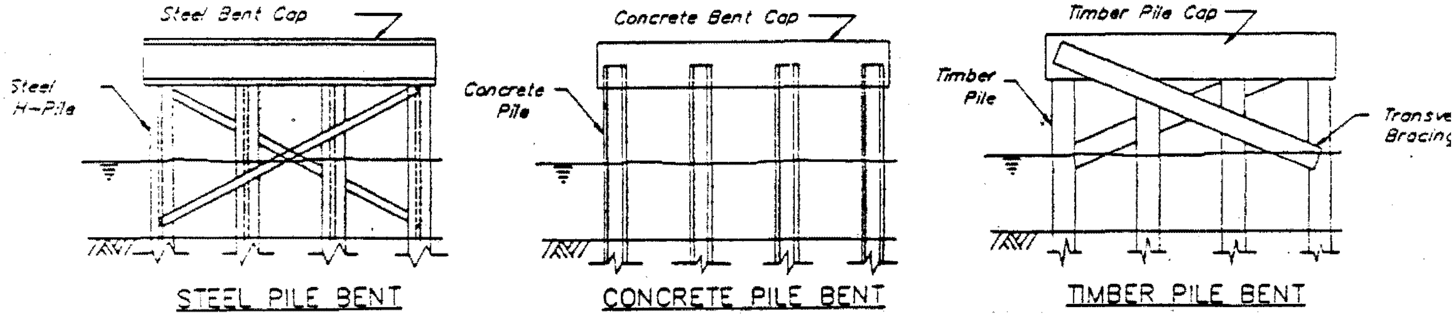
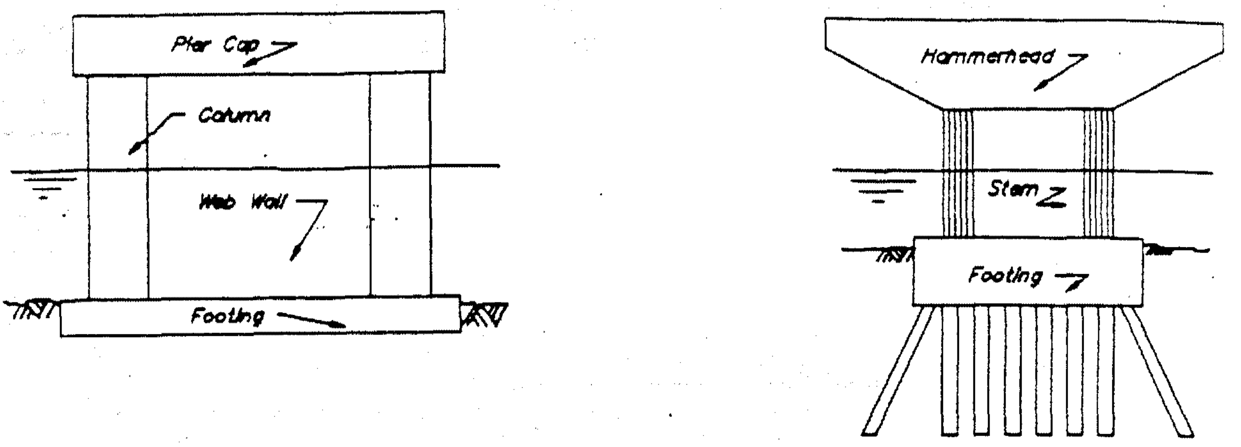
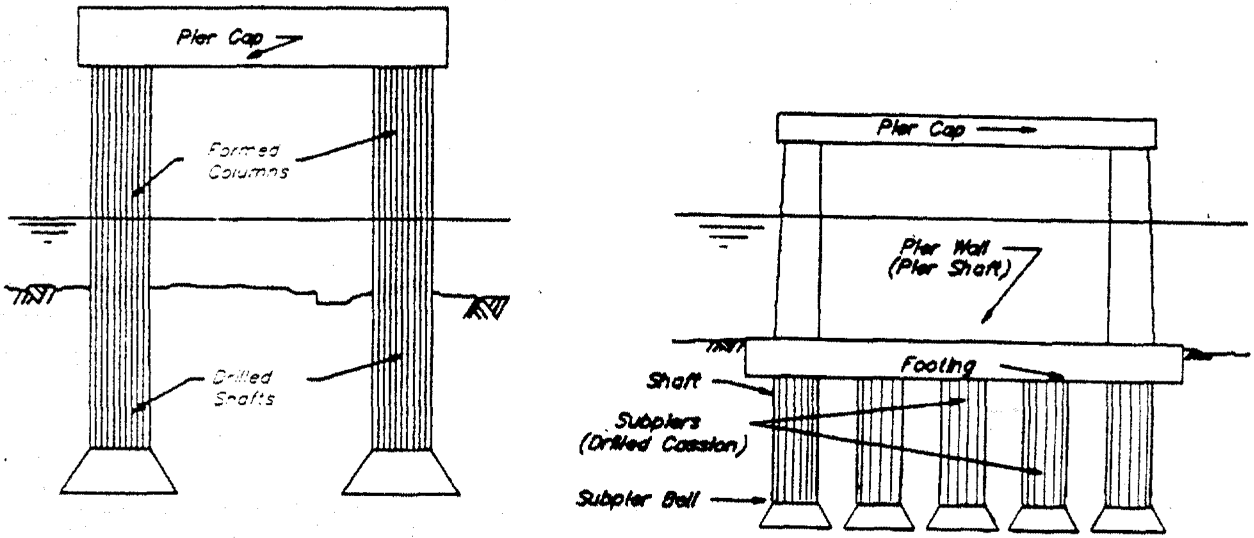


Figure 3-2 Pile bents.



COLUMN PIERS WITH SOLID WEB WALL ON SPREAD FOOTING

CANTILEVER OR HAMMERHEAD PIER ON PILES



FORMED COLUMNS AND DRILLED SHAFTS

SOLID PIER ON DRILLED SUBPIER

Figure 3-3 Representative pier types.

inches wide. Some of these piles have longitudinal holes to assist in jetting them into place and reduce weight for handling.

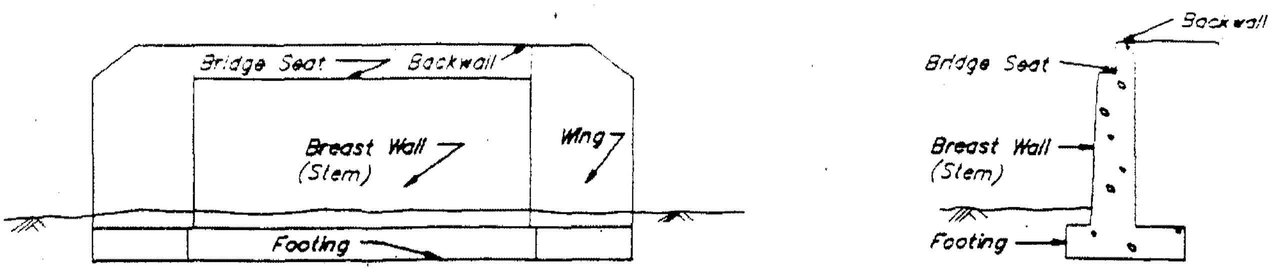
Steel piles may be pipe piles, concrete-filled pipe piles, or H-piles. Steel sheet piles are often used also as stay-in-place forms for foundations of piers and abutments.

Piles which are a combination of materials are called composite piles. Often, timber and steel piles are partially or totally encased in concrete for protection and repair.

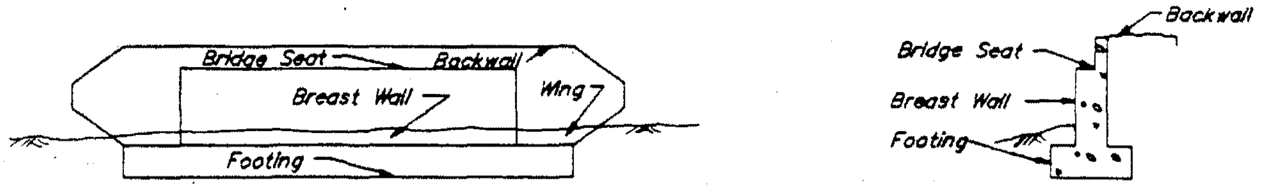
3-2.2 Piers

Piers are transverse, intermediate supports constructed of concrete, masonry, timber or steel. A pier consists of three basic elements: a footing, a shaft, and a pier cap (Fig. 3-3).

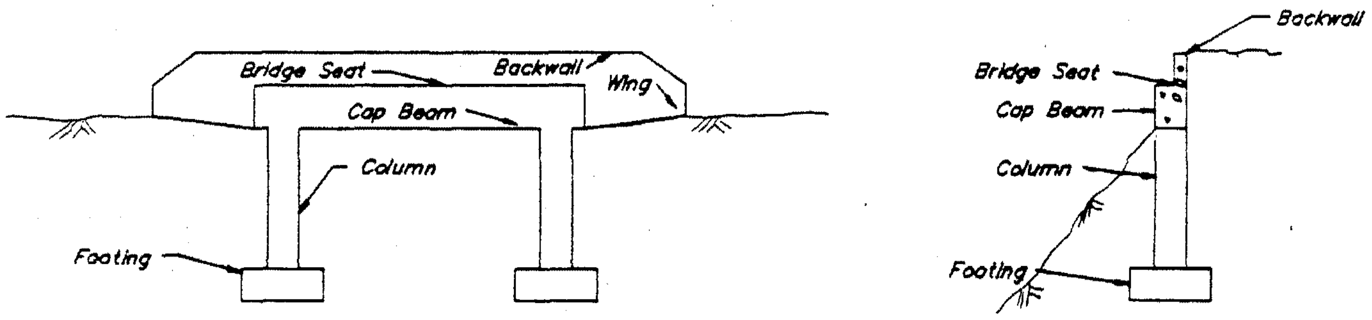
Footings can be founded on driven piles, drilled shafts, caissons, or directly on soil or rock, i.e., on spread footings. The pier shaft may be a solid wall or may consist of a number of columns, with or without a solid diaphragm wall between columns. The pier may be a separate member, or integral with the shaft.



FULL HEIGHT ABUTMENT



STUB ABUTMENT



OPEN ABUTMENT

Figure 3-4 Types of abutments.

3-2.3 Abutments

The term "abutment" is usually applied to the substructure units at the ends of bridges. An abutment provides end support for a bridge and retains the approach embankment.

Abutments, classified according to their locations, are full height (closed), stub, or open (spill-through) (Fig. 3-4). Pile bents are also used as abutments. Wingwalls are abutment extensions on the sides of an abutment which enclose the approach fill.

3-2.4 Caissons

A caisson is an enclosure used to build a pier's foundation and carry a load through poor soil and water to sound soil or rock. In bridges designed over rivers, a floating caisson (closed-end caisson) may be used. Once in place, the caisson acts as the pier's footing.

Caissons are constructed of timber, reinforced concrete, steel plates, or a combination of materials. The structure is towed to the construction site and sunk. Soil below a caisson is removed through openings in its bottom which are sometimes referred to as "dredging wells." Once the caisson is in place, it is filled, generally with concrete, and the bridge pier is built on it (Fig.3-5).

3-2.5 Protection Devices

Dolphins, fenders, and shear fences are placed around substructures to protect them from vessels. These devices are designed to absorb the energy of physical

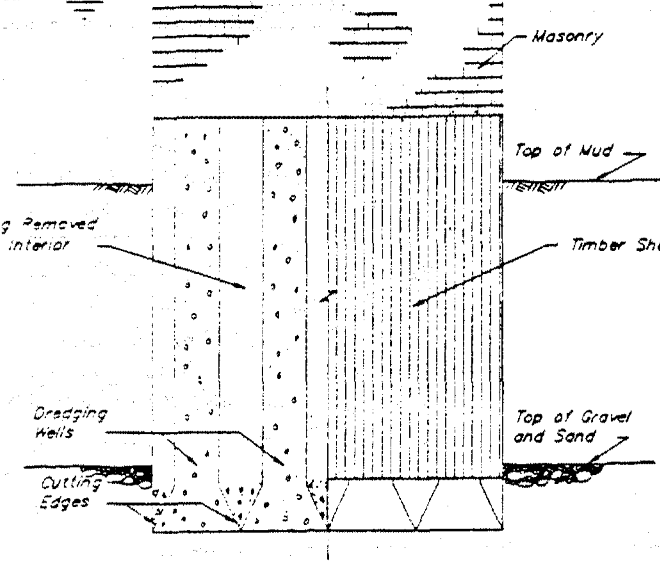


Figure 3-5 Floating caisson.

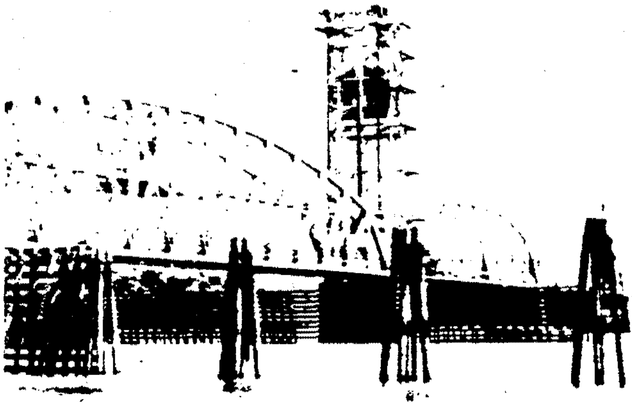


Figure 3-6 Timber dolphins.

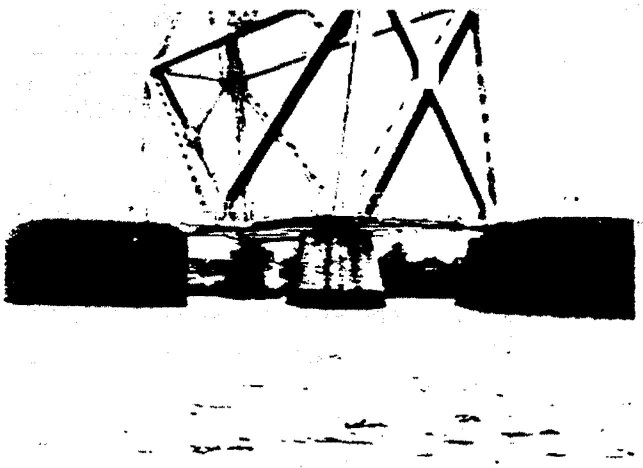


Figure 3-7 Steel sheet pile dolphins.

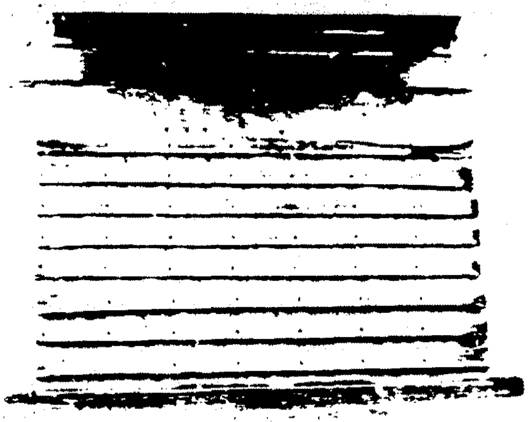


Figure 3-8 Fenders attached to a pier.

contact with a vessel, and may be able to protect the bridge from serious damage by redirecting an errant vessel. Some of these devices, or portions of them, are designed to absorb very large forces, while others are designed to absorb only smaller vessel impacts.

Dolphins are generally constructed of a group of timber piles. The piles are driven into the channel bottom and the tops are pulled together and wrapped tightly with steel cables or chains (Fig. 3-6). Steel piles may also be used. Dolphins are also constructed of steel sheet piling driven to form a large cylinder that is filled with stone or sand, and capped with a concrete slab (Fig. 3-7).

A fender system usually consists of timber or steel members attached directly to the substructure unit, or to piles driven adjacent to the substructure unit. (Fig. 3-8).

A shear fence is generally an extension of a fender system consisting of a series of timber piles supporting timber walers (Fig. 3-9). Steel piles are sometimes used instead of timber.

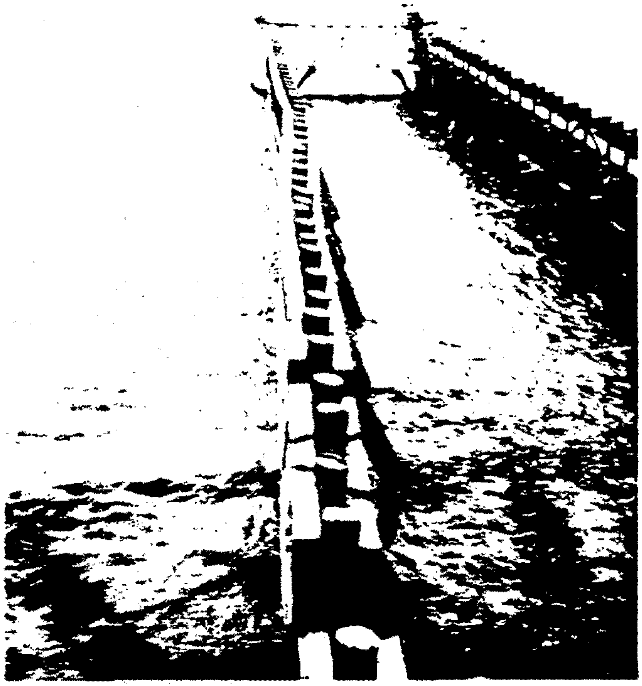


Figure 3-9 Shear fence.

3-2.6 Culverts

A culvert is a small bridge normally constructed entirely below the elevation of the roadway surface and having no part or portion integral with the roadway. Structures over 20 feet in span, parallel to the roadway, are usually called bridges, rather than culverts; and structures less than 20 feet in span are called culverts even though they may directly support traffic loads, and may be constructed similarly to larger structures. Refer to the FHWA's Culvert Inspection Manual for an in-depth discussion of culvert inspection.

Culverts which cannot be inspected in the dry should be inspected by diving or some other means as necessary to determine their structural condition with certainty. The inspection of dry culverts having poor air quality may be facilitated by use of diving equipment. The underwater inspection of culverts by diving presents special safety considerations because of their confining nature.

SECTION 3. DETERIORATION OF STRUCTURAL MATERIALS

3-3.1 Concrete

There are basically three types of concrete structures: plain, reinforced and prestressed. Although current AASHTO specifications require that shrinkage and temperature reinforcement be placed near exposed surfaces of walls not otherwise reinforced, older bridges may have piers constructed of plain concrete. Prestressed concrete is used to obtain high bending strength and is generally used in bridge beams. Piles are also often constructed of prestressed concrete and it is in this form that prestressed concrete will most commonly be encountered underwater. Because the prestressing forces tend to close cracks and limit intrusion of water, prestressed concrete piles are widely used in marine construction.

Concrete itself is a compressive material with little tensile strength. The compressive strength of concrete commonly used in bridges varies from 3 to 11 ksi. The addition of reinforcing steel or prestressing steel gives the member tensile or flexural strength.

a. Cracking. Almost all concrete cracks. Cracks are common in both new and old concrete. Because concrete has little tensile strength cracks occur due to volume changes as temperatures vary and a concrete member contracts or expands. Cracks may also be an indication of overloading, corrosion of the reinforcing steel, or settlement of the structure. Even when the cracks themselves are not structurally significant, they are often the early stages of more serious deterioration and they are an avenue through which water and deleterious substances can enter the concrete.

Cracks can occur at any location on a substructure element. When reporting cracks, the length, width, location and orientation (horizontal, vertical, diagonal, etc.) should be noted, and the presence of rust stains, efflorescence, or evidence of differential movement on either side of the crack should be indicated.

Cracking can also occur during the fabrication or installation of precast concrete members. Overdriving, for example, can cause cracking of concrete piles (Fig. 3-10).

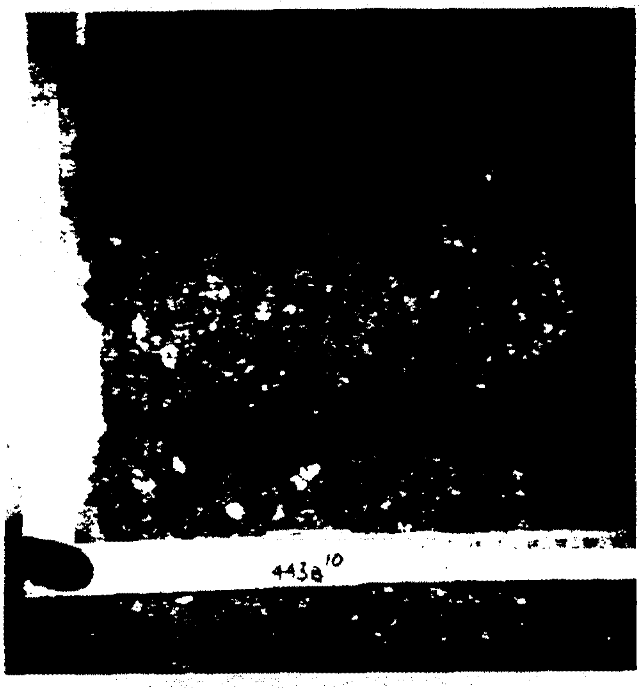


Figure 3-10 Cracked concrete pile below water.

b. Scaling. Scaling is a gradual and continuous loss of surface mortar and aggregate from an area. This condition is commonly found at the waterline on piers and piles (Fig. 3-11). It is caused by freeze-thaw action and, therefore, is found in colder climates. Pores and minor surface defects allow water to penetrate and saturate the concrete. When the temperature drops, the water freezes and expands causing the surface of the concrete to "pop-off" or appear to disintegrate. At the waterline, conditions are ideal for scaling to occur.

The Bridge Inspectors' Training Manual classifies scaling in the following categories:

(1) Light Scale. Loss of surface mortar; up to 1/4 inch penetration, with surface exposure of coarse aggregates.

(2) Medium Scale. Loss of surface mortar; 1/4 inch to 1/2 inch penetration, with some added mortar loss between aggregates.

(3) Heavy Scale. Loss of surface mortar surrounding aggregate particles; 1/2 inch to 1 inch penetration. Aggregates are clearly exposed and stand out from the concrete.

(4) Severe Scale. Loss of coarse aggregate particles as well as surface mortar and the mortar surrounding the aggregates. Penetration of the loss exceeds 1 inch.

When reporting scaling, the inspector should note the location of the defect, the size of the area, and the depth of penetration of the defect. To avoid confusion in reporting defects, a standard format and nomenclature should be used consistently. Location should be reported by horizontal distance from a known point such as a corner of an abutment and vertical distance by depth below water surface. The extent of the defect should be reported as height and width, with height referring to a vertical distance and width referring to a horizontal distance. The extent of intrusion of the defect into the member should be referred to as "penetration", rather than "depth", since "depth" could also refer to the distance below water.

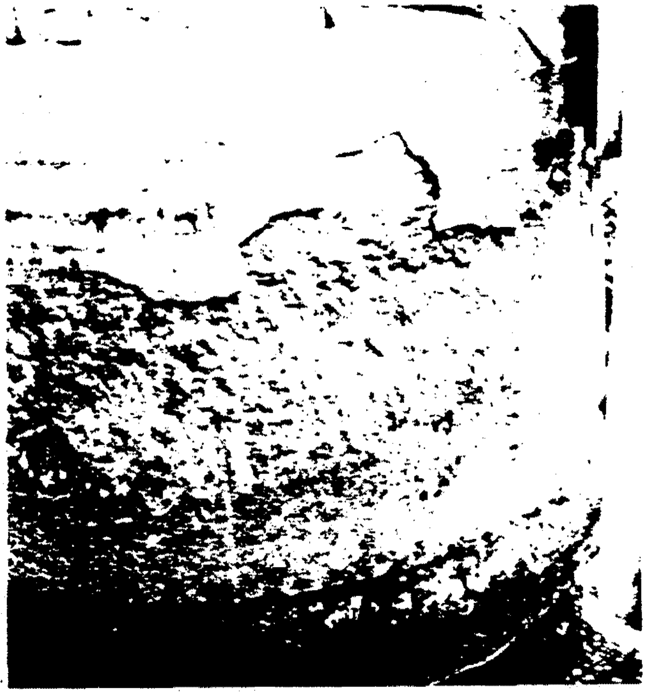


Figure 3-11 Scaled concrete on a pier at the waterline.

c. Spalling. Spalling is a depression in the surface of concrete which exposes corroded reinforcing steel (Fig. 3-12). It is primarily the result of internal pressures within the concrete caused by corrosion of the steel. Extensive research has been conducted into the spalling process in bridge decks. Much of this information can be transferred directly to the waterline environment.

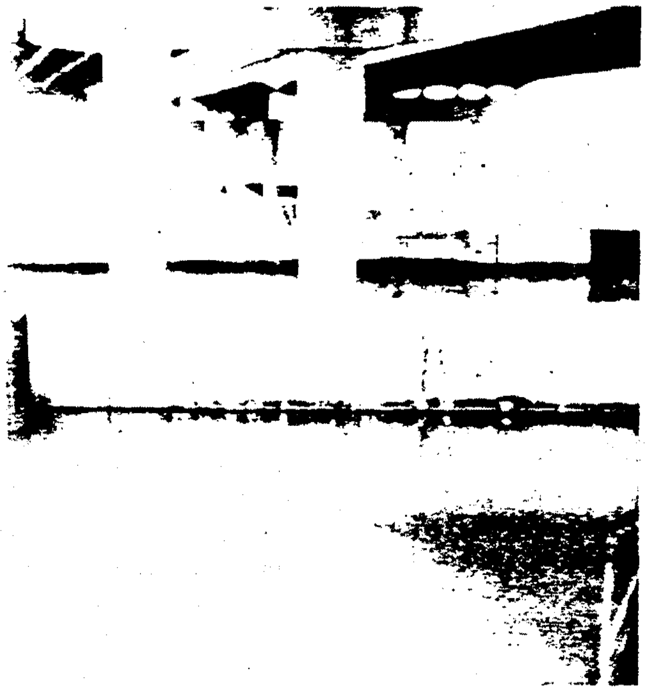


Figure 3-12 Spalling concrete at the waterline.

Cracks in concrete over bars near the surface, due to shrinkage, cracks due to external damaging forces, and pores that occur naturally in concrete allow moisture and air (oxygen) to reach reinforcing steel near the surface. When the steel corrodes, the products of corrosion occupy up to ten times the volume of the parent material and can produce forces in excess of 5,000 psi. This expansive force cracks the concrete and "pops-off" areas on the surface of the concrete member exposing the reinforcing steel to the environment. The process then accelerates until large areas are spalled.

The environment at the waterline of bridges is especially conducive to spalling. Abrasion and constant wet-dry cycles can provide the initial paths for moisture and oxygen to reach the steel. Salt water or water with acidic pollutants make excellent electrolytes for the corrosion process, and wave and tidal action regularly remove the film of corrosion that develops to provide a new surface for rapid corrosion. In colder climates, water freezing in small cracks also expands and accelerates the spalling process.

At times, spalling can occur over a large area, hidden by the surface concrete. Internal fracture planes may develop below the surface of the concrete. These generally can be detected by the hollow sound produced by striking the surface with a hammer.

Reinforcing steel placed with insufficient cover is subject to corrosion, and it is not uncommon to find pieces of reinforcing steel protruding from concrete structures below water. It is also common to find steel rods used to tie form work together on piers, steel beams used to brace cofferdams, and wire rope lifting loops on concrete piles. Over a period of time, this steel can also corrode, causing spalling of the concrete.

When inspecting concrete substructure units, the diver-inspector should especially look for visual signs of spalling above and in the area of the waterline. These areas should also be struck with a hammer to determine if there are fracture planes hidden below the surface of the concrete.. Particular attention should be paid to areas that are intermittently wet and dry. Below the water surface, the areas adjacent to construction accessories should be closely examined.

d. Chemical Attack. Substructures located in water are often subjected to chemicals which attack the concrete. The forms of chemicals vary widely and may be present naturally or due to man-made pollution.

The penetration of chlorides into concrete can cause corrosion of the reinforcing steel. Chlorides may enter the concrete from deicing agents, saltwater, or admixtures. Spalling and cracking of the concrete is likely to occur when chlorides are present.

Sulfates are present in seawater and are common in ground waters, especially when high proportions of certain clays are present. Structures in seawater can suffer sulfate attack in the tidal zone. Sulfate attack is usually detected as a softening of the surface of the concrete. With further deterioration, the surface ravels as material is easily chipped away, and the newly exposed surface is often white in color. When sulfate damage is far advanced, there may also be swelling and cracking of the concrete. Sulfate attack is more common in older structures and those constructed of Type I cement.

Polluted water can cause various defects depending upon the type of pollution present, but where chemical attack is suspected, it is common to find uniform scaling on the submerged portions of a structure.

e. Abrasion. Abrasion damage is due to external forces acting on the surface of the concrete member. Minor abrasion damage resembles scaling, and major abrasion damage may cause gouges, cracks and voids. Ice can cause severe scaling and abrasion at the waterline. In some rivers, scaling near the mudline is also found due to the abrasive action of bottom material being carried along in a swift current.

Cracks, voids, and chipped corners can be caused by vessel impact. Marine traffic or cables used to fasten vessels to structures can also cause abrasive damage. Ferry vessels, which repeatedly and rapidly start and reverse their propellers, and tugs maneuvering close to bridges can effectively sand-blast underwater elements, causing severe damage over the long term.

3-3.2 Steel

Steel is used as a structural material and as external protective cladding on concrete foundation elements. The primary cause of damage to steel is corrosion. Corrosion is most prevalent in the splash and tidal zones, but can occur both above and below water.

Steel foundation elements located in water, commonly H-piles, pipe piles, or sheet piling, can suffer distress in the form of corrosion. The corrosion can be especially severe when the bridge is located in salt water or brackish water. The most important factors influencing and producing corrosion are the presence of oxygen, moisture, chemicals, pollution, stray electrical currents, and water velocity.

a. Corrosion. Corrosion of steel H-piles in saltwater and brackish water can be severe. In a typical bridge configuration, relatively lightweight piles driven into a massive soil channel bottom support a massive concrete deck system. These two massive end conditions act as cathodes and the exposed slender metal pile acts as an anode, giving up electrons which go into solution. Often the most severe corrosion occurs near the waterline.

A common remedial action is to encase the H-pile with concrete from the underside of the deck to a few feet below mean low water. In many cases, this is only temporarily successful because the loss of metal is shifted to just below the concrete encasement. This repair may, in fact, make the situation worse, as the cathodic areas become more massive and the anodic H-pile becomes smaller. Rapid and severe corrosion of H-piles has been noted below the concrete encasement (Fig. 3-13).

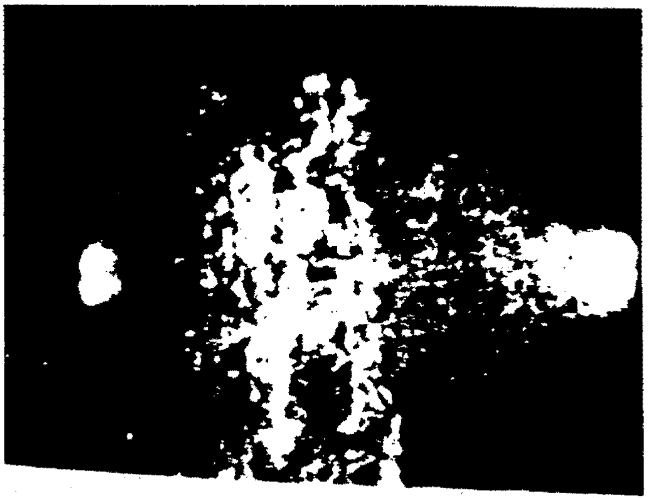


Figure 3-13 H-Pile corroded below concrete encasement.

Corrosion is the conversion of the metallic ion, through electrochemical reactions, into a compound form (rust). In the electrochemical process, there must be a current flow. This current flow can be caused by external forces, or as the result of differences in potential between different metals. Bridges in industrial areas, where there may be many stray electrical currents, may experience severe corrosion problems.

For bridge elements located in water and not protected from the water, the water acts as an electrolyte. Salt water or those waters that contain significant amounts of sulfur or chlorides are more acidic and make better electrolytes so that the corrosion rate is much greater than in fresh water. In the splash zone, caused by waves and tides, and in areas of high velocity flow, the corrosion rate is also much greater than in still waters. The moving water provides more wet-dry cycles, carries more oxygen to the metal, and tends to remove the initial film of corrosion which would normally retard further deterioration. If there are abrasive materials in the water, these can also remove the initial film of corrosion and increase the rate of corrosion. Corrosion rate is also generally greater in warm waters than in cold waters.

Bacterial corrosion is sometimes found below the waterline in fresh waters. This corrosion forms brownish orange nodules, which can be removed with a hand scraper. The metal under the nodule is usually shiny and pitting is normally found.

Heavy marine growth, found in seawater, can sometimes inhibit corrosion, but it can also hide severe distress or loss of section. During an inspection, areas of heavy growth should be spot-cleaned to check for loss of section.

b. Coatings. Coatings are used to prevent corrosion. Steel structures should be checked for breaks, or "holidays", in the coating because these are areas of potential deterioration. Small breaks in the coatings can concentrate corrosion in a small area.

Care must be used in cleaning steel structures so as not to damage any coating which is present. Marine growth may adhere more tightly to the coating than the coating does to the steel member. Damage to the coating caused by inspection methods could be more injurious to the long term condition of the structure than present damage to the steel itself, and detailed examinations of the coating should be made with care.

c. Cathodic Protection. Cathodic protection systems are used in some areas to protect reinforcing steel in bridge decks, and they have been used to protect harbor facilities, but they are not commonly found on bridge substructures. In the future, cathodic protection systems will probably become more common on bridge substructures.

Cathodic protection systems can be active or passive. In an active system a small impressed current is used to counter the electron flow found in the corrosion cell. Passive systems use sacrificial anodes. Sacrificial anodes are made from elements, such as manganese, which are more active than the base metal of the structure.

d. Connections. Connections, such as bolts, welds, and interlocks on sheet piling, are potential areas of corrosion. While bridge substructures are generally constructed without connections below water, there are some instances where underwater connections may be encountered, such as at splices in piles and at bracing connections, and on wales of sheet pile bulkheads. Connections are also often found in the splash zone for bracing members.

Connections are potential sites of corrosion because their composition may be dissimilar from the structure's main material, causing the formation of corrosion cells at these discontinuities.

Bolts and rivets should be cleaned and examined for corrosion and fit. Nuts should be examined for tight fit. Even the bolts used to connect timber bracing can corrode. Dissimilarities between materials of nuts and bolts can cause significant losses to either the nut or the bolt.

Connections such as H-piles splices should be examined at the welds. The dissimilarities between weld metal and the base metal can be corrosion producers. If backup bars for the weld have not been removed, these are highly suspect since their material composition may differ greatly from the base material. The configuration of the weld, if it has not been ground smooth, can also cause a local corrosion cell to develop. In coated structures, the area at welds should be closely examined since coatings are usually thinnest and tend to break at irregularities such as welds.

The interlocks on sheet piling should be examined for cracks, corrosion, and gaps between sheets. Cracks can develop during driving of the sheets or from vessel impact. Gaps between sheets may occur during construction causing loss of fill material from behind the sheeting.

3-3.3 Masonry

Masonry is not now commonly used in bridge construction, although it is sometimes used as an ornamental facing. Many older bridges, however, have piers and abutments constructed of masonry. The types of stone commonly found are granite, limestone, and sandstone (Fig. 3-14). Problems commonly found in masonry structures include cracking, scaling and deteriorated pointing.

Masonry is a naturally porous material and although it is generally more durable than concrete, it is susceptible to deterioration by freezing and thawing. The stone may fracture and break off in small pieces (Fig. 3-15) and the man-made mortar deteriorates like

Figure 3-14 Masonry pier.

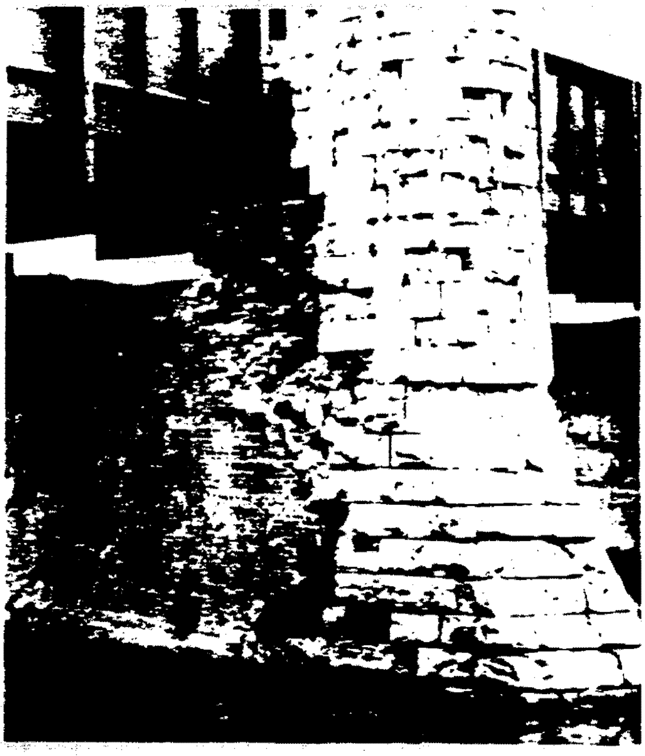


Figure 3-15 Severely deteriorated masonry.

concrete. More rapid deterioration, such as cracking along bedding planes, may also occur in stone of lower quality.

Masonry mortar joints near the waterline are usually most susceptible to freeze-thaw damage. It not uncommon for the stone masonry to be in good condition, and for the mortar to be completely missing from several courses of stone near the waterline.

The abrasive action of sand in water may cause the masonry below water to experience losses in both the masonry and the pointing. The areas of deterioration should be measured, noting the length, width, and penetration of the defect.

Older masonry structures may have been repaired using masonry or concrete. The condition of the repairs should also be noted.

3-3.4 Timber

Timber pile bents are common in smaller and shorter span bridges (Fig. 3-16). On larger bridges, many protection devices are constructed of timber, and many piers and abutments are supported on timber piles.

Deterioration in timber members results from a variety of sources, including the decaying action of bacteria, fungus, marine infestations, abrasion, and collisions.

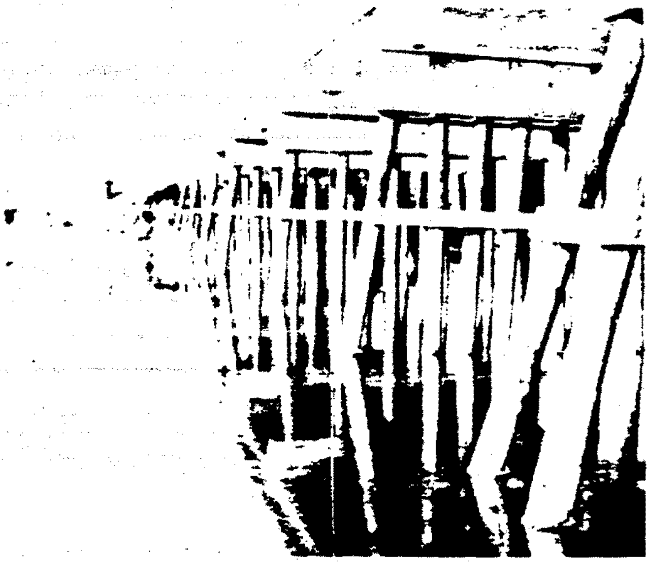


Figure 3-16 Bridge supported by timber piles.

Other damage may result from careless construction practices and faulty or missing connectors.

a. Preservatives. Preservatives are used to protect timber from freshwater infestations of fungi and insects. In coastal waters, preservatives must also protect against infestations from marine borers. Creosote, coal-tar creosote and arsenate solutions are common preservatives.

Creosote, like other preservatives, is applied to the timber under pressure in a tank. Because the preservative does not completely penetrate the wood (Fig. 3-17), it is desirable that the timber be precut and all holes be predrilled so that the maximum surface area can be treated during the fabrication of the members.

Figure 3-17 Section cut from treated timber pile. Note penetration of the preservative is limited to the outer portion of the timber.

Where timber members must be cut or drilled in the field, preservative must be applied in the field to protect the exposed surfaces. Penetration of this preservative, however, will be less than in pressure treated areas. Timber treated with creosote is deep dark brown or black in appearance. An inspector should look for the presence or absence of creosote and should pay especially close attention to holes and the cut ends of cross bracing (Fig. 3-18).

b. Fungal Processes. Fungi thrive on the organic matter in wood cells. Ideal conditions for their growth include sufficient moisture, oxygen, and warmth. Near the waterline of timber elements, these conditions are at least present intermittently. These micro-organisms

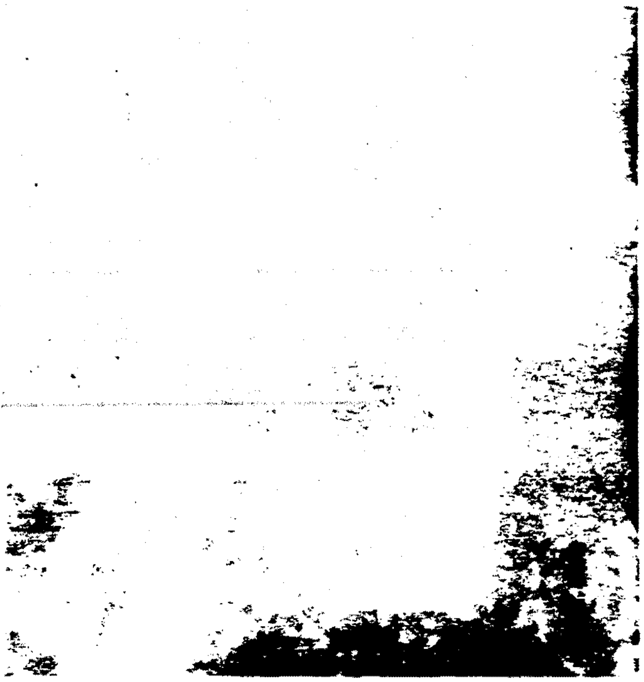


Figure 3-18 Marine borer damage to end of cross brace.

Figure 3-19 Decayed pile.

can easily penetrate untreated timber or older timber where the preservative has become ineffective. In early stages, decaying members appear slightly discolored.

In advance stages of rot, the wood becomes spongy, stringy, crumbly, and splintered. Members with internal decay may appear slightly splintered and produce a hollow sound when struck with a hammer or metal bar (Fig. 3-19). Vegetation growing from a pile is usually an indicator that decay is occurring on the interior of the pile (Fig. 3-20).

Figure 3-20 Vegetation growing on a decayed pile.

c. Marine Borers. Two types of marine borers are most common to the saltwater environment: molluscan borers and crustacean borers. Because of their destructive capabilities, the teredo and the bankia, which have similar characteristics, are the most important molluscan borers, and the limnoria is the most important crustacean borer. Both infest wood that is untreated or whose preservative has become ineffective. Additionally, any holes drilled during construction or other defects invite the infestation of these creatures.

The teredo, or bankia, enters the timber at an early stage of life and remains there for the rest of its life. While the organism bores to the inner core of the timber it leaves its tail in the opening to obtain nourishment from the water. It is possible for some species to grow up to six feet in length. The hole made by the teredo varies from 1/4 to 1/2 inch in diameter (Fig. 3-21), with some species of bankia growing to 3/4 inch in diameter and four feet in length.

Figure 3-21 Section cut from a pile damaged by the teredo.

Figure 3-22 Limnoria attack at the waterline.

Since the damage caused by these shipworms is hidden within the timber, it is often difficult to detect. A Close visual inspection for the entrance hole is one method of detection. Suspect areas may require destructive testing to confirm the teredo's presence.

Unlike the teredo, the limnoria (also called the wood louse or gribble) is a surface boring crustacean. The limnoria, which is about 1/8 inch long, bores only a short way into the wood surface and as water action breaks down the thin layer of wood protecting it, the crustacean bores deeper, eventually producing the hour glass shape commonly found in wood piles in the splash zone (Fig. 3-22).

Damage from marine borers can occur anywhere between the mudline and the waterline (Fig. 3-23). Creosote preservatives have proven effective against teredo attack and arsenate preservatives have been effective against limnoria. A combination of both of these preservatives can be used to protect against both borers.

d. Caddisfly. The caddisfly, an insect which is generally found in freshwater, but can tolerate brackish water, can also damage timber piles.

The caddisflies are an order of insects closely related to moths and butterflies. In water, during the larva and pupa stages of their life cycle, they can dig small holes into the timber for protection. The homes consist of a silken retreat portion which shelter the larva that is fixed to the substrate after the larva chews out a small depression to reduce its profile. In addition, an anterior net of some type which strains food from the flowing water is attached to the shelter. At the end of the larval stage, all species construct some sort of shelter for the ensuing pupa. At this time the shelter is enlarged, deepened and strengthened. After completion of the pupal period, the pupa cuts its way out of the shelter, swims to the surface, crawls out of the water and onto solid substrate. The pupa's skin splits and the adult emerges and flies away, thus beginning the cycle again.

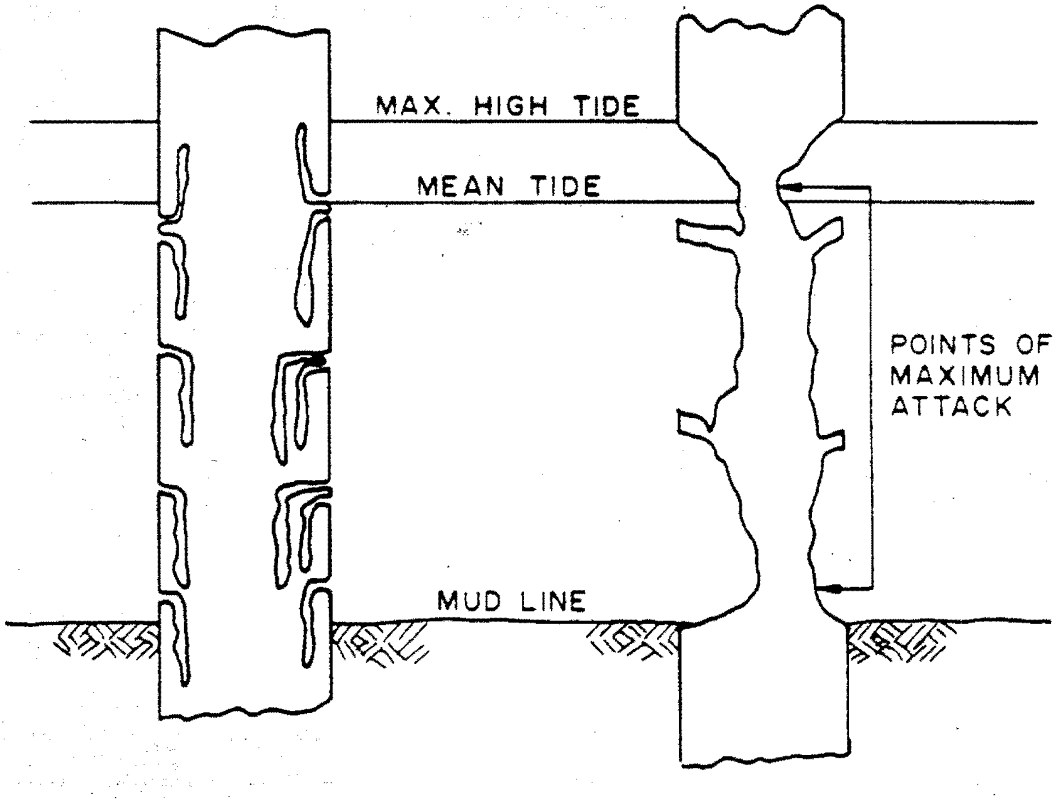


Figure 3-23 Drawing of typical borer damage.

The next generation of larvae may inhabit the same hole and perhaps several larvae live in the same retreat, enlarging the hole until retreats intersect, and create large irregular depressions. While most species have a single life cycle annually, research has documented as many as two or three generations per year. The high density of caddisflies on a timber pile can create so many pits that pieces of timber have been characterized as having the appearance of a person scarred by smallpox. After being attacked for numerous years the number of pits within a given area may not be distinguishable.

e. Bacterial Degradation. Over the last approximately twenty years, several instances have been reported in which continuously submerged timber structures have undergone considerable strength reductions over long periods of time. This degradation is the result of bacteria which can live in totally submerged piling.

Bacterial attack is a slow process promoted by wet conditions. The attack may be classified as tunneling, in which the bacteria penetrate the wood cell walls and thus produce channels within the walls; erosion, in which the layers of the wood cells are attacked; and cavitation, in which the bacteria form cavities within the cell walls. All three can significantly reduce the strength and other properties of the timber. While little quantitative data is available on these effects, degradation appears to be greatest near the outer area of the pile and decreases toward the center.

f. Abrasion. The abrasive action of waterborne materials, such as ice and sand, can also damage timber members. Damaged areas appear worn and smooth. Abrasive damage typically occurs at the waterline and mudline. There are indications that the bacterial action in acidic waters may soften the surface of timber piles so that they are vulnerable to abrasion. A gradual and general reduction in diameter can occur along the entire length of the pile between the waterline and the mudline. Detection of this general reduction in diameter may only be possible by measuring pile diameter. The freeze-thaw action of surface ice can also break down the surface of timber piles.

g. Construction Defects. Damage to timbers that occurs during construction often leads to serious deterioration later. Common problems include splits or cracks in piles caused by rough handling or overdriving, scars caused by machines used to place the timbers, and holes drilled into the wood which render its preservative ineffective and make it vulnerable to borer attack.

h. Damaged Connectors. Damage to bolts and drift pins which connect elements of timber structures can also weaken the facility. The inspector should note missing, bent, or corroded connectors, as well as any loss of section in the connector due to corrosion. Dissimilarities between material properties of nuts and bolts can cause significant losses to either the nut of the bolt. It may be necessary to remove bolts to inspect for hidden corrosion (Fig. 3-24).

Figure 3-24 Timber bolt with slight loss of section on threads.

CHAPTER IV

UNDERWATER INSPECTION EQUIPMENT

SECTION 1. THE DIVER'S ENVIRONMENT

The diver's work environment is inherently hostile. He often works in dark, cold isolation and is exposed to a variety of pressure-decompression related illnesses and injuries (Fig. 4-1). Divers must rely completely on external life support systems while working under severe limitations such as diminished sensory and perceptual capabilities; and interference with cognitive processes and psychomotor skills. Reduced physical working capacity, and physiological and psychological stress limit his effectiveness.

Figure 4-1 Diver working in a hostile environment.

To work effectively, the diver must adapt to his environment, be familiar with his equipment, and select methods appropriate to the task. He cannot properly conduct an inspection if he must concern himself solely with his survival.

Divers are particularly and uniquely exposed to physiological hazards such as pressure, oxygen deficiency and nitrogen narcosis.

When air is breathed under pressure, as in diving situations, inert nitrogen diffuses into the tissues of the body. The amount of nitrogen absorbed increases with depth and duration of the dive. When the diver ascends, the nitrogen comes out of solution. If the ascent rate is too rapid, the nitrogen will not be dissipated and gas bubbles can form in the diver's tissues and blood. These bubbles tend to form at the body's joints resulting in what is commonly known as the "bends" or more correctly as decompression

NO-DECOMPRESSION LIMITS[1]

Depth (ft)	No-Decompression Limit (minutes)
30	310
40	200
50	100
60	60
70	50
80	40
90	30
100	25
110	20
120	15
130	10
140	10
150-190	5

Figure 4-2 No-Decompression Limits
(From the U.S. Navy Dive Manual)

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[1] This table is not structured for repetitive dives.

sickness. For this reason, a diver's time in the water must be carefully monitored. Combinations of deeper dives and dives of long duration may require the diver to decompress in stages by slowly ascending and spending time at intermediate depths. The majority of bridge inspection dives are of short duration or at shallow depth, therefore decompression is not needed. Such dives are referred to as no-decompression dives. Figure 4-2 indicates the no-decompression time limits for various depths of diving.

Even though decompression is not required within the limits shown in Figure 4-2, an amount of nitrogen remains in the diver's tissues after every dive. If he dives again, the diver must consider this residual nitrogen.

Breathing air under pressure can cause nitrogen narcosis, a feeling of euphoria sometimes referred to as "rapture of the deep." At depths below about 100 feet, most divers feel the early lightheaded effects associated with nitrogen narcosis. Beyond 200 feet few divers can work effectively while breathing air.

The diver's greatest threat is loss of his air supply, but inadequate ventilation of the diver's mask or helmet can cause carbon dioxide poisoning. Because exhaust fumes from internal combustion engines in a diver's air supply can cause carbon monoxide poisoning, special care must be taken when locating a compressor's air intake.

Breathing air under high partial pressures can cause oxygen poisoning. Partial pressures of oxygen in excess of that encountered at normal atmospheric conditions may be toxic to the body. Oxygen toxicity is dependent upon both the partial pressure and the exposure time. In the range of 0.2 to 0.6 atmospheres (atm) of oxygen no toxicity is detectable. From approximately 0.6 to 1.6 atm of oxygen, with exposure times from hours to days, lung toxicity may occur. At pressures greater than 1.6 atm of oxygen, central nervous system oxygen toxicity occurs before lung toxicity produces symptomatic damage. The air diver seldom encounters oxygen partial pressures greater than 1.6 atm since it represents a depth of over 200 f.s.w. His greatest opportunity for being exposed to the potential of oxygen poisoning is during recompression treatment or surface decompression using oxygen.

Because of the potential for nitrogen narcosis and oxygen poisoning when breathing air under high pressure, mixed gas, generally a helium-oxygen mixture, is used for deep dives, generally 190 feet or greater. Mixed-gas dive stations are costly to set up and operate, and they require specially trained dive personnel. Most bridge inspections are conducted at depths where air can be used. For this reason, air diving is the only type discussed in detail in the following sections.

SECTION 2. MODES OF DIVING

4-2.1 General

Within air diving, two principal modes are used: scuba, in which the diver carries his air supply with him in a tank, and surface-supplied diving in which the diver's air source is in a boat or on shore. While some organizations may be predisposed to one mode over the other, both modes are permitted by OSHA standards and both have a place in bridge inspections. In some situations, one mode may have significant economic benefits over the other, while providing all the inspection information required without in any way compromising safety. Their appropriateness for any specific diving situation depends on a number of factors including depth, bottom time, inspection tasks, waterway, environment, and the experience and capability of the diver. Each mode has unique operational advantages and disadvantages.

a. SCUBA. Scuba is an acronym for Self-Contained Underwater Breathing Apparatus. Scuba is generally recognized today in the open-circuit form: air is inhaled from a supply tank and the exhaust is vented directly to the surrounding water. The first efficient and safe open-circuit scuba was developed in France during World War II by Captain Jacques-Yves Cousteau and Emile Gagnan by combining an improved regulator with high pressure air tanks. Through further years of research and testing, Cousteau and others have brought scuba to its current level of development where it is used militarily, commercially, and recreationally.

Scuba utilizes high pressure steel or aluminum air cylinders (Fig.4-3) with two-stage regulators to deliver

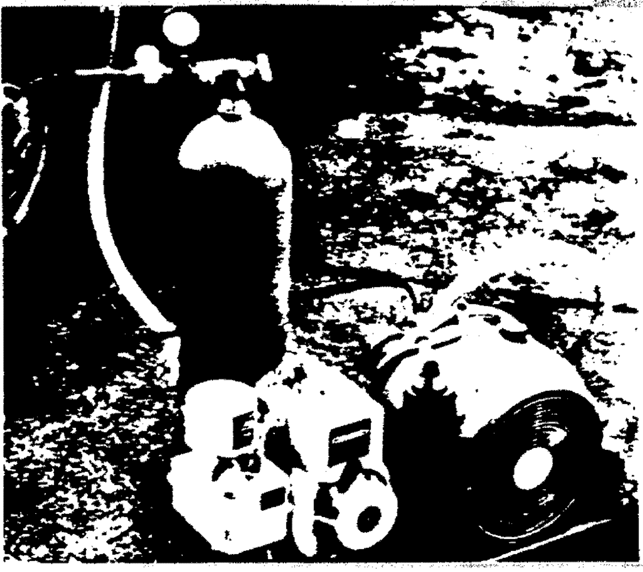


Figure 4-3 Small high pressure compressor used to fill scuba tank.

air to the diver. The first stage of the regulator is attached directly to the valve on the high pressure bottle. This first stage reduces the high pressure air (up to 3,500 psi) in the tank to an intermediate pressure (110 to 150 psi above ambient). The second stage of the regulator reduces the intermediate pressure air to ambient pressure and delivers it to the diver on demand (Fig. 4-4). As the diver inhales, he activates a valve which allows the air to flow to him.

Scuba is well suited for inspection work because of its portability and ease of maneuverability in the water where many dives of short duration at different than one sustained dive. Scuba equipment weighs about 75 pounds and requires no elaborate support operation. It has the advantage that the diver does not have to drag an air hose behind him. The use of scuba is limited by OSHA to depths of 130 feet and the bottom time is limited by the amount of air the diver can carry with him. The depth and bottom time requirements of most bridge inspections are well within the limitations of scuba diving as shown in Figure 4-5.

Figure 4-4 Diver with scuba equipment.

Surface to diver communication is possible using scuba with either hard wire or wireless systems. Communication may be desirable in deep water or for complicated structures.

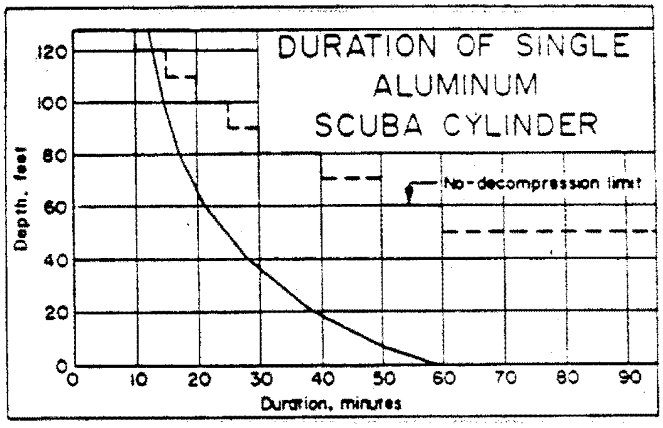


Figure 4-5 Typical dive duration for scuba diver with one 80 c.f. tank.
Note: Dive duration varies significantly for different divers and different levels of exertion. locations are required rather

b. Surface-Supplied Air. There are two types of surface-supplied equipment: deep-sea (hard-hat) and lightweight. Deep-sea equipment consists of a helmet and breastplate, diving dress and weighted shoes (Fig. 4-6). The equipment worn by the diver alone can weigh more than 200 pounds. Add to this the air compressor, hoses, lines and possibly a diving launch to work from, and the problems of mobility and transportation become significant. This equipment is cumbersome, not well suited for bridge inspections, and generally not considered economical for most modern diving operations since the development of lightweight equipment. The deep-sea hard-hat has changed little in the last 150 years.

Figure 4-6 Diver in deep-sea equipment.

Lightweight equipment usually consists of a full face mask or helmet, safety harness, weight belt, boots or fins, back-up air supply, and an exposure suit (a wet or dry suit). Early helmets were free-flow air hats in which a constant stream of air is supplied to the diver. Today, demand regulators similar to those used in the second stage of scuba equipment have been incorporated in helmets and full face masks (Fig. 4-7).

In a surface-supplied system, air is supplied by a high volume, low pressure compressor or from a bank of high pressure cylinders equipped with a regulator to reduce the high pressure. The compressed air is sent through a filtering system into a volume tank at about 150-200 psi. From the volume tank, the air goes to a manifold which has the diver's umbilical connected to it.

The diver's umbilical is a combination air hose, safety line, communication cable, and pneumofathometer hose. The pneumofathometer allows the diver's depth to be monitored by a tender at the surface. With a surface supplied system, a tender must monitor the diver's air supply and depth, and communicate with him.

The primary advantage of surface-supplied air diving is the "unlimited" air supply. Longer bottom times can be obtained on surface-supplied dives if decompression schedules are used. Dives in accordance with OSHA standards can be conducted to depths of 190 feet or, if bottom times are less than thirty minutes, to depths of 220 feet. The major disadvantage of surface-supplied diving is the lack of mobility. Inspection work generally requires the diver to constantly change depth or travel around structures or obstacles. In doing so, the diver using surface-supplied equipment may become entangled in his umbilical. As a minimum, he has the added effort of dragging it after him.

Additional support equipment, for both scuba and surface supplied gear, could include a decompression chamber. A chamber is required when dives exceed 100 fsw or the no-decompression limits.

Figure 4-7 Diver wearing lightweight helmet.

SECTION 3. DIVER'S EQUIPMENT

4-3.1 Scuba

a. Exposure Suits. Water is one of the most effective cooling agents known. A diver immersed in water at a temperature less than body temperature rapidly loses body heat. Even in relatively warm water, the diver will become chilled after prolonged exposure. To protect and insulate the diver, an exposure suit is usually necessary. There are two kinds of exposure suits commonly in use; the wet suit and the dry suit.

In warm waters, generally above 50 degrees fahrenheit, a wet suit will provide adequate thermal protection. The suit is tight fitting and constructed of neoprene. The wet suit allows a thin layer of water between the suit and the diver's skin. This layer of water, which is warmed by body heat, acts as insulation to keep the diver warm. A full suit consists of a jacket, pants, boots, gloves, and hood.

The variable volume dry suit is an extremely effective suit in cold water. Dry suits are also used in polluted waters. The more popular suits are constructed of either closed cell neoprene with nylon backing on both sides, nylon, or vulcanized rubber. Boots are normally integrated with the suit; hoods may be attached or separate; and gloves are usually separate. The suits have a waterproof and pressure-proof zipper for entry. The suits are designed to use a layer of air as insulation and can normally be inflated from a low pressure air supply. Air inside the suit can be exhausted through a separate valve on the suit. The suits are designed to be worn with thermal underwear which provide excellent protection against cold both in and out of water. The dry suit normally requires the diver to wear more weight than he would with a standard wet suit, due to the volume of air in the suit.

b. Scuba Equipment. In addition to an exposure suit, the diver generally has a standard list of dive equipment. Essential equipment, other than the scuba regulator and tank, includes:

(1) Face mask
(2) Buoyancy compensator
(3) Weight belt
(4) Swim fins
(5) Knife
(6) Wristwatch
(7) Depth gauge
(8) Submersible pressure gauge

Each item is discussed below.

The face mask protects a diver's nose and eyes from the water. The air pocket within the mask allows the eye to focus on underwater images. Masks which have corrective lenses are also available.

OSHA requires the use of an inflatable flotation device capable of maintaining the diver at the surface in a face-up position when using scuba equipment. The buoyancy compensator, or "BC", is a system of one or two rubberized air bags protected by an outer shell. It allows the diver to maintain neutral buoyancy at depth or to maintain a face-up position on the surface without having to tread water. Proper use of the BC reduces the effort of vertical movement. There are three ways of inflating the BC: 1) through an oral inflator, 2) with air from the scuba tank or 3) in an emergency with a CO_2 (carbon dioxide) cartridge attached to the BC.

A diver uses a weight belt to help control buoyancy. The most popular weights are molded lead which fit onto a nylon web belt buckled with a quick-release mechanism. The amount of weight worn by the diver depends on his natural buoyancy and the buoyancy of the equipment he is wearing. For a scuba diver wearing a wet suit, ten to twenty pounds of weight is commonly worn. With a dry suit as much as fifty pounds of weight may be required in order to become negatively buoyant.

Swim fins increase the propulsive force generated by the legs while swimming underwater. Swimming efficiency is greatly increased with the proper pair of fins.

The diver's knife is used primarily as a tool and is available for emergencies. There are many styles of knives available. Typically the knife is made of corrosion-resistant metal, usually stainless steel, and has a serrated edge for sawing through larger and stronger lines.

A watch or bottom-timer is very important. A diver uses one of these to stay within the no-decompression limits or to control decompression dives. The unit must be waterproof, pressure-proof, accurate, and dependable.

The depth gauge measures the pressure created by the column of water above the diver and is calibrated to indicate a direct reading of depth in feet of sea water. Accurate depth readings are essential when diving in order to stay within no-decompression limits or to locate decompression stops if outside the no-decompression limits.

The submersible cylinder pressure gauge provides the diver with a continuous indication of the air remaining in the air cylinder.

Additionally, dive lights and portable decompression meters (dive computers) may be used. The dive light is a waterproof, pressure-proof, underwater flashlight. It can be very useful where natural light does not

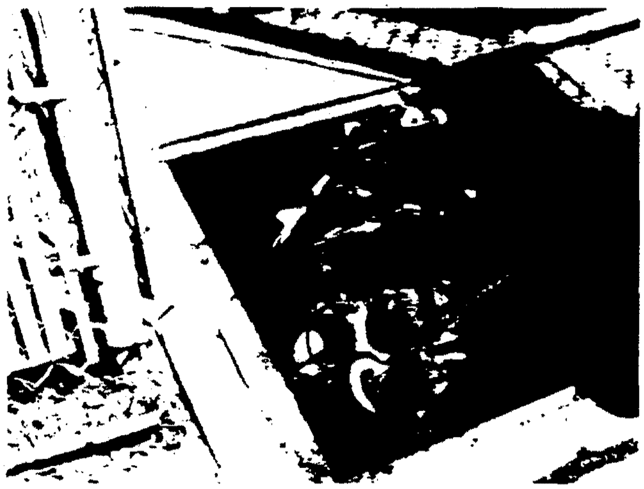


Figure 4-8 Scuba diver using full face mask with communications.

penetrate, but it is of limited usefulness in muddy or dirty water where there are suspended particles.

A recent invention, the dive computer, monitors bottom time and depth. Some computers will determine a decompression schedule, if required. When the diver descends and ascends, the computer continually updates and recalculates the dive profile taking into consideration the times spent at different depths on the way to the surface. The advantage of this method of calculation is that the diver can stay in the water for longer periods of time than if his dive profile were computed just once based on the deepest depth reached. This device is especially useful in inspection work because the diver does not spend long periods of time at any one depth, but it should not be used without a full understanding of its capabilities and limitations.

c. Communication. In general, there are two types of diver-to-surface communication systems available to the scuba diver. In a hard wire system, the diver has a microphone and speaker connected by cable to a surface transmitter-receiver. This is used regularly in surface-supplied diving and can be used when a scuba diver is tethered with a safety/communication line (Fig. 4-8).

Wireless systems are also available for use with SCUBA equipment. There are a variety of units on the market. The advantage of a wireless system is that it allows the diver greater mobility.

4-3.2 Lightweight Surface-Supplied Diving

a. Basic Equipment. Lightweight surface-supplied divers share a few basic items with scuba divers, namely: an exposure suit, a weight belt, and a knife. Swim fins or boots are worn depending upon the work requirements. A wristwatch is generally not worn by surface-supplied divers because the tender is responsible for accurate timekeeping. For lightweight diving, a diver is required to wear a safety harness with the umbilical attached to it to prevent any strain on the mask and to provide a lifting point to assist pulling a diver out of the water in an emergency.

b. Breathing Apparatus. There are two types of surface-supplied breathing equipment: free-flow and demand. Both types allow the diver to breathe through his mouth or his nose.

With a free-flow system, air is delivered to helmet, or mask, continuously and exhausted through an open valve to the surrounding water. The diver has to adjust the exhaust for different working depths or levels of physical exertion. Each helmet has a purge button which the diver can use if necessary to reduce air pressure quickly. The Navy's MK12 (Fig. 4-9) is a good example of a modern free-flow air hat. With this type of helmet, a jocking harness is worn to keep the helmet secure and relatively stable on the diver because, with a continuous air flow, the helmet has a tendency to float.

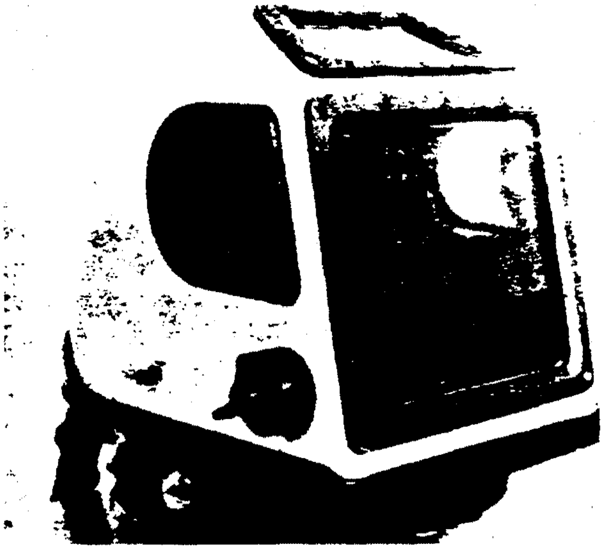


Figure 4-9 Navy MK12 helmet, a modern free-flow helmet.

Demand masks and helmets essentially combine a regulator, similar to the scuba regulator's second stage, with a "face mask" in one unit. The masks, referred to as "band masks," have a large face plate and a regulator. The band mask generally has a neoprene hood and a rubber strap, called a "spider," to secure the mask to the diver's head, making a seal around his face. Air is supplied to the regulator via a sideblock, a one-way valve attached to the mask or safety harness, which is connected to a primary and backup air source (Fig. 4-10)

Demand helmets are basically free-flow hats to which a regulator has been added. The helmet has a sideblock and regulator assembly similar to a band mask. Both the helmet and the band mask generally have a movable nose pad to assist the diver in clearing his ears and sinuses. More weight will be required by a diver in a helmet because of the volume of air inside it. Jocking harnesses are not necessary with the demand masks.

Figure 4-10 Diver wearing a band mask.

All lightweight diving helmets and masks can be outfitted for two-way communication. The diver's umbilical has a communication line which connects the helmet's or mask's earphone and microphone assembly to a surface radio (Fig. 4-11).

c. <u>Backup Air Source</u>. When a dive is conducted deeper than 100 fsw or outside the no-decompression limits, OSHA requires that a diver carry a reserve breathing gas supply. Many organizations also require this reserve for shallower dives. This is typically a scuba tank, with appropriate fittings, connected to the helmet, for free-flow apparatuses, or to the sideblock of a demand mask or helmet.

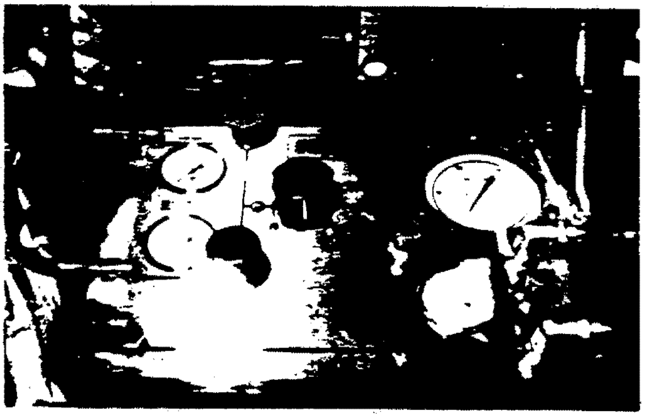


Figure 4-11 Surface-supplied diver's control console with communication and pneumofathometer.

d. <u>Tenders</u>. Each diver must be continually tended while in the water. Tenders are responsible for ensuring the dive profile is followed and maintaining the dive station. All dive systems, i.e., communications, compressors, pressure gauges, backup systems, as well as the diver, are to be monitored. As a minimum, a tender should be trained in the topside requirements of surface-supplied diving.

SECTION 4. INSPECTION TOOLS

4-4.1 General

To work effectively underwater, the diver must have the proper tools and equipment. Much of the underwater work in inspection diving involves cleaning of structural elements. Sampling and testing may also have to be accomplished. The use of specialized tools may be necessary for testing. Both power and hand tools are used under water.

In deciding whether to use power tools or hand tools, the dive manager must weigh the advantages gained in conserving the diver's energy versus the mobilization costs and the loss of mobility. For underwater inspection work, unless the biofouling is especially severe, extremely difficult to remove, and the areas to be cleaned are extensive, hand tools are usually more economical. Power tools, if selected, must be used with care so that the structural material is not damaged after the biofouling is removed.

For underwater repair work, where extensive cleaning is required, use of power tools would normally be warranted.

4-4.2 Tools

a. Hand Tools. Almost all standard hand tools can be used underwater, but they require better care and maintenance. Typical tools used during an inspection include screwdrivers, scrapers, ice picks, hammers, axes, hand drills, wire brushes, pry bars, and hand saws (Fig. 4-12) Divers routinely drop tools, so it is usually best to secure the tools to the diver with a lanyard to save time searching for lost tools in soft silt. Work with hand tools underwater can be slow and arduous, making their use impractical for larger jobs.

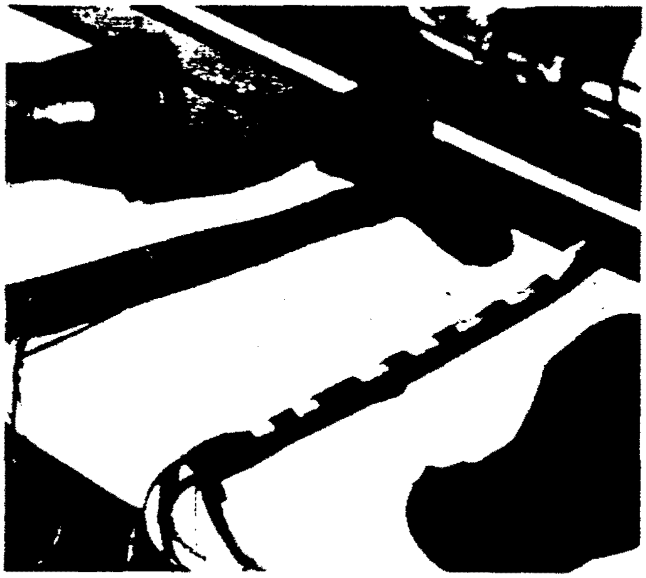


Figure 4-12 Typical hand cleaning tools.

b. Power Tools. Both pneumatic and hydraulic tools are used underwater. Although pneumatic tools are not usually designed specifically for underwater use, they can usually be readily adapted to perform the required tasks. Pneumatic drills, chippers, hammers, scalers, and saws are available. Use of pneumatic power is limited to practical depths of 100 to 150 feet and is costly to operate and maintain. Pneumatic tools also produce streams of bubbles that can block the diver's vision.

Underwater hydraulic tools are modified versions of hydraulic tools used on land. Providing a hydraulic power source can be costly, and the tools themselves are often fatiguing to use because they produce torque or vibrations which may be hard for the diver to counteract unless he is heavily weighted or secured to something at the work site. Stiff hoses add to the diver's difficulty. The biggest advantage of hydraulic tools is that they do not create the bubbles that pneumatic tools do.

Power tools have also been developed which use sea water rather that hydraulic oil or air. A pump located on the surface pumps water to the tools, and the water is expelled underwater by the tools.

A water blaster can also be a useful piece of equipment for cleaning a structure. Popular commercial models have gas powered engines, are relatively compact, and can deliver pressures between 3000 and 4000 psi, which is enough to remove deteriorated concrete and corrosion.

SECTION 5. UNDERWATER PHOTOGRAPHY AND VIDEO EQUIPMENT

4-5.1 General

Improvements in underwater documentation equipment and techniques have been significant in the last few years, in part, because of work on offshore oil platforms, and because of improvements in 35mm underwater cameras and video equipment in the consumer market. Underwater documentation in the form of color photography or video can be provided at an economical cost under almost all water conditions.

4-5.2 Photography

Black and white, and color 35mm photographs can be made of underwater conditions relatively easily. Most popular above water cameras from the "instamatic"

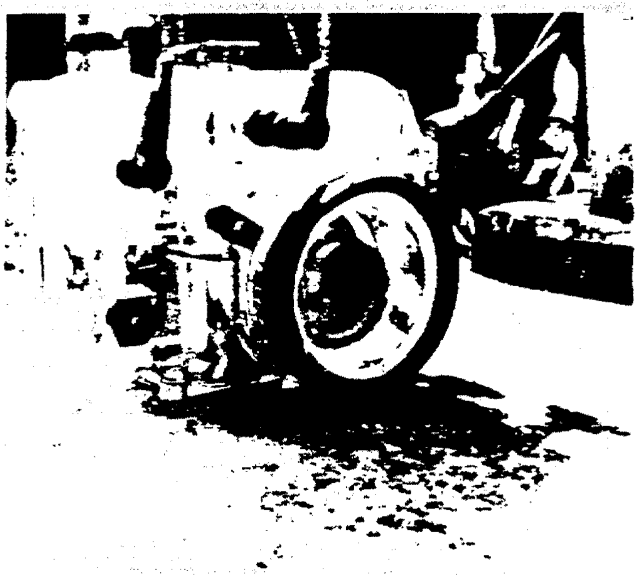


Figure 4-13 Waterproof camera housing.

type to sophisticated 35mm units can be used underwater in waterproof cases, which are commonly called "housings." Most cases today are made of clear acrylic plastic and sealed with rubber gaskets. (Fig. 4-13)

There are also waterproof 35mm cameras designed specifically for use underwater. These cameras can be equipped with a variety of lenses and electronic flash units for underwater photography. Some of these cameras, when used with a compatible flash unit, will control the amount of light delivered on the subject by the flash (Fig. 4-14).

In underwater photography, selecting the proper combination of camera lens and light is very important. Photographs must be taken from much closer distances to maintain clarity since most bridges are not located in clean, clear water. In some waters, like the Mississippi and Ohio Rivers, visibility is only a few inches. In many rivers, however, there is one or two feet of visibility. The camera-subject distance must be minimized, and a wide angle lens, such as a 15mm lens, must be used to photograph a reasonably sized area in one picture. It should be noted that because of the refractive property of the water, the apparent distances are about three-fourths of actual distances and objects appear larger than they actually are. Underwater cameras are generally calibrated in apparent distances.

4-5.3 Lighting

The lighting for underwater photography is especially important because of the alluvial material suspended in the water. Suspended material reduces the light that actually reaches the subject, and it can reflect light back into the camera lens. To minimize this problem, the electronic flash unit must be placed to one side so that light does not reflect directly into the lens. It is usually best to use two light sources of lower intensity located far to each side of the camera. To reduce the localized intensity of the flash, a diffuser should be used when photographing reflective objects such as bright steel, or when there is considerable sediment in the water.

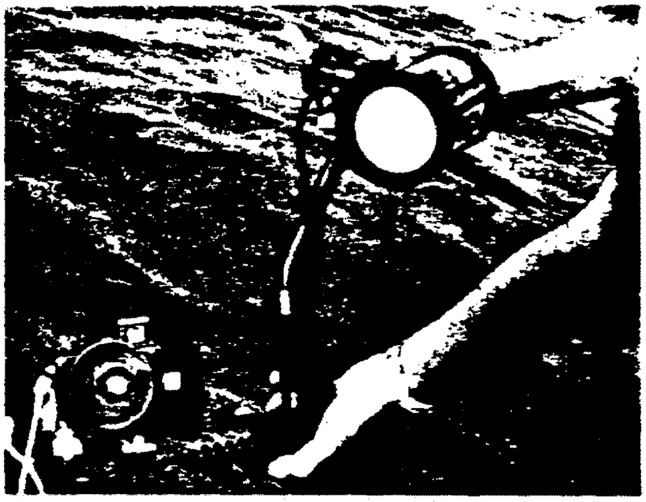


Figure 4-14 Underwater camera and flash unit.

4-5.4 Film

Almost any film that can also be used above water with artificial light can be used below water. Where low intensity light sources must be used to reduce reflection problems, higher speed films can compensate for this. Generally, it may be best to use one particular speed film, such as ASA 100, maintaining the light source at the same distance from the subject, and compensating by using various aperture openings. In this way, only one variable is changed, and it is only necessary to have one type of film on hand.

It is usually best to document conditions with underwater photography as the inspection progresses, rather than waiting until the end of the project to take pictures. This permits review of the

Figure 4-15 Graphic scale with location shown.

initial photographs and adjustment in the technique before all photography is completed. It is better to find out that the first few shots have to be taken again rather than finding out that all the photographs must be retaken. Usually, color print film is the easiest to have processed before leaving the job site because of the "one-hour" shops that are readily accessible.

Even in relatively clear water where natural light penetrates to the depth at which photo-documentation is to take place, artificial light sources should be used to obtain true color reproduction. As natural light penetrates water, the water filters and absorbs colors in the natural light spectrum. Some red is lost just below the surface, and at about 30 feet all objects appear blue-green. Thus, without artificial light, key details and contrast can be lost.

In reviewing photographs of underwater objects, it is often difficult to determine the size of objects and their true color or tint without some standard of reference. There is also no frame of reference for locating the picture because underwater photographs often look similar. Technicians processing film exposed underwater also often have difficulty in determining the correct tint. One processing technician may make an object blue, while another might make the same object brown. To provide a basis for reference, a scale, and the location of the picture should be indicated, and a patch of known color should be included the photograph to provide a standard against which the processing technician can adjust the color (Fig. 4-15).

4-5.5 Clearwater Box

When the water is extremely turbid, visibility may be reduced to a few inches, making normal photographic techniques useless. In such cases, a clearwater box may be used. A clearwater box is a box constructed of clear acrylic plastic that can be filled with clean water through which the camera can be aimed. The box of clean water, when pressed against the subject, displaces the dirty water. Various sizes and shapes of boxes can be constructed, depending on the objects to be photographed.

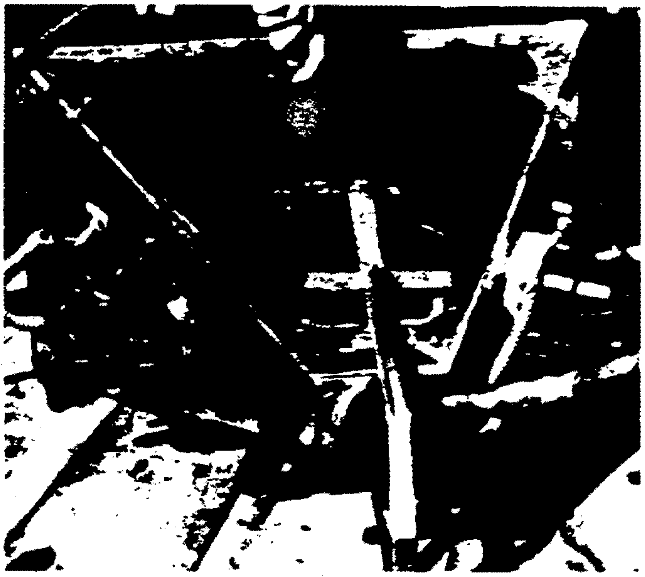


Figure 4-16 Clearwater box.

A typical clearwater box for general purpose underwater photography is fitted with handles to make control easier, brackets for mounting the camera and flash units, and caps for filling (Fig. 4-16). The box is designed to be filled with clean water while it is in water so that there is no great difference in pressure between the inside and outside of the box (Fig. 4-17). The box is slightly negatively buoyant when filled completely with water. An air gap may be left inside the box to make it positively buoyant.

The face of the box shown in Figure 4-16 is about 20 inches high by 30 inches wide, and the distance from the front of the box to the back is 20 inches. A wide angle lens is mounted on the back face of the box and the camera is connected to the back of the lens. A scale that is mounted on the front of the box will appear in all pictures. At the time of publication of this manual, clearwater boxes were not commercially available, but must be custom made.

Electronic strobes are mounted on each side of the box. The strobes are aimed so that there is no reflection into the lens off the front face of the box. One strobe is connected to the camera by a cable, and the other strobe functions as a slave unit that fires automatically when it senses the other strobe firing. Use of the clearwater box normally requires two divers: one to operate the camera and one to control the box. In stronger currents, it may require three divers, and in extremely strong currents it may not be possible to effectively use the device.

Figure 4-17 Divers filling clearwater box.

Figure 4-18 View of damaged concrete pile through clearwater box.

Refer to Figures 4-18 and 4-19 for two photographs taken with a clearwater box.

Figure 4-19 View of severely corroded steel H-pile through clearwater box.

4-5.6 Video

Just as consumer video cameras and recorders have improved dramatically in the last few years, underwater video equipment has likewise improved. Highly sophisticated, compact underwater cameras were developed in recent years for underwater inspection of offshore oil platforms. In the past few years, consumer equipment has developed at a similar pace and is available at a relatively low price. Commercial underwater cameras and above-water consumer cameras in waterproof housings can be used with an umbilical cable to the surface for real-time viewing on a monitor, or for recording. Smaller camera-recorder systems in underwater housings of acrylic plastic or metal are available which can be used with or without the umbilical to the surface (Figs. 4-20 and 4-21).

These video systems can be configured to provide on-screen titles and clock, and also include narration by

Figure 4-20 Video camera with umbilical to surface.

the diver and the surface observer. In underwater video work, there is often a large portion of the tape which is of no value to the inspection record, such as when the diver is adjusting equipment and getting into position to operate the camera. In addition, there are often large portions of tape which illustrate only good conditions. If the tape is to be reviewed by high level personnel, it is usually cost-effective to edit the tape to reduce viewing and review time.

One of the most popular types of video units for which housings are made is the 8mm camera-recorder. The camera and recorder are combined in one unit. These units are compact, easy to use and, take very good pictures. Housings for the units are made by a number of manufacturers and can be modified so a surface monitor can be used.

4-5.7 Remote Operated Vehicle (ROV)

A remotely operated vehicle (ROV) is a tethered underwater video camera platform, sometimes equipped with manipulator systems, and an electric or electro-hydraulic propulsion systems. An ROV is controlled from the surface by means of a video system, for operator observation; and "joystick" type propulsion and manipulator controls. Originally the vehicles were designed for extremely deep diving and to provide video inspection in places that were inaccessible or too hazardous for conventional diving, such as polluted, contaminated, or extremely cold water.

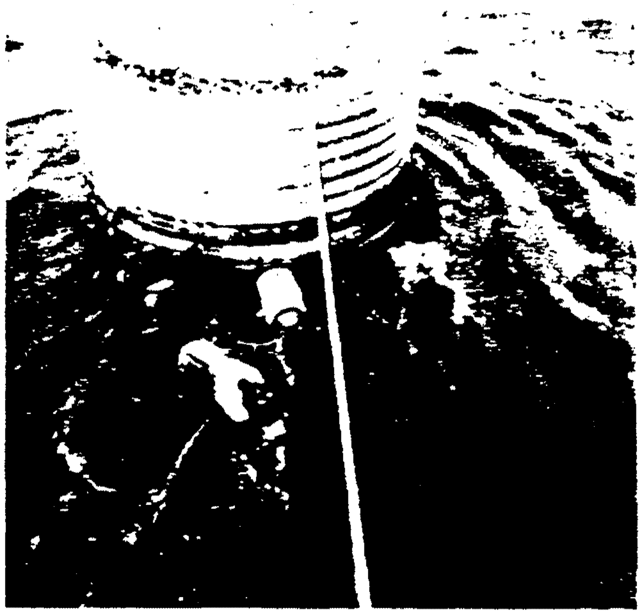


Figure 4-21 Camera-recorder in underwater housing..

Figure 4-22 Remotely operated vehicle with control console.

Although the dependability of the ROV has steadily increased, some problems still remain. The ROV can only supply a two-dimensional view of a problem; the full extent of any defects generally cannot be obtained from a picture. In murky water, the effectiveness of an ROV is extremely limited; a diver can at least conduct a tactile inspection. It is difficult to know the exact orientation or position of the vehicle to accurately identify the area being observed and the operator may also encounter problems with controlling the vehicle in a current or tangling its umbilical.

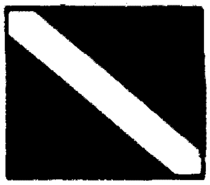
4-5.8 Dive Platforms

In bridge inspections, the primary dive platform is typically a small boat. There are many different sizes and types available. Hulls are made of aluminum, wood, and fiberglass. There are also inflatable boats that work well as dive platforms. A key criterion when choosing a boat is adequate space for all dive equipment and personnel. Working conditions must be safe for both the above-water crew and the diver.

Generally, the boat should be equipped with an engine, the size dictated by waterway conditions, degree of portability desired, and boat size. All Coast Guard and local government rules and regulations must be followed, and appropriate dive flags should be displayed.

The international code flag "A," a blue and white flag, must be displayed to comply with OSHA. Some states also require display of the red and white sport diver flag. Since recreational boaters may not recognize the code flag "A," both flags should generally be flown for safety.

A I have a diver down; keep well clear at slow speed. (White stripe on blue).



Sport Diver (White stripe on red).

Figure 4-23 Dive Flags.

CHAPTER V

UNDERWATER INSPECTION TECHNIQUES

SECTION 1. PREPARATION AND SAFETY

5-1.1 Site Reconnaissance and Data Collection

Underwater bridge inspections, especially the initial inspections, require careful planning to ensure that the work is performed effectively and economically. Underwater inspections can be expensive, but prior site reconnaissance can reduce the cost by leading to selection of equipment and methods best suited to the work and staffing with appropriate personnel.

During the site reconnaissance, the dive manager should: 1) Determine the number of substructure units in water, 2) estimate those units which can be inspected by wading and those which require diving, 3) determine the approximate water depth from the drawings or using a lead-line, and 4) determine the approximate velocity of the water, by timing some floating object as it passes under the bridge or in tidal areas, consulting tide tables.

5-1.2 As-Built Drawings and Previous Reports

The diver should be given drawings of the structure, preferably as-built drawings, to prepare for an inspection. By previewing the bridge drawings, the inspector can learn what he may encounter during the dive. It will also make communication between the diver and note-taker easier.

Previous reports provide additional information. If the diver reviews a report prior to the inspection, during the dive he can check the condition of previously found defects and report any new ones. Soundings contained in previous reports provide a baseline for checking scour activity. The inspector should be told of any repairs made since the last inspection to allow him to check the condition of the repairs.

5-1.3 Plan and Procedures

Information obtained from site reconnaissance and previous reports help a dive team to prepare for an inspection by aiding in the selection of the most efficient methods and equipment.

As discussed in Chapter II, commercial diving operations must be conducted according to OSHA standards. Scuba can be used to a maximum depth of 130 feet. In currents exceeding 1 knot and when entering confined spaces a diver must be line tended. Surface-supplied diving equipment can be used to a maximum depth of 220 feet. For full details, refer to the OSHA standards in the Appendix.

For many bridge inspections, scuba equipment is the most efficient. It requires less set-up time and generally allows greater mobility than surface-supplied equipment. If communications are desired, a full face mask with wired communication and scuba may suffice. This combination eliminates the need for hoses, mixing consoles, volume tanks, and other apparatus needed with surface-supplied equipment. Wireless communication devices are also available.

Communications are also used for deep dives because they eliminate the need for the diver to surface to report findings. During shallow dives in swift current, where mobility is limited and when the diver is line tended, communications can expedite the work by allowing the diver to direct the tender and report conditions.

Safety or other considerations may dictate the use of surface-supplied diving equipment in some inspection situations.

Access to many small bridges can be from the adjacent shore; for larger waterways, a boat will be necessary. Aluminum or inflatable boats in the 14 ft. range will be adequate for many bridges. They are small enough to be carried, can be transported on the roof of a vehicle, can be launched without a boat ramp, and can carry the diving equipment for a small operation.

A boat in the 18 ft. range will be adequate for most larger rivers. It is big enough to support a small surface-supplied operation. Boats used for underwater bridge inspection can easily be damaged by bumping against bridge piers so it is important that all sides be protected with resilient fenders. Boats should be securely anchored or tied to the structure before diving operations are started.

At a few sites, such as when river banks are steep and there are no boat ramps nearby, it may be necessary to use special equipment such as a crane to lower either the boat or divers into the water.

If there is a history of debris collection at the site, arrangements should be made for its removal, or additional time should be allowed for the underwater inspection team to remove it.

The type of equipment needed for cleaning areas to do a Level II inspection needs to be determined. Most cleaning can be done with hand tools such as scrapers, hammers, or pry bars, but unusually heavy growth may require power tools such as chipping hammers and water blasters.

SECTION 2. INSPECTION

5-2.1 General

Certain aspects of inspection procedures are common to structures requiring underwater inspections.

Standard equipment for an inspection should include a hammer or scraper. These tools can be used for Level II inspections, and for probing and sounding defective areas to determine the extent of distress. An underwater light is also useful at times, depending on water clarity.

Water clarity often limits the diver's ability to visually inspect the structure. In such cases, he must use his tactile senses to supplement or replace the visual inspections. Usually it is most effective if the diver examines the underwater elements by moving his hands and arms in large sweeping motions to cover all areas of each underwater element.

Likewise, marine growth can obscure the condition of substructure elements. In fresh water, growth is generally light and can often be removed by rubbing with a gloved hand. In salt water environments, however, hand scrapers or power tools may be needed. Refer to Article 4-4.2 for additional discussion of these tools.

Scour is the removal of channel bottom material by the erosive action of running water. Stone, concrete blocks or similar material, referred to as riprap, is commonly placed around piers to retain bottom material. The inspector should note the type of bottom material, and the presence and size of riprap. This information can help determine how vulnerable a bridge is to being damaged by scour. Divers can obtain bottom samples using unbreakable sample jars or mechanical sampling buckets. Divers can also probe the channel bottom to obtain a measure of the relative density of the bottom material.

5-2.2 Piers and Abutments

Divers should inspect piers in a circular pattern, if possible, using visual and tactile methods. The inspection should be started by making a circular path around the base of the pier; then moving up a uniform increment, such as an arms length and circling the pier again. This pattern should be repeated until the inspection is complete.

When the inspector is line tended or using surface-supplied equipment, he cannot circle the pier without tangling the lines. In this case, the diver should inspect one side of the pier in a back and forth motion starting at the bottom (Fig. 5-1). The diver can then repeat the path on the other side of the pier.

Abutments should be inspected using the same back and forth method described above.

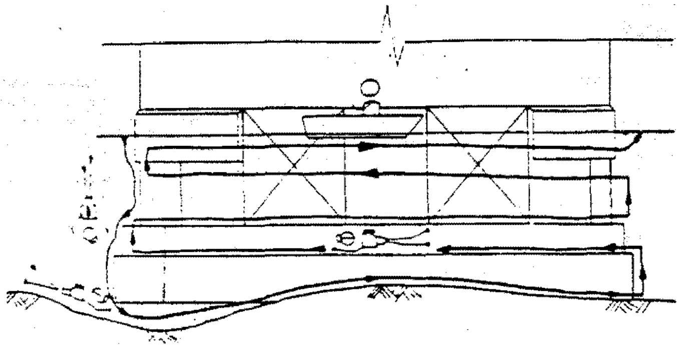


Figure 5-1 Schematic representation of a diver inspecting a pier

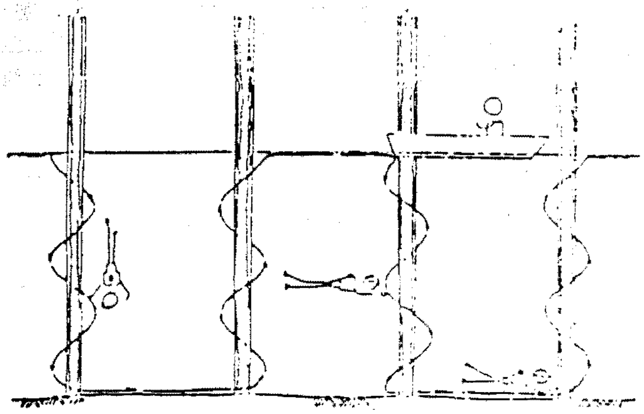


Figure 5-2 Schematic representation of a diver inspecting a pile bent.

The inspector should report if the footing is exposed, any defects within the material, and any evidence of scour.

5-2.3 Piles

Piles should be inspected in a spiral motion. The diver begins at the top of one pile and inspects it while descending; then moves to the next pile and inspects it while ascending (Fig. 5-2). If water visibility is poor the inspector may have to ascend and descend on the same pile. When the inspector is without communication to the surface and a defect is found he should surface immediately, report it, and then return to the point of the defect to continue the inspection.

When the inspector is line tended or using surface-supplied equipment, he must move from side to side to keep the lines free. Other aspects of the pier inspection procedure are the same as when using scuba.

5-2.4 Cells, Cofferdams and Bulkhead

The inspection procedure for cells, cofferdams, and bulkhead is similar as for piers. The inspector should also note the presence, size and condition of any riprap placed at the base of these units, and any indication of scour.

SECTION 3. SPECIAL TESTING, LEVEL III EXAMINATION

5-3.1 General

The types of testing described in this section are among those which may also be used for Level III examinations. Level III examinations are employed when Level I and Level II examinations cannot conclusively determine the structural condition of the underwater items. Findings of previous inspections or the age of the structure may also dictate the level of examination needed. A Level III examination is not required for all inspections.

5-3.2 Steel

In steel structures, the inspector is often concerned with measuring the remaining thickness of corroded members. This can be done with a graduated scale, caliper and ultrasonic thickness measuring devices. Weld testing methods, although not commonly used for underwater bridge inspection, include magnetic particle testing and radiography.

a. <u>Graduated Scales</u>. For measuring the exposed edges of flanges, a rule, or graduated scale is the most basic tool. It is not very precise, however, and should be used only for approximate measurements. Its accuracy is limited by the diver's vision and it's

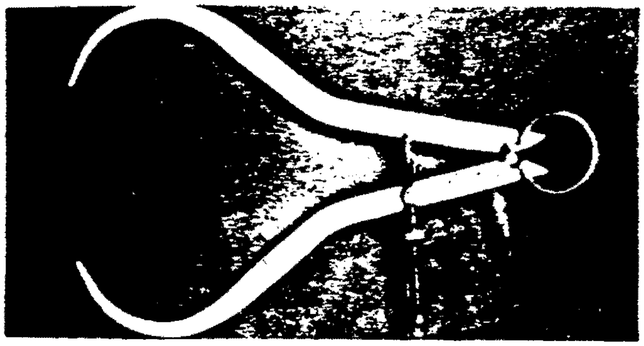


Figure 5-3 Calipers

use is limited to exposed member surfaces and edges.

b. Calipers. Another simple method of thickness measuring is to use a set of calipers (Fig. 5-3). Calipers are compact and easy to use under most conditions. A disadvantage, however, is that they cannot take direct measurements of sheet piling or webs of H-piles. To obtain direct measurements of sheet piles, holes could be drilled in the member. The same drilled hole method could be used to measure the web of H-piles, or a special large set of calipers could be fabricated that would provide clearance around the H-pile flanges.

c. Ultrasonic Measuring Devices. Ultrasonic devices are also available for measuring remaining steel thickness. The device sends a sound wave through the member. It then measures the travel time of the sound wave and calculates the thickness of the steel. An advantage to this device is that it only needs a transducer to be placed on one side of the member. The thickness of the steel is displayed on an LED display. To use the ultrasonic thickness measuring device underwater, the diver must clean a small area of the steel of marine growth and any loose protective coatings or scale. If the steel is very rough or badly pitted, it may be difficult to obtain accurate measurements. There are, however, special transducers that can be used to overcome this problem.

There are two types of devices ultrasonic thickness measuring devices available. One type is totally submersible and the diver must record or relay the measurements to the surface (Fig. 5-4). The second type has a waterproof transducer and cable which are carried below water while the electronics and display remain on the surface (Fig. 5-5). These units, however, can also be placed inside a waterproof housing and be completely submerged.

Figure 5-4 Waterproof D-Meter

Figure 5-5 Waterproof transducer for an ultrasonic thickness measuring device.

d. Magnetic Particle Testing. Magnetic particle testing detects flaws in steel and welds. The process involves inducing a magnetic field in the object to be tested. A liquid suspension containing a fluorescent dye and ferro-magnetic particles is applied to the area. If a flaw is present, the particles flow along the flaw.

Underwater magnetic particle testing is most commonly used during inspections of shore structures. This test method is not commonly used for bridge inspections because it is difficult to implement in flowing water and because off-the-shelf underwater testing devices are not available. The area to be examined must also be carefully cleaned to obtain good results.

e. Radiography. Radiography is the use of X-rays to "photograph" the interior of a member. A film cassette is placed on one side of a member and a radiographic source on the other. The film is developed and interpreted by a technician at the surface. This technique is expensive and not commonly used in bridges.

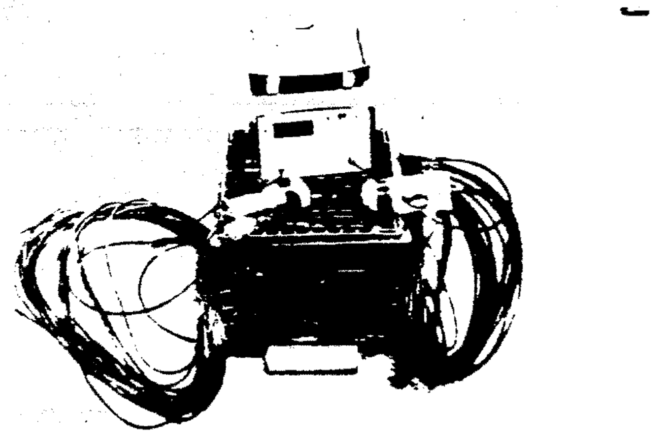


Figure 5-6 V-meter with waterproof cables

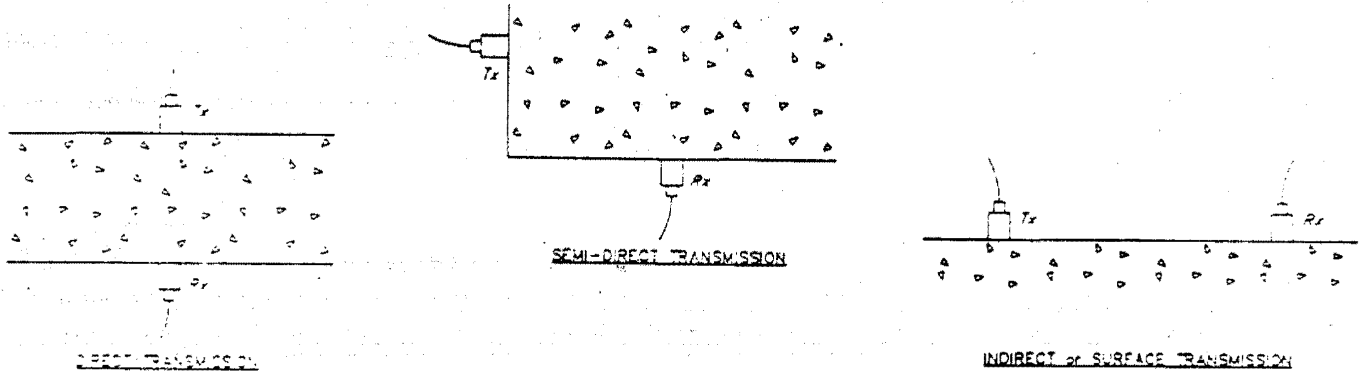


Figure 5-7 Positioning of transducers for V-meter

5-3.3 Concrete

Several nondestructive tests can be performed on concrete; however, the nondestructive testing instruments must be modified for underwater use.

a. V-Meter. The V-meter is an ultrasonic testing device. Using ultrasonics to check the condition of materials such as concrete requires two transducers (Fig. 5-6). When taking measurements, the transducers can be arranged in three different positions (Fig. 5-7). The direct transmission method provides the most accurate data. The semi-direct and indirect methods require correction factors to interpret the data.

The V-meter measures the time it takes a sound wave to pass through a material. Location of discontinuities in the material, such as cracks and voids are determined by abnormal velocities. Data has to be interpreted by a trained technician.

b. Schmidt Hammer. The Schmidt Hammer is a mechanical device which measures the compressive strength of in-place concrete. For underwater use the hammer is placed within a housing and the equipment modified somewhat, including a special scale (Fig. 5-8).

To use the hammer, the diver places it on the concrete surface and presses against the spring loaded plunger until a mass within the hammer is released causing an impact. The inspector estimates the concrete's strength with the data from this test.

c. R-Meter. The R-meter can determine the location of reinforcing steel within concrete and measure its depth of cover and size. The meter accomplishes this by inducing a magnetic field within the concrete. R-Meters must be modified for underwater use (Fig. 5-9). This method of testing is of limited use for heavily reinforced structures where it is difficult to obtain depth readings of individual bars.

d. Coring. Coring is a partially destructive test method. It can be used alone or to verify and correlate data from non-destructive test methods. Pneumatic and hydraulic coring equipment can be adapted for underwater use. Cores obtained underwater can be tested in a laboratory in accordance with standard procedures.

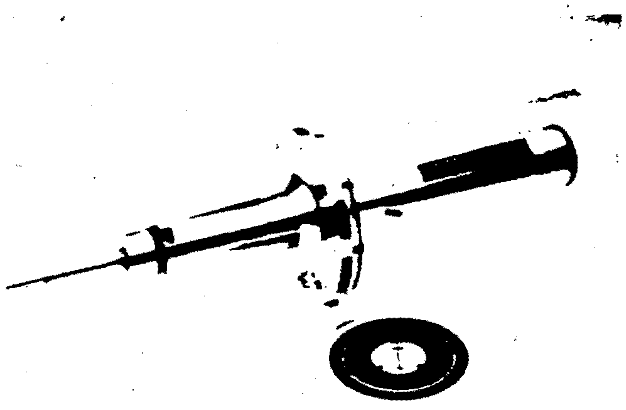


Figure 5-8 Waterproof Schmidt Hammer

5-3.4 Timber

Until recently testing of timber underwater has generally been limited to visual inspections, sounding with a hammer and using an ice pick to probe the timber. An ultrasonic method, which is now a proprietary product of one company for in-place testing of timber, was developed in the 1950's by British Columbia Laboratories and has also been used.

In about 1979, following the partial failure of timber piles supporting a bridge that had previously been visually inspected, the University of Maryland developed a non-destructive ultrasonic wave propagation method of determining the in-situ residual strength of timber piling. The testing equipment consists of a commercially available ultrasonic non-destructive digital tester and two transducers, each mounted in a waterproof case, with an operating frequency of 54 kHz. It provides a means of producing ultrasonic pulses in a timber pile and measuring the time for passage of the sound across the pile. From tests made on numerous timber pile samples, both in the laboratory and the field, the study developed empirical formulas to estimate the residual strength of timber piles. The empirical formulas were developed from a band of data, and engineering judgment must be used when evaluating a particular structure to select average strength values consistent with the engineer's confidence in the data obtained. Care must also be used in evaluating the data when internal marine borer attack is present. The cost of an ultrasonic meter and transducers are in the range of $5,000 to $7,000. For further information, refer to the FHWA's Inspection of Bridge Timber Piling, Publication FHWA-IP-89-017.

Figure 5-9 Modified R-Meter

Partially destructive testing of timber by coring and boring can be accomplished with hand, pneumatic, and hydraulic tools. Samples of the pile material can be obtained by coring, but the process is rather slow and costly. Boring a hole in the timber and probing the inside of the pile with a thin, hooked rod to determine if there are voids due to decay or marine borers is usually more cost-effective. After taking the core or drilling, the hole should be plugged with a treated hardwood dowel.

Every underwater inspection of timber piles should include representative measurements of the pile diameter. Losses of timber section due to abrasion, decay, or insect or marine borer attack may not be readily detected by visual means alone.

SECTION 4. DOCUMENTATION

5-4.1 Communication

The methods a diver uses to communicate his findings depends on diving conditions. The majority of bridge inspections, that is, those in shallow water with little damage, can be conducted with the diver reporting notes at the surface. In deep water, swift current or where there are extensive notes to report it may be desirable to have diver-to-surface communication. This allows the diver to concentrate his efforts on obtaining inspection data, and results in a more accurate description of the condition of the structure.

5-4.2 Still Photography

Still photographs can be of great value since they can help an inspector communicate his findings. Photographs of defects are useful in preparing repair plans, can be used as part of the repair bid documents, and may assist in obtaining funding for repair work.

Certain conditions will limit or prevent use of photography. Dark water may require the use of a clearwater box although strong river currents may preclude its use. Refer to Chapter 4 for a discussion of various types of photography equipment.

5-4.3 Video

Underwater video can provide documentation for an entire inspection or for selected areas. Video systems with a surface monitor can facilitate communication between inspector and note-taker. Self-contained systems also provide good documentation at low cost.

A monitor on the surface is necessary if an inexperienced or unqualified inspector is performing the diving work. This allows an engineer on the surface to see the same area as the diver and to view what the diver is describing.

The use of video can be cumbersome. It requires a larger support operation and has limited use in strong currents, if the diver must fight to maintain position, hold a camera, and describe a defect. Refer to Chapter 4 for a discussion of various types of video equipment.

CHAPTER VI

SCOUR INVESTIGATIONS

SECTION 1. BACKGROUND[1]

The most common cause of bridge failures stems from floods, and scouring of bottom material around bridge foundations is the most common cause of damage to bridges during floods. During the Spring floods of 1987, 17 bridges in New York and New England were damaged or destroyed by scour. In 1985, 73 bridges were destroyed by floods in Pennsylvania, Virginia, and West Virginia. A 1973 study for the FHWA of 383 bridge failures caused by catastrophic floods showed that 25 percent involved pier damage and 72 percent involved abutment damage. A second, more extensive, study made in 1978 indicated local scour at bridge piers to be a problem about equal to abutment scour problems.

Bridge scour evaluations should be conducted for each bridge to determine whether it is scour critical. A scour critical bridge is one with abutment or pier foundations which are rated as unstable due to (1) observed scour at the bridge site or (2) a scour potential as determined from a scour evaluation study.

SECTION 2. BASIC CONCEPTS AND DEFINITIONS OF SCOUR

6-2.1 General

Scour is the result of the erosive action of running water, excavating and carrying away material from the bed and banks of streams. Different materials scour at different rates. Loose granular soils are rapidly eroded under water action while cohesive or cemented soils are more scour resistant. Ultimate scour in cohesive or cemented soils, however, can be as deep, or deeper, than scour in sand bed streams. Scour will reach its maximum depth in sand and gravel bed materials in hours, cohesive bed materials in days; glacial tills, sandstones and shales in months; limestones in years and dense granites in centuries. Massive rock formations with few discontinuities can be highly resistant to scour and erosion during the lifetime of a typical bridge

Inspectors need to carefully study site-specific information in evaluating scour potential at bridges.

6-2.2 Total Scour

Total scour at a highway crossing is comprised of three components: aggradation and degradation, contraction scour and local scour. These components are described in detail below.

Aggradation and Degradation. These are long term streambed elevation changes due to natural or man induced causes within the reach of the river on which the bridge is located. Aggradation involves the deposition of material eroded from other sections of a stream whereas degradation involves the lowering or scouring of the bed of a stream.

Long term bed elevation changes may be the natural trend of the stream or may be the result of some modification to stream or watershed conditions. The streambed may be aggrading, degrading or not changing (i.e., in equilibrium) in the bridge crossing reach. The state of change of the streambed, i.e., aggradation, degradation, or equilibrium, is considered in terms of long

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[1] This chapter is based primarily on FHWA Technical Advisory, Scour at Bridges and publication RD78-162, "Countermeasures for Hydraulic Problems at Bridges. Portions of these publications are reproduced here with little or no change.

term trends, as opposed to the cutting and filling of the bed of the stream that might occur during a runoff event (general scour). A stream may cut and fill during a runoff event as well as have a long term trend of an increase or decrease in bed elevation.

Factors that affect long term bed elevation changes include: dams and reservoirs (upstream or downstream of the bridge), changes in watershed land use (urbanization, deforestation, etc.), channelization, cutoffs of meander bends (natural or man-made), changes in the downstream base level (control) of the bridge reach, gravel mining from the streambed, diversion of water into or out of the stream, natural lowering of the total system, movement of a bend, bridge location in reference to stream platform and stream movement in relation to the crossing.

General Scour and Contraction Scour. This type of scour involves the removal of material from the bed and banks across all or most of the width of a channel. General scour can result from a contraction of the flow, a change in downstream control of the water surface elevation, or the location of the bridge in relation to a bend. In each case, the scour is caused by increased velocities and resulting increased bed shear stresses. The most common form of general scour at a bridge is caused by the approach embankments to the bridge encroaching onto the floodplain or into the main channel with resulting contraction of the flow. This type of general scour is commonly known as contraction scour (Fig. 6-1).

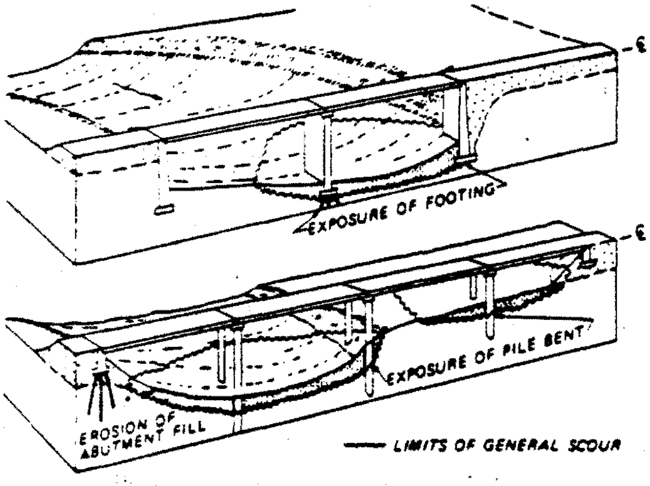

Figure 6-1 General scour.

General scour at a bridge can be caused by a decrease in flow area or an increase in velocity. This form of general scour is called contraction scour. The decrease in flow area or channel width may be naturally occurring or may be caused by the bridge. General scour can also be caused by short term (daily, weekly, yearly or seasonal) changes in the downstream water surface elevation that controls the backwater and hence the velocity through the bridge opening. Because this scour is reversible, it is included in general scour rather than in long term scour. If the bridge is located on or close to a bend, the concentration of the flow on the outer part of the channel can erode the bed.

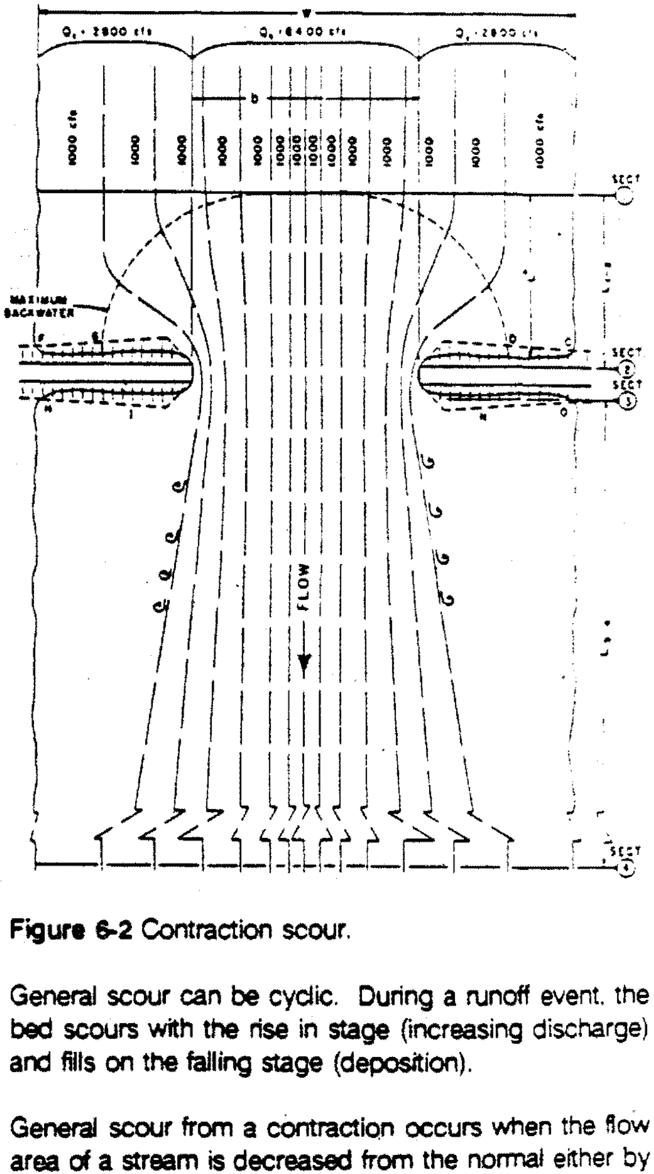

Figure 6-2 Contraction scour.

General scour can be cyclic. During a runoff event, the bed scours with the rise in stage (increasing discharge) and fills on the falling stage (deposition).

General scour from a contraction occurs when the flow area of a stream is decreased from the normal either by a natural constriction or by a bridge. With the decrease in flow area there is an increase in average velocity and bed shear stress. Hence, there is an increase in stream power at the contraction and more bed material is transported through the contracted reach than is transported into the reach. The increase in transport of bed material lowers the bed elevation. As the bed elevation is lowered, the flow area increases and the velocity and shear stress decrease until equilibrium between the bed material that is transported into the reach is equal to that which is transported out of the reach.

The contraction of flow at the bridge can be caused by a decrease in flow area of the stream channel by the abutments projecting into the channel, or the piers taking up a large portion of the flow area (Fig. 6-2). Also, the contraction can be caused by the approaches to the bridge cutting off the overland flow that normally goes across the floodplain during high flow. This latter case causes clear-water scour at the bridge section because the overland flow normally does not transport any bed material sediments. This clear water picks up additional sediment from the bed when it returns to the bridge crossing. In addition, if it returns to the stream channel at an abutment, it increases the local scour there. A guide bank at that abutment decreases the risk from scour to that abutment from this returning over-bank flow. Also, relief bridges in the approaches, by decreasing the amount of flow returning to the natural channel, decrease the scour problem at the bridge cross section.

Other factors that can cause scour are: (1) a natural stream constriction; (2) long approaches over the floodplain to the bridge; (3) ice formation or jams; (4) berms formed along the banks by sediment deposits; (5) island or bar formations upstream or downstream of the bridge opening; (6) debris; and (7) the growth of vegetation in the channel or floodplain.

General scour of the bridge opening may be concentrated in one area. If the bridge is located on or close to a bend the scour will be concentrated on the outer part of the bend. In fact, there may be deposition on the inner portion of the bend, further concentrating the flow, which increases the scour at the outer part of the bend. Also, at bends the thalweg (the part of the stream where the flow or velocity is largest) will shift toward the center of the stream as the flow increases. This can increase scour and the non- uniform distribution of the scour in the bridge opening.

Local Scour This type of scour involves removal of material from the channel bed or banks and is restricted to a minor part of the width of a channel. This scour occurs around piers, abutments, spurs, and embankments and is caused by the acceleration of the flow and the development of vortex systems induced by the obstructions to the flow (Fig. 6-3).

The basic mechanism causing local scour at a pier or abutment is the formation of vortices at their base. The formation of these vortices results from the pileup of water on the upstream face and the subsequent acceleration of the flow around the nose of the pier or embankment. The action of the vortex removes bed materials from the base region. If the transport rate of sediment away from the local region is greater than the transport rate into the region, a scour hole develops. As the depth of scour is increased, the strength of the vortex or vortices is reduced; the transport rate is reduced; and an equilibrium is reestablished and scouring ceases.

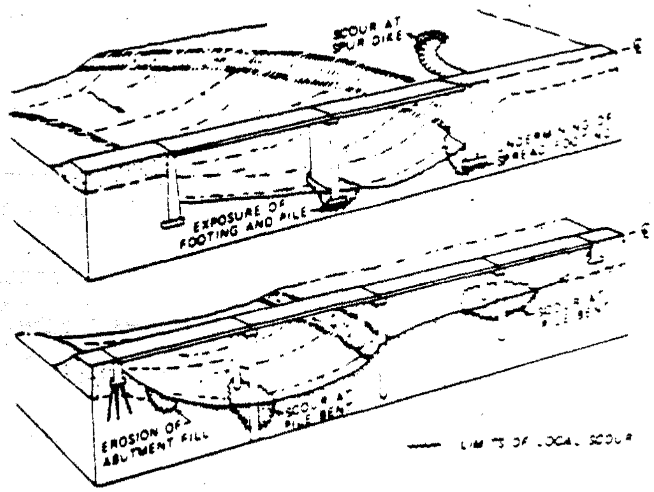

Figure 6-3 Local scour.

With a pier, in addition to the vortex around the base, which is called the horseshoe vortex, there is a vertical vortex downstream of the pier, which is called the wake vortex. (Fig. 6-4).

Both vortices remove material around the pier. Immediately downstream of a long pier, however, there is often deposition of material (Fig. 6-5).

There are two conditions of local scour: clear-water scour and live-bed scour. Clear-water scour occurs when there is no movement of the bed material of the stream upstream of the crossing, but the acceleration of the flow and vortices created by the piers or abutments causes the

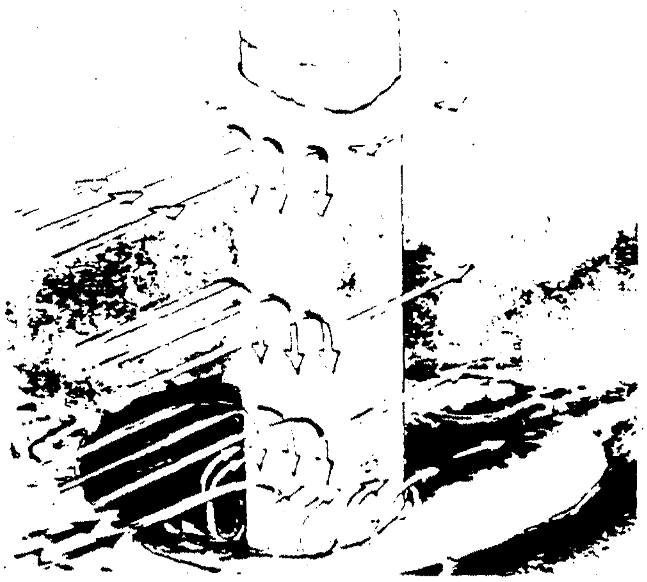

Figure 6-4 Schematic representation of scour at a cylindrical pier.

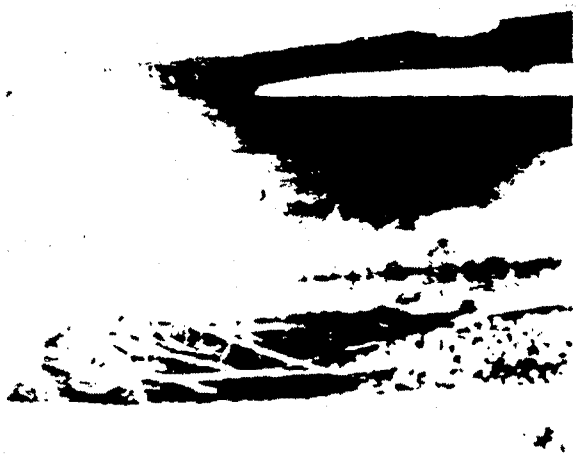

Figure 6-5 Scour hole and downstream deposition of material shown in dry.

material at their base to move. Live-bed scour occurs when the bed material upstream of the crossing is also moving.

Factors affecting local scour are: (1) width of the pier; (2) projected length of the abutment into the flow; (3) length of the pier; (4) depth of flow; (5) velocity of the approach flow; (6) size of the bed material; (7) angle of attack of the approach flow to the pier or abutment; (8) shape of the pier or abutment; (9) bed configuration; (10) ice formation or jams; and (11) debris.

The width of a pier has a direct effect on the depth of scour. For example, an increase in pier width causes an increase in scour depth.

With an increase in the projected length of an abutment into the flow there is an increase in scour. There is, however, a limit on the increase in scour depth with an increase in length. This limit is reached when the ratio of the projected length into the stream to the depth of the approaching flow is 25.

Pier length has no appreciable effect on scour depth as long as the pier is lined up with the flow. If the pier is at an angle to the flow, however, the length has a very large effect. At the same angle of attack, doubling the length of the pier increases scour depth 33 percent. Flow depth has a direct effect on scour depth. An increase in flow depth can increase scour depth by a factor of 2 or larger for piers. With abutments the increase is from 1.1 to 2.15 depending on the shape of the abutment.

Velocity of the approach flow increases scour depth. The greater the velocity the deeper the scour depth. There is also a high probability that the state of flow, i.e., whether the flow is tranquil or rapid (subcritical or supercritical), will affect the scour depth.

Figure 6-6 Debris increasing width of pier.

The size of the bed material in the sand size range has no effect on scour depth. Larger size bed material, if it will be moved by the approaching flow or by the vortices and turbulence created by the pier or abutment, will not affect the ultimate or maximum scour but only the time it takes to reach it. Very large particles in the bed material, cobbles or boulders, may armor plate the scour hole. The size of the bed material also determines whether the scour at a pier or abutment is clear-water or live-bed scour.

Fine bed material (silts and clays) will have scour depths as deep or deeper than sand bed streams. This is true even if bonded together by cohesion. The effect of cohesion is to determine the time it takes to reach the maximum scour. With sand bed material, the maximum depth of scour is measured in hours. With cohesive bed material, it may take days, months, or even years to reach the maximum scour depth.

Angle of attack of the flow to the abutment or pier has a large effect on local scour as was pointed out in the discussion of the effect of pier length above. With abutments, the depth of scour is reduced for embankments angled downstream and is increased if the embankments are angled upstream. The maximum depth of scour at an embankment inclined 45 degrees downstream is reduced by 20 percent, whereas the scour at an embankment inclined 45 degrees upstream is increased about 10 percent.

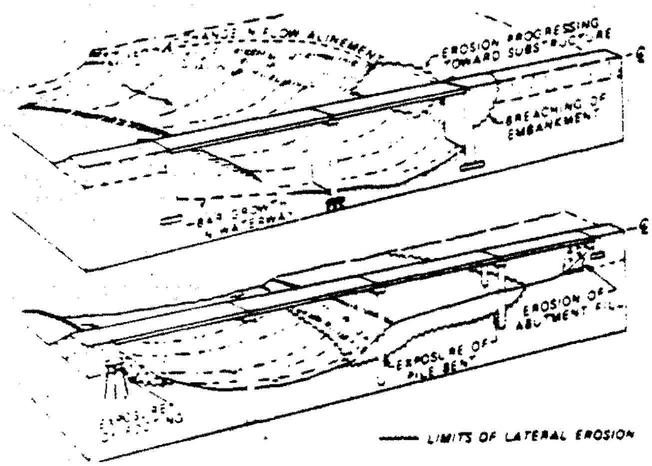

Figure 6-7 Lateral scour.

The pier or abutment shape has a significant effect on scour. With a pier, streamlining the upstream nose reduces the strength of the horseshoe vortex which reduces scour depth. Streamlining the downstream end of piers reduces the strength of the wake vortices. A square-nose pier will have maximum scour depths about 20 percent greater than a sharp-nose pier and 10 percent greater than a cylindrical or round-nose pier. Abutments with vertical walls on the stream side and upstream side will have scour depths about double that of spill slope abutments.

Bed configuration affects the magnitude of local scour. In streams with sand bed material, the shape of the bed (bed configuration) may be ripples, dunes, plane bed and antidunes. The bed configuration depends on the size distribution of the sand bed material, flow conditions, and fluid viscosity. The bed configuration may change from dunes to plane bed or antidunes during an increase in flow. It may change back with a decrease in flow. The bed configuration may also change with a change in water temperature or change in concentration of silts and clays. The bed configuration and any change in bed configuration will affect flow velocity, sediment transport, and scour.

Ice and debris, by increasing the width of piers, changing the shape of piers and abutments, increasing the projected length of an abutment or causing the flow to plunge downward against the bed can increase both local and contraction scour. The magnitude of the increase is still largely undetermined but can be as much as 10 or 20 feet (Fig. 6-6).

In addition to the types of scour mentioned above, lateral movement or shifting of the stream may also erode the approach roadway to the bridge or change the total scour by changing the angle of the flow in the waterway at the bridge crossing (Fig. 6-7). Factors that affect lateral movement and the stability of a bridge are the geomorphology of the stream, location of the crossing on the stream, flood characteristics, and the characteristics of the bed and bank materials.

SECTION 3. EVALUATING THE VULNERABILITY OF EXISTING BRIDGES TO SCOUR

6-3.1 General

Bridges over streams subject to scour should be evaluated to determine their vulnerability to floods and to determine whether they are scour critical. This assessment or evaluation should be conducted by an interdisciplinary team of professional engineers who can make the necessary engineering judgments to decide:

- priorities for making bridge scour evaluations;
- the scope of the scour evaluations to be performed in the office and in the field;
- whether or not a bridge is vulnerable to scour damage; i.e., whether the bridge is a scour critical bridge;
- which alternative scour countermeasures may serve to make a bridge less vulnerable or invulnerable;
- which countermeasure is most suitable and cost-effective for a given bridge;
- priorities for installing scour countermeasures; and
- monitoring and inspection schedules for scour critical bridges.

The factors to be considered in a scour evaluation require a broader scope of study and effort than those considered in a bridge inspection. Whereas the major purpose of the bridge inspection is to identify changed conditions which may reflect an existing or potential problem, the scour evaluation is an engineering assessment of what might possibly happen in the future and what steps can be taken now to eliminate or minimize future damage.

6-3.2 The Evaluation Process

The following approach is recommended regarding the development and implementation of a program to assess the vulnerability of existing bridges to scour:

STEP 1: Compile a list of those bridges with actual or potential problems with scour. Structures that are candidates for this category include:

a. Bridges currently experiencing scour or that have a history of scour problems during past floods as identified from maintenance records and experience, bridge inspection records, soundings etc.

b. Bridges over streams with erodible beds or design features that make them vulnerable to scour including:

   1. piers and abutments designed with spread footings or short pile foundations;

   2. superstructures with simple spans or non-redundant support systems that render them vulnerable to collapse in the event of foundation movement; and

   3. bridges with inadequate waterway openings or with designs that collect ice and debris. Particular attention should be given to structures where there are no relief bridges or embankments for overtopping, and where all water must pass through or over the structure.

c. Bridges on aggressive streams and waterways including those with:

   1. active degradation or aggradation of the streambed;
   2. significant lateral movement or erosion of stream banks;
   3. steep slopes or high velocities;
   4. gravel or mining operations in the vicinity of the bridge; and
   5. histories of having been damaged during past floods.

d. Bridges located on stream reaches with adverse flow characteristics including:

1. crossings near stream confluences, especially bridge crossings of tributary streams near their confluence with larger streams;
2. crossings on sharp bends in a stream; and
3. locations on alluvial fans.

STEP 2: Prioritize the list compiled in Step 1, using the following factors as a guide:

a. The potential for bridge collapse or for damage to the bridge in the event of a major flood.

b. The functional classification of the highway on which the bridge is located, and the effect of a bridge collapse on the safety of the travelling public and on the operation of the overall transportation system for the area or region.

STEP 3: Conduct field and office scour evaluations of the bridges on the prioritized list developed in Step 2, using an interdisciplinary team of structural, hydraulic, and geotechnical engineers.

STEP 4: For bridges identified as scour critical, (Step 3), determine a plan of action for monitoring and correcting the scour problem including:

a. Timely installation of scour countermeasures.

b. Plans for inspecting scour critical bridges during and after flood events and for blocking traffic if necessary until scour countermeasures are installed.

STEP 5: After completing the scour evaluations for the list of bridges compiled in Step 1, the remaining waterway bridges included in the bridge inventory should be evaluated. In order to provide a logical sequence for accomplishing the remaining bridge scour evaluations, another bridge list should be established giving priority status to the following:

a. Bridges, based on the functional classification of the highway on which the bridge is located, with highest priorities assigned to arterial highways and lowest priorities to local roads and streets.

b. Bridges that serve as vital links in the transportation network and whose failure could adversely affect area or regional traffic operations.

The ultimate objectives of this scour evaluation program are:

- to review all bridges over scourable streams in the National Bridge Inventory;
- to determine those foundations which are stable for estimated scour conditions and those which are not;
- to provide for frequent inspections of scour critical bridges during and after flood events until adequate scour countermeasures are installed;
- to install scour countermeasures in a timely manner.

SECTION 4. SCOUR INSPECTIONS

6-4.1 General

There are two main objectives to be accomplished in inspecting bridges for scour:

- to accurately record the present condition of the bridge and the stream;
- to identify conditions that are indicative of potential problems with scour and stream stability for further review and evaluation by others.

In order to accomplish these objectives, the inspector needs to recognize and understand the interrelationship between the bridge, the stream, and the floodplain. Typically, a bridge spans the main channel of a stream and perhaps a portion of the floodplain. The roadway approaches to the bridge often are constructed on embankments which obstruct flows on the floodplain. This over-bank or floodplain flow must, therefore, return to the stream at the bridge or overtop the approach roadways. Where over-bank flow is forced to return to the main channel at the bridge, zones of turbulence are established and scour is likely to occur at the bridge abutments. Further, piers and abutments may present obstacles to flood flows in the main channel, creating conditions for local scour because of the turbulence around the foundations. After flowing through the bridge, the floodwaters will expand back to the floodplain, creating additional zones of turbulence and scour.

The following sections present guidance for the bridge inspector's use in developing an understanding of the overall flood flow patterns at each bridge inspected; and in rating the present condition of the bridge and the potential for damage from scour. When an actual or potential scour problem is identified by a bridge inspector, the bridge should be further evaluated by an interdisciplinary team using the approach discussed above.

6-4.2 Office Review

It is desirable to make an office review of bridge plans and previous inspection reports prior to making the bridge inspection. Information obtained from the office review provides a better basis for inspecting the bridge and the stream. Items for consideration in the office review include:

- Has an engineering scour evaluation study been made? If so, is the bridge scour critical?

- If the bridge is scour critical, has a plan of action been made for monitoring the bridge and installing scour countermeasures?

- What do comparisons of streambed cross-sections taken during successive inspections reveal about the streambed? Is it stable? Degrading? Aggrading? Moving laterally? Are there scour holes around piers and abutments?

- What equipment is needed to obtain streambed cross-sections (Rods, poles, sounding lines, depth sounders, etc.)?

- Are there sketches and aerial photographs to indicate the plan form location of the stream and whether the main channel is changing direction at the bridge?

- What type of bridge foundation was constructed (Spread footings, piles, drilled shafts, etc.)? Do the foundations appear to be vulnerable to scour?

- Do special conditions exist requiring particular methods and equipment for underwater inspections (Divers, boats, electronic gear for measuring stream bottom and infilling, etc.)?

- Are there special items that should be inspected? Examples might include damaged riprap, stream channel at adverse angle of flow, and problems with debris.

6-4.3 Field Inspection

During the bridge inspection, the condition of the bridge waterway opening, substructure, channel protection, and scour countermeasures should be evaluated along with the condition of the stream. The inspector must observe and record conditions at the bridge, upstream of the bridge, and downstream of the bridge.

<u>Upstream Conditions</u>

Upstream conditions to be observed include:

a. Banks

1. Stable	Natural vegetation, trees, bank stabilization measures such as riprap, paving, gabions, channel stabilization measures such as dikes and groins.
2. Unstable	Bank sloughing, undermining, evidence of lateral movement, damage to stream stabilization installations, etc.

b. Main Channel

1. Clear and open with good approach flow conditions, or meandering or braided with main channel at an angle to the orientation of the bridge;
2. Existence of islands, bars, debris, cattle guards, fences that may affect flow;
3. Aggrading or degrading streambed; and
4. Evidence of movement of channel with respect to bridge (make sketches, take pictures).

c. Floodplain

1. Evidence of significant flow on floodplain;
2. Floodplain flow patterns (Does flow overtop road and/or return to main channel?);
3. Existence and adequacy of waterway opening of relief bridges (If relief bridges are obstructed, they will affect flow patterns at the main channel bridge);
4. Extent of floodplain development and any obstruction to flows approaching the bridge and its approaches; and
5. Evidence of overtopping approach roads (debris, erosion of embankment slopes, damage to riprap or pavement, etc).

d. Debris

Extent of debris in upstream channel.

e. Other Features

Existence of upstream tributaries, bridges, dams, or other features, that may affect flow conditions at bridge.

Conditions at bridge

The following items should be considered in inspecting the present condition of bridge foundations and adjacent conditions.

a. Substructure

1. evidence of movement of piers and abutment;
    - rotational movement (check with plumb line).
    - settlement (check lines of substructure and superstructure, bridge rail, etc. for discontinuities; check for structural cracking or spalling).
    - check bridge seats and bearings for excessive movement.
2. damage to scour countermeasures protecting the foundations (riprap, guidebanks (spur dikes), sheet piling, sills, etc.);
3. changes in streambed elevation at foundations (undermining of footings, exposure of piles); and
4. changes in streambed cross section at bridge including location and depth of scour holes.

In order to note the conditions of the foundations, the inspector should take cross sections of the stream, noting location and condition of stream banks. Careful measurements should be made of scour holes at piers and abutments including probing soft material in scour holes to determine the location of firm bottom.

b. Superstructure

1. Evidence of overtopping by floodwaters (Is superstructure anchored to substructure to prevent displacement during floods?);
2. Obstruction to flood flows (Does it collect debris or present a large surface to the flow?); and
3. Design (Is superstructure vulnerable to collapse in the event of foundation movement as are simple spans and non-redundant designs for load transfer?).

c. Channel Protection and Scour Countermeasures

1. Riprap (Is riprap adequately toed-in or is it being undermined and washed away? Is riprap pier protection intact, or has riprap been removed and replaced by bed load material? Can displaced riprap be seen in streambed below bridge?);
2. Guidebanks (spur dikes). (Are guidebanks in place? Have they been damaged by scour and erosion?); and
3. Stream and Streambed (Is main current striking the piers and abutments at an angle; is there evidence of scour and erosion of streambed and banks, especially adjacent to piers and abutments? Has stream cross section changed since last measurement? If so, in what way?).

d. Waterway Area Does waterway area appear small in relation to stream and its floodplain? Is there evidence of scour across a large portion of the streambed at the bridge? Do bars, islands, vegetation, and debris constrict flow and concentrate it in one section of the bridge or cause it to attack piers and abutments? Do the superstructure, piers, abutments, fences, etc. collect debris and constrict flow? Are approach roads regularly overtopped? If waterway opening is inadequate, does this augment the scour potential at bridge foundations?.

Downstream Conditions

Downstream conditions to be observed include:

a. Banks

1. Stable Natural vegetation, trees, bank stabilization measures such as riprap, paving, gabions, channel stabilization measures such as dikes and groins.
2. Unstable Bank sloughing, undermining, evidence of lateral movement, damage to stream stabilization installations, etc.

b. Main Channel

1. Clear and open with good "getaway" conditions or meandering or braided with bends, islands, bars, cattle guards, and fences that retard and obstruct flow.
2. Aggrading or degrading streambed.
3. Evidence of downstream movement of channel with respect to the bridge (make sketches and take pictures.)

c. Floodplain

1. Clear and open so that contracted flow at bridge will return smoothly to floodplain, or restricted and blocked by dikes, developments, trees, debris, or other obstructions;
2. Evidence of scour and erosion due to downstream turbulence.

d Other Features Downstream dams or confluences with larger stream which may cause variable tailwater depths. (This may create conditions for high velocity flow through bridge)

Perhaps the single most important aspect of inspecting the bridge for actual or potential damage from scour is the taking and plotting of measurements of stream bottom elevations in relation to the bridge foundations.

SECTION 5. SOUNDINGS

6-5.1 Equipment

The most common equipment used to make soundings are black and white recording type chart fathometers (depth sounders), sounding poles, and lead lines. In small, slow moving streams lead lines can be used to take soundings from the bridge deck, but generally, soundings are taken from a boat to permit making measurements under the bridge and at distances upstream and downstream of the bridge. In addition, soundings are difficult to take in fast moving streams with lines and poles, and may not reflect bottom conditions if not taken at very close intervals.

a. Black and White Fathometer. A black and white recording fathometer is the most efficient way of recording depths (Fig. 6-8). The units are compact and easy to use. They consist of a transducer, which is suspended in the water, a sending/receiving device, and a recording chart which displays the depth on paper (Fig. 6-9). High frequency sound waves

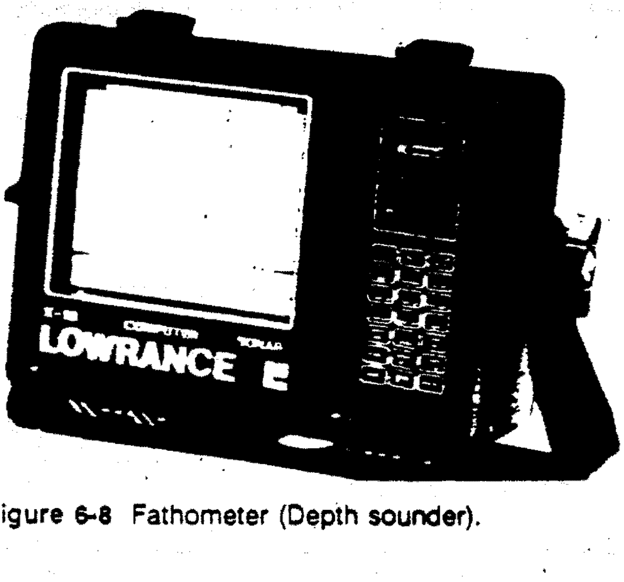

Figure 6-8 Fathometer (Depth sounder).

Figure 6-9 Fathometer in a small boat. Note transducer mounted on gunnel.

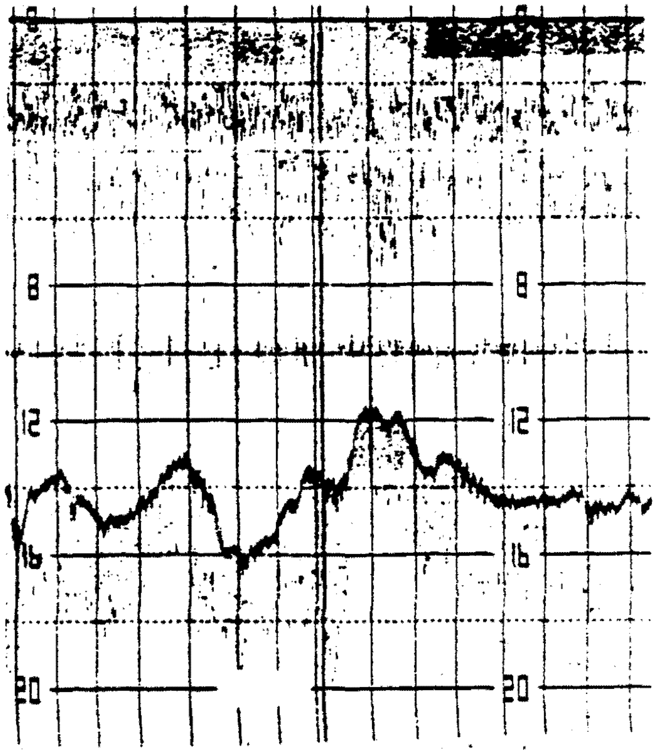

Figure 6-10 Typical fathometer record.

generally in the range of 200 kHz, emitted from the transducer travel through the water until they strike the channel bottom and are reflected back to the transducer. The fathometer measures the time it takes the sound waves to return to the transducer and converts that time to depths of water which are displayed on a graphic recorder in the form of a continuous plot of the channel bottom (Fig. 6-10). Most fathometers are readily portable, weighing 5 to 10 pounds including the transducer and hardware. They will operate from a boat's battery, lantern batteries, or a self-contained battery pack. They can be used in large boats, or are easily attached and detached from small boats. Most devices have controls to mark the paper so depths at particular locations can be designated.

When using one of these devices it is common practice to verify its operation with a lead line or by suspending a calibration target beneath the transducer prior to sounding the entire bridge.

Although the best time to obtain the true depth of scour is during a flood, this is rarely done because of the danger involved. Data obtained immediately after a flood is also very helpful. Logistics, however, can make this difficult.

The fathometer provides a profile of the channel bottom. It also gives a good indication of scour activity at piers and abutments. While it does not indicate the nature of sub-bottom material it is helpful in the interpretation of data from devices which do provide sub-bottom data.

By using transducers with different beam angles, either a small or large area can be monitored at one time. These units also can locate large submerged objects, such as barges and trees, which could influence scour.

b. <u>Color Fathometer</u>. Color fathometers are also available which provide a good representation of the channel bottom, and some penetration into the substrata (Fig. 6-11). Materials of different densities are displayed as different colors. Studies by the U.S. Geological Survey and the Federal Highway Administration show that in some soils a color fathometer can detect infilling of scour holes, data impossible to get with a black and white fathometer.

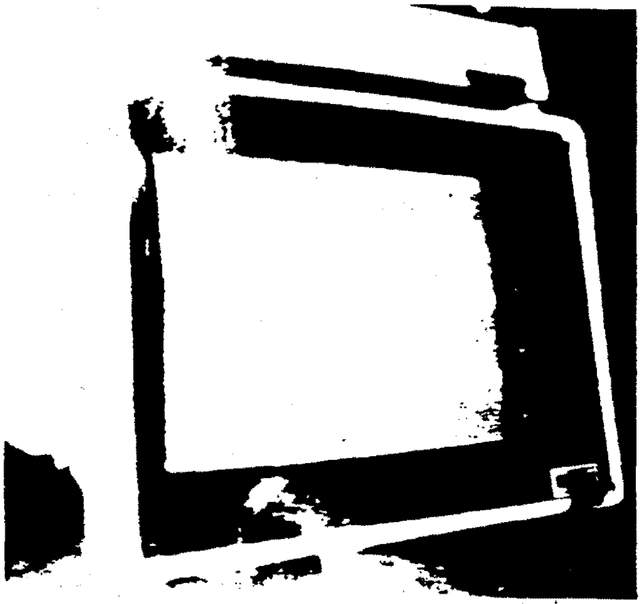

Figure 6-11 Color fathometer.

One of the drawbacks of the color fathometer is that hard copy cannot be obtained. The data can, however, be stored on video tape and, some models have direct connections for this purpose.

6-5.2 Data Presentation

A common way of performing and presenting soundings is in a grid format (Fig. 6-12). Soundings are taken on lines parallel to the faces of the bridge and along both sides of the bridge piers. This pattern

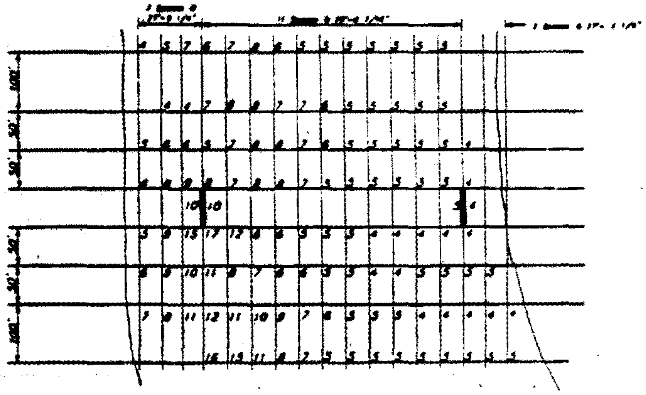

Figure 6-12 Sounding plan showing typical grid.

will provide information on the channel upstream and downstream of the bridge, and around each pier. It provides enough information to plot spot elevations and contours of the channel bottom at each pier. Soundings should be taken continuously along these lines.

To take soundings on the lines transverse to the channel, a target system should be established on shore and used to align the boat. With two targets on the same shore, the boatman can position the boat so that the targets are in line. This is usually easier than trying to stay in position between targets on opposite banks. If key bridge dimensions are determined before the soundings are begun, transverse reference with the bridge can be maintained by siting on floorbeams and truss panel points.

A much more precise method of locating the soundings is by use of a transit reading stadia or an electronic distance measuring (EDM) device each time a sounding is to be made. This method is, however, significantly more costly, and the precision obtained is generally not warranted for this type of work.

In making soundings around the piers, the ends of the piers and the floorbeams above are used as reference points. When working close to the piers, the soundings must be carefully interpreted. Stepped footings which extend from the face of the shaft, or debris piled against the pier, may suggest that the channel bottom is much higher than it really is.

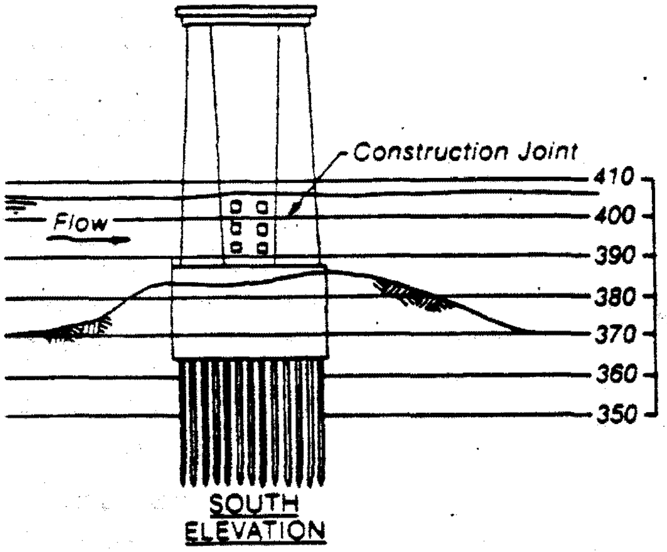

Figure 6-13 Profile showing channel bottom relative to the foundation.

The soundings can also be presented as channel bottom profiles with the foundation plotted on them (Fig. 6-13). These provide graphic evidence for reports.

SECTION 6. DIVER INSPECTION

6-6.1 Visual

During an underwater inspection, the diver should note bottom conditions adjacent to submerged foundation elements. Local scour can generally be identified by the presence of scour holes near the upstream end of the unit and a build-up of soil at the downstream end. He should also note the presence of debris which can cause local scour.

The diver should note the type of bottom material and the presence, location, and size of riprap. The height of the exposed footing and any undermining should also be reported. If piles under a footing are exposed, they should be examined.

6-6.2 Tools

The diver may be able to determine if riprap has been covered over by bottom material by probing the bottom with a steel rod, such as a piece of reinforcing steel.

The presence of buried riprap and subsoil conditions can be checked by removing overlying soil. This may most easily be done with an airlift, a steel or plastic pipe, usually 3 to 8 inches in diameter, with a 1-inch air hose connected near the bottom of the pipe. Compressed air introduced into the pipe reduces the density of water as the air expands. The rising air and water creates suction at the bottom of the pipe which removes the soil. The expense of the equipment and manpower required may, however, make it impractical for most situations.

SECTION 7. GEOPHYSICAL INSPECTION

Scour is most prevalent during a flood, which is the time when monitoring is most difficult. Obtaining scour measurements from the bridge or by boat during peak flood flows is not recommended because of the hazardous conditions, complex flow patterns, presence of drift and debris, and problems getting personnel to the bridge site.

After a flood, the stream velocity decreases resulting in the sediment being redeposited in the scour hole. The redisposition is also referred to as infilling. Since infill material often has a different density than the adjacent unscoured channel bottom material, the true extent of scour can be measured by determining the interface where the density change occurs. Methods for determining this include soil borings with standard testing, cone penetrometer exploration, and geophysical techniques. While soil borings can be accurate they are expensive, time consuming and do not provide a continuous profile. Less expensive geophysical methods are available, however, which will provide continuous subsurface profiles.

Three geophysical tools which can be used to measure scour after infilling occurs are: ground penetrating radar; tuned transducer or low frequency sonar; and color fathometer. Each of these methods has advantages and limitations.

Figure 6-14 Ground penetrating radar equipment.

The color fathometer has been described above. Soil borings, ground penetrating radar, and tuned transducer are described below. A matrix comparing the geophysical equipment and the black and white fathometer is shown in Figure 6-17.

6-7.1 Borings

Soil borings can help identify the effects of long-term scour, the extent of aggradation, degradation, stress shifting, and contraction scour. Borings also provide samples which may be tested. Borings can be obtained from a barge or, in some cases, the bridge deck.

6-7.2 Ground Penetrating Radar

Ground penetrating radar (GPR) can be used to obtain high resolution, continuous, subsurface profiles on land or in relatively shallow water (less than 25 feet). This device transmits short, 80 to 1000 MHz, electromagnetic pulses into the subsurface and measures the two way travel time for the signal to return to the receiver. When the electromagnetic energy reaches an interface between two materials with differing physical properties, a portion of the energy is reflected back to the surface, while some of it is attenuated and a portion is transmitted to deeper layers. The penetration depth of GPR is dependent upon the electrical properties of the material through which the signal is transmitted and the frequency of the signal transmitted.

Highly conductive (low resistivity) materials such as clay materials severely attenuate radar signals. Similarly, sediments saturated with or overlain by salt water will yield poor radar results. Fresh water also attenuates the radar signal and limits the use of radar to sites with less than 25 feet of water. The lower frequency signals yield better penetration but reduced resolution, whereas higher frequency signals yield higher resolution and less penetration. Ground penetrating radar systems which include a transmitter, receiver, high density tape recorder and player for storage of records and antenna cost between $50,000 and $60,000 (Fig. 6-14).

Figure 6-15 shows a cross section generated by a ground penetrating radar signal upstream of a bridge

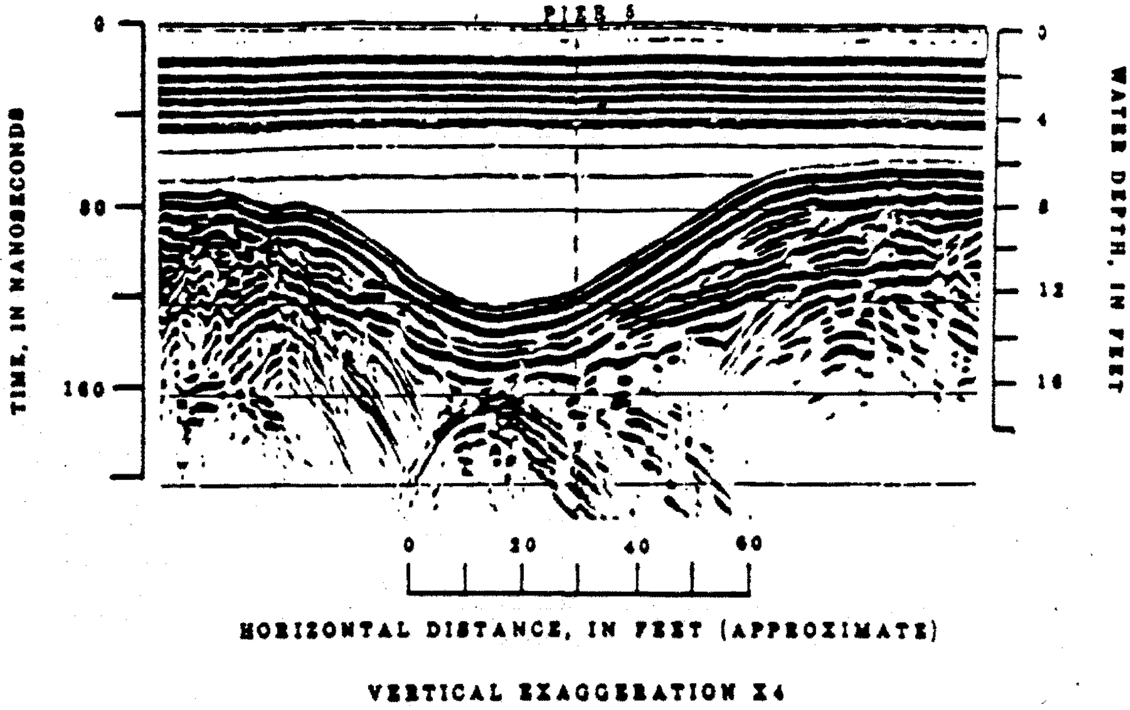

Figure 6-15 Typical ground penetrating radar record.

pier. A scour hole located at the pier is approximately 7 feet deeper than the river bottom base level and 60 to 70 feet wide. Two different infilled layers can be observed at this location. The apparent thickness of the infilled material at the center of the hole is 3 feet to the first interface and 6 feet to the second interface. Thus, the total depth of the scour hole, at least at one time, was about 16 feet, not 7 feet as soundings would have indicated.

6-7.3 Tuned Transducer

The tuned transducer, or low frequency sonar, is a seismic system which operates through the transmission and reception of acoustic waves. The low frequency sonar system consists of a transmitter, a transducer towed alongside the boat, a receiver, and a graphic recorder. The transmitter produces a sound wave which is directed toward the channel bottom by the transducer. A portion of the sound wave will be reflected back to the transducer by the channel bottom surface; and a portion of that signal will penetrate into the sub-bottom material. Portions of the signal will also be reflected by various layers of sub-bottom material and when there is a change in accoustical impedance between two layers. The major difference between this device and the fathometer is frequency. The tuned transducer uses lower frequency signals (3.5-14 kHz) which yield better penetration at the expense of resolution (Fig. 6-16). High frequency fathometers (200 kHz) have good resolution with little or no penetration. In fine grained materials up to 100 feet of penetration can

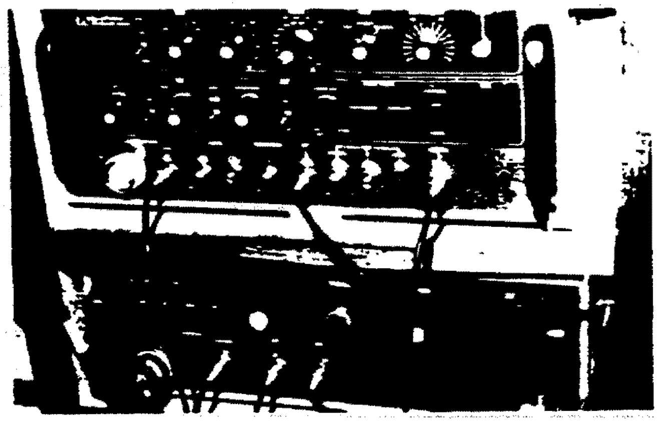

Figure 6-16 Tuned transducer transmitter and receiver.

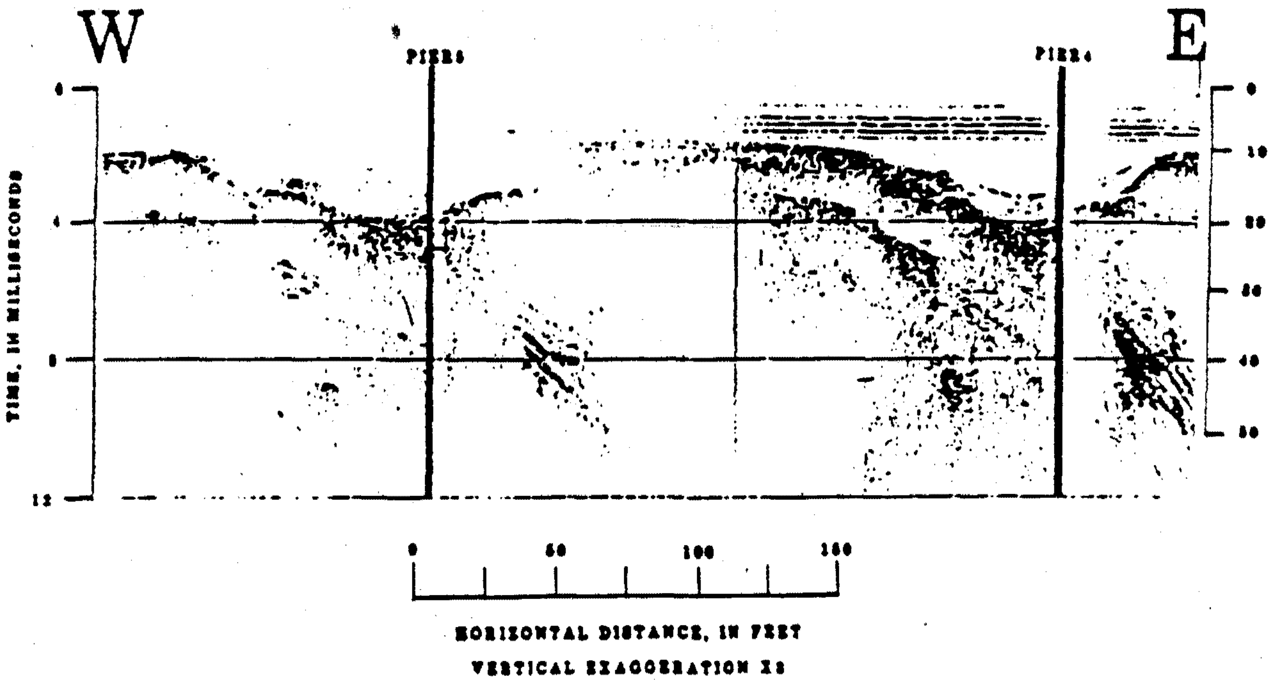

Figure 6-17 Typical tuned transducer record

be obtained with a 3 to 7 kHz transducer, while in more coarse material subsurface penetration may be limited to a few feet. The tuned transducer system costs between $20,000 and $30,000.

Figure 6-17 above shows a cross section record provided by a 14 kHz tuned transducer. This is the same location as the GPR record in Figure 6-15. This record shows 6 feet of infilled material. The two layers which could be seen on the radar record are not evident on the tuned transducer record.

Figure 6-18, following this page, summarizes the characteristics and capabilities of the types of scour investigation equipment discussed in this chapter.

METHOD:	BLACK AND WHITE FATHOMETER:	COLOR FATHOMETER:	TUNED TRANSDUCER:	GROUND PENETRATING RADAR:
FREQUENCY:	200 KHz	20- 100 KHz	3.5 - 14 KHz	80 - 1,000 MHz
PENETRATION:	None in typical marine sediments. 1 - 5 feet in very soft material.	0 - 20 feet depending on frequency selected and sub-bottom material. Little penetration in coarse grained material.	0 - 50 feet depending on frequency and sub-bottom material. Little penetration in coarse grained material.	<20 feet in water column (fresh). <50 feet in resistive material (depending on frequency). A few feet in conductive materials.
RESOLUTION:	A few inches.	Inches	A few inches to a few feet (depending on frequency).	A few inches to a few feet (depending on frequency).
LIMITATIONS:	No definition of sub-surface materials.	Minimum water depth of 5 feet. Won't penetrate gases/gasey organics. Multiple reflections may obscure data. Does not provide a hard copy record. Little penetration in coarse grained material.	Minimum water depth of 5 - 10 feet (depending on bottom materials). Won't penetrate gases/gasey organics. Difficult to operate. Little penetration in coarse grained material	Limited penetration in salt water, clays, and other conductive materials. Multiple reflections may obscure data Signal may be scattered due to cobbles and boulders. Difficult to operate and interpret. Signal is highly attenuated in the water column.
ADVANTAGES:	Good definition of sediment/water interface. Accurate assessment of water depth. Easy to operate. A hard copy of data is obtained.	May penetrate conductive materials. Variable frequency. May be used to define sub-bottom materials and stratigraphy. Good in deep water. May indicate some physical properties of sediments (ie. density, porosity, grain size).	May penetrate conductive materials. Variable frequency. May be used to define sub-bottom materials and stratigraphy. Good in deep water. A hard copy of the data is obtained.	Defines sub-bottom materials and stratigraphy. Good for use on land and in shallow water. Penetration through organic material. High resolution in shallow sub-surface. No multiples on land. A hard copy of data is obtained.
APPROXIMATE COST:	$400 - $3,000	$2,000 - $5,000	$20,000 - $30,000	$20,000 - $60,000
NOTE:	Utilizes a small transducer (a few in. diameter) to transmit high frequncy acostic pulses, and receive signals reflected at interfaces between layers or objects of differing acoustical properties.	Operates with a variable frequency transducer (about 4 inches in dia.) which transmits acoustic pulses and receives the reflected signal from interfaces between layers or objects of differing acoustical properties. Cassette recordings of data may be obtained.	Operates with a variable frequency transducer (about 4 inches in dia.) which transmits acoustic pulses and receives the reflected signal from interfaces between layers or objects of differing acoustical properties. Cassette recordings of data may be obtained.	Operates through the transmission of electromagnetic energy into the sub-surface, and the subsequent reception of energy reflected at interfaces between layers or objects of differing electrical properties.
BRIDGE SCOUR STUDIES: ENVIRONMENT	Shallow or deep water.	In >5 feet of water.	In >5 feet of water.	In shallow, fresh water or on land.
BRIDGE SCOUR STUDIES: EXPECTED RESULTS	May define existing holes. Accurate depth measurement.	May define existing and refilled holes. May vary frequency to optimize penetration/resolution. May indicate some physical properties of sediments.	May define existing and refilled holes. May vary frequency to optimize penetration/resolution.	May define existing and refilled holes. Good definition of shallow stratigraphy.

Figure 6-18 Matrix Comparing Geophysical Methods, from "The Use of Surface Geophysical Methods in Studying Riverbed Scour at Three Connecticut River Bridges in Hartford, Connecticut," Gorin,S.R. and Haeni,F.P., U.S. Geological Survey in cooperation with the Federal Highway Administration, 1988.

CHAPTER VII

REPAIR OF UNDERWATER MEMBERS

SECTION 1. INTRODUCTION

7-1.1 General

Maintenance and repair of underwater bridge elements, like underwater inspection, has often been neglected in the past. This, however, is changing as the number of underwater inspections being conducted increases.

Almost any repairs that can be accomplished above water, can also be made below water, but the work can be much more expensive and time consuming, and require specialized equipment. It is, therefore, most important before performing repairs that one first understand the causes of the distress. The cause of the damage or deterioration may not always be apparent, and further investigation may be required to determine the cause. Sometimes far reaching studies of changes in channel configuration, testing of samples or changes in the environment may be necessary.

There are two options for performing repairs: in the dry, or the wet. For the first option, a cofferdam can be driven around the pier and dewatered, and the repair work performed in the dry. The advantages of this method are that conventional above-water repair procedures can be used and construction inspection is easier. The major disadvantage is the high cost of building the cofferdam.

The second option is to use underwater repair methods which eliminate the need for a cofferdam. The disadvantages of this method are that the quality of repairs is difficult to maintain, quality assurance inspections must be conducted by a diver, and more time may be required since underwater construction is done on a smaller scale.

SECTION 2. CONCRETE

7-2.1 Prevention of Distress

Prevention of deterioration and damage is, of course, more desirable than repair, and begins during design and construction of the bridge. Conscientious construction inspection, in particular, can minimize future maintenance costs.

Quality control of materials used and careful attention to construction procedures can help ensure long term serviceability. Aggregates should be free of chlorides and reinforcing steel should have adequate cover. Concrete with a low permeability, such as high strength concrete, is desirable, but the mix must be proportioned to reduce shrinkage cracking. Protective coatings applied to piles can control permeability, but the durability of these coatings in some environments is questionable.

Many problems associated with concrete are caused by corrosion of reinforcing steel. Using epoxy coated reinforcing steel can alleviate this problem in many situations. Special care should be taken when handling the bars to prevent damage to the coating. Cut ends and holidays should be touched-up in the field with liquid epoxy.

Precast concrete piles can be damaged during construction. Rough handling or overdriving can result in scars or cracks which allow water to penetrate.

Minor deterioration of concrete surfaces may not be significant in itself, but it provides a path for oxygen and moisture to reach the interior of the member where more serious deterioration can occur.

7-2.2 Repair of Cracks

Cracks in concrete can indicate severe damage has occurred or may lead to severe deterioration, if not repaired. When water enters the cracks, spalling and scaling damage can be accelerated.

Cracks can be repaired with epoxy injections both above and below water. The area around and within the crack should be thoroughly cleaned. A high pressure water blaster is very effective for this cleaning. The outside of the crack should then be sealed with a hand-applied or trowel-applied epoxy grout and injection ports placed at regular intervals in the epoxy along the crack. After the epoxy seal is allowed to harden, epoxy is injected through the ports working from one port to the next.

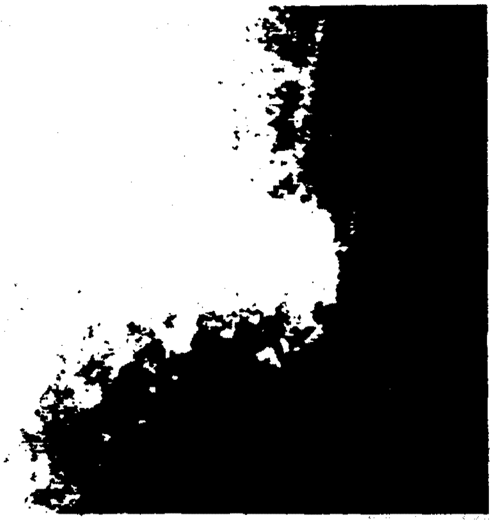

Figure 7-1 Injecting epoxy into a crack underwater.

Generally, cracks up to 1/4 inch are filled with epoxy resin. For larger cracks, a fine aggregate is added to the epoxy as a filler.

7-2.3 Repair of Small Voids

Voids caused by spalling, scaling or other distress mechanisms can be repaired by several methods. Common to all these methods is the type of surface preparation required:

(1) The area should be cleaned of all marine growth.
(2) Loose and broken concrete should be removed to sound material.
(3) Missing or reduced reinforcing steel should be restored.
(4) The concrete should be restored to at least the original contours.

Quick setting cement mortars have been used to repair small areas. The material is mixed with fresh water and is then carried by or conveyed to a diver who hand packs the material in place. Epoxy mortar can also be used to patch small voids. A typical mortar consists of one part epoxy binder and one part silica sand. The mixture has the consistency of putty and can be placed by gloved hands or trowels above or below water. One consideration in using this mortar is its relatively short pot life. No more should be mixed that can be immediately used.

7-2.4 Repair of Large Voids

For the repair of large void areas in concrete members, the use of cement and epoxy grouts is generally not economical. Larger voids must be formed and the member recast to the original cross section with concrete placed underwater (Fig. 7-2). Forming methods include conventional wood and steel forms, steel sheeting, and a number of proprietary rigid and flexible forming systems.

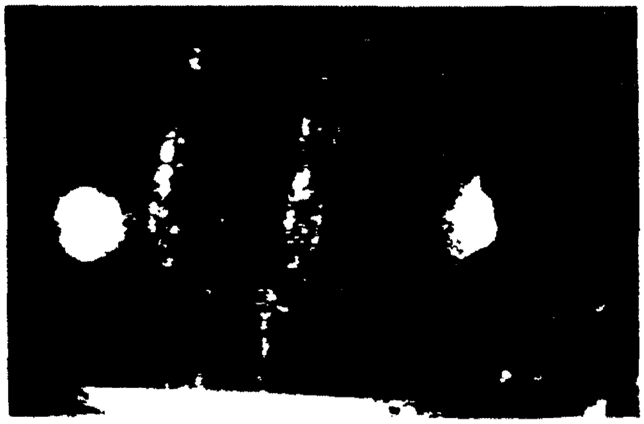

Figure 7-2 Damaged concrete pile; all reinforcing steel exposed.

Several methods can be used to place concrete underwater. The primary concern in placing concrete below water is to prevent washout of the cement. The unhardened concrete should be kept out of direct contact with the water to the extent possible, and protected against fast flowing water. A number of methods have been developed to accomplish this. Five methods, tremie concrete, preplaced aggregate, the bottom opening bucket, pumped concrete, and bagged concrete are described below.

a. Tremie Concrete. In the tremie method, concrete is delivered through a vertical pipe, 6 or 8 inches in diameter. A funnel shaped hopper is attached at the top of the pipe through which the concrete is fed (Fig. 7-3). The concrete that is used in this method must have a high slump so that it flows easily. The bottom of the tremie is maintained below the top surface of the fresh concrete so that the concrete exiting the bottom of the tremie forces the previously placed concrete upward, displacing the water in the form. It is essential that a sufficient head be maintained on the concrete in the tremie to raise the surface of the fresh concrete. As the level of the concrete rises, the tremie pipe is moved upward, but always kept in the fresh concrete.

At the beginning of the pour, the end of the tremie is plugged to prevent water from entering the pipe. Once placement is started, it must continue until the entire form is filled. Even short delays can cause blockage in the pipe.

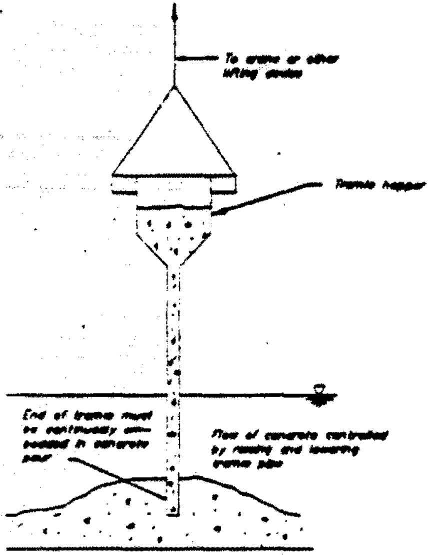

Figure 7-3 Placing concrete underwater with a tremie.

b. Preplaced Aggregate. The preplaced aggregate method consists of packing forms with coarse aggregate and injecting the cement mortar or grout into the mass. The aggregate is packed around tubes through which mortar is injected. This method has advantages underwater if placement of concrete by conventional methods would result in segregation because it allows the larger aggregate to be placed, by hand if necessary, and permits pumping of the mortar to fill the voids.

In order to achieve quality concrete, the aggregate must be well graded, high quality and clean. The grout must be fluid to ensure proper coverage and be able to develop good strength. The grout should be pumped from the lowest point upwards using a smooth and uninterrupted operation.

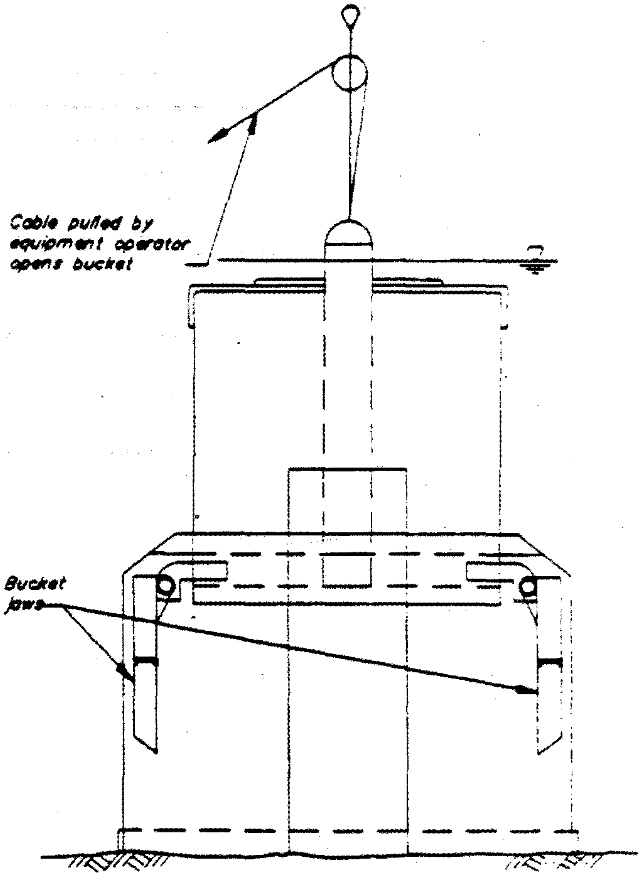

Figure 7-4 Drawing of bottom opening bucket.

c. Bottom Opening Bucket. Special buckets (Fig. 7-4) covered at the top to protect the concrete are also used to place concrete underwater. The bucket is lowered into place by crane and the bottom opened to place the concrete. These buckets usually have a skirt around the outside of the bucket that is lowered to protect the concrete during placement.

d. Pumped Concrete. Pumped concrete is widely used in above water construction. One of the advantages of using it below water is that the placement work is less dependent on highly skilled workers than other underwater placement methods.

Concrete can be pumped through pipes or hoses. Pipes are preferred since resistance to the concrete is lower and they will not kink. Hoses are better suited for operations where flexibility is required. The pipelines should be of a material which does not react with concrete. For this reason aluminum pipes are generally not used.

Concrete pumped underwater should start at the bottom of a form and progress upwards. The concrete should not be allowed to free-fall through the water.

e. Bagged Concrete. Concrete can also be placed in jute or porous synthetic bags. The bags should be small enough to be handled by a diver. They are filled with dry cement and aggregate, and are placed in contact with each other to allow bonding. The surrounding water starts the hydration process, and the bags harden in place.

Another method is to fit nylon bags with injection ports for mortar or grout. The bags can be sewn to any size to fit cavities to be filled. The bags are placed below water and the mortar is pumped into them from the surface. This method has an advantage over the hand placed small bags in that the bags can be pumped to completely fill a void under an existing structure.

These bagged concrete methods can also be used to construct a riprap blanket to prevent scour at piers. Additionally, both small, hand-placed bags and pumped, sewn bags, can be placed or pumped around the perimeter of a footing to act as a form for a tremie concrete repair.

7-2.5 Jacketing Piles

Deteriorated concrete piles can be repaired by encasing the pile in concrete; that is, by jacketing. In this method, the pile is first cleaned of marine growth; broken and loose concrete is removed; reinforcing steel on the pile is cleaned to bright metal; additional steel is added, if necessary; and forms are installed. Conventional wood and steel forms can be used; rigid plastic forms to match a variety of pile configurations are available; and flexible fabric forms can be sewn to fit most situations.

For repair of minor defects, forms only slightly larger than the original pile can be used, and the small defects filled with a thin cement or epoxy grout.

Figure 7-5 Open fabric form on a concrete pile.

SECTION 3. STEEL

7-3.1 Prevention of Distress

The majority of structural steel used for bridge substructures consists of H-piles and pipe piles with concrete pile caps, or piles driven to support a pier. In general, piles in seawater or brackish water have higher rates of corrosion than those in fresh water. Polluted fresh water, however, can also cause severe corrosion. Three means of protecting steel are coatings, cathodic protection, and concrete jackets.

a. Coatings. Coatings can prevent steel corrosion by separating the steel from the marine environment. Numerous coatings are available for steel piling, including paint, epoxy, bituminous and coal-tar materials, and plastic shrink-wraps.

Surface preparation for most types of coatings consists of near white blast cleaning or pickling. Solvents, hand tools, and power tools can also be used to remove heavy deposits of rust and any grease prior to blasting or pickling.

Coatings are applied either by brush, roller, spraying or wrapping. Applications are best made in a shop, but can be accomplished in the field with suitable protection during the application and curing of the coating. Care should be taken not to damage the coating during installation.

b. Cathodic Protection. Cathodic protection can be used to protect steel in seawater, freshwater and soil. Refer to Article 3-3 for a discussion of corrosion as an electrochemical process. There are two systems of cathodic protection; galvanic anode and impressed current.

In the galvanic anode system, sacrificial anodes, which are more active than the steel piles, are attached to piles at regular intervals. The anodes of zinc, aluminum alloys and magnesium, which have high negative potentials, eliminate local corrosion cells on the piling by sacrificing themselves. Periodically, the sacrificed anodes must be replaced.

The galvanic anode system has several advantages. It does not require an external power source; installation is easy; it can be installed prior to driving a pile; and maintenance is negligible over the life of the anode. The disadvantages of the galvanic anode system are that it requires an electrolyte of low resistance, and many anodes may be needed to protect a large structure. After the system is installed, a corrosion survey of the structure should be made to ensure that the system is effective.

The impressed current system uses iron and graphite anodes which are suspended in water adjacent to the piles. The anodes are connected to a direct current (d.c.) power source. Sufficient current, usually low in voltage, is impressed on the structure system in opposition to the current flow that is produced by the corrosion process. The impressed current makes the structure cathodic and eliminates corrosion of the steel. A d.c. power source, anodes, reference electrode and negative return circuit from the structure to the power supply are needed to operate this system.

The advantages of the impressed current system are that it can regulate and provide current according to requirements of the environment and that one installation can protect a large area.

c. Concrete Jackets. Concrete jackets are used to inhibit further corrosion of existing piles. When properly installed they can be very effective.

The concrete used for jacketing must be of high quality, be relatively impermeable and have good bonding characteristics. Jacketing of steel piles is similar to jacketing concrete piles as described in Article 7-2.

Jackets should extend from several feet above the high water line into the mudline. It had previously been considered only necessary to protect the portion of the pile in the tidal zone. It has been observed, however, that exposed areas of steel between the mudline and encasement can be susceptible to rapid and severe corrosion, especially if the length of exposed steel is relatively short. This is because a galvanic cell is created. This same type of corrosion has also been observed when the encasement ends at the mudline.

One disadvantage to concrete jackets is that they are rigid and can develop cracks due to bridge movement or vessel impact. They can, however, greatly extend the life of piling.

7-3.2 Repair

The repair of steel sections underwater is generally accomplished by encasing the deteriorated section in concrete as described in the preceding section. Repair of steel sections by bolted or welded replacement underwater is generally not cost-effective, but it can be done if necessary. Quality control of underwater repair, especially welding, is quite difficult.

SECTION 4. TIMBER

7-4.1 Prevention of Distress

Timber immersed in freshwater needs protection against decay. Timber immersed in salt water additionally needs protection against damage from marine borers. Two types of protection which have proven effective are preservatives and flexible barriers.

a. Preservatives. Preservatives, in use for many years, are applied to timbers under pressure in order to impregnate the wood cells.

Many types of preservatives are in use today with the most widely used being coal-tar creosote. The American Wood Preservers Institute defines coal-tar creosote as a preservative oil obtained by distillation of coal-tar produced by high temperature carbonization of bituminous coal; it consists principally of liquid and solid aromatic hydrocarbons and contains appreciable quantities of tar acids and tar bases; it is heavier than water; and it has a continuous boiling range of at least 125 degrees Centigrade, beginning at about 200 degrees Centigrade.

Coal-tar creosote effectively protects timber immersed in freshwater against fungal attack. In saltwater, it protects against teredo, but is ineffective against limnoria. Protecting timber against both types of borers requires dual treatments. The timber is first treated ,with a water-soluble compound toxic to limnoria; the compound becomes insoluble after impregnation. The wood is then treated with coal-tar creosote.

There are two processes for treatment: the full-cell process and empty cell process. In the full-cell process, the timber is placed in a chamber and air is removed to create a vacuum. Preservative is then introduced into the chamber, without letting air into the chamber, and pressure is applied until the timber has absorbed the proper amount of preservative. A vacuum may be applied after the chamber is emptied to remove dripping preservative. The full-cell process allows the largest retention of preservative.

In the empty cell process, timber is placed in the chamber and pressure treated with preservative. No vacuum is initially applied. After required absorption is obtained, the chamber is emptied. The result is that the timber cells are coated with preservative. Standards for timber treatment are available through the American Wood Preservers Association.

b. Protective Films. Pilings in existing structures can be protected against marine borer attack by wrapping them in a protective jacket. The purpose of the jacket is to create an anaerobic environment which is lethal to the borers. To be effective the jacket must fit tightly around the pile with no breaks in the jacket which would allow oxygen to enter. Jackets are not recommended for use in areas where abrasion may occur.

One system consists of one layer of PVC and one layer of polyethylene sheeting. A layer of protective film, PVC (Polyvinyl Chloride) sheets, 30 mils thick, is prepared on land. The sheet is wrapped tightly around the pile and fastened with aluminum or nylon straps and aluminum nails. A layer of polyethylene sheeting, 6 mils thick, is placed between the PVC and timber to prevent the creosote from softening the PVC. Piles are generally encased from several feet above the high waterline to the mudline.

7-4.2 Repair

a. Marine Borers. Damage from marine borers can generally be halted, when section loss is less than 15 percent, by installation of a protective film. If damage is more severe, it may be necessary to replace the damaged section or replace the entire pile.

When the loss of cross-sectional area is greater than about 20 percent it is generally recommended that pile be encased in a reinforced concrete jacket. A flexible or rigid jacket form can be placed around the pile and concrete placed by tremie or pumping similar to the methods as described for concrete piles in Article 7-2. Care should be taken to ensure the concrete is evenly distributed around the pile.

b. Splits and Cracks. Split piles can be repaired by installing compression rings around the damaged area. The rings consist of two semi-circular, rectangular steel bars. The steel is placed around the split and joined together by bolts at the ends of the ring halves. Splits can also be bolted together using one or more bolts with washers. In both cases, the area should be protected against further deterioration with a protective film.

CHAPTER VIII

MANAGEMENT OF UNDERWATER CONTRACTS

SECTION 1. INTRODUCTION

8-1.1 General

This chapter provides guidance for procuring and monitoring professional services for underwater bridge inspection. While the information is primarily concerned with securing outside services, this chapter should also aid in the planning, execution and management of inspections by in-house dive teams.

Local agencies are responsible for the overall adequacy of their underwater inspection programs. While the FHWA and state departments of transportation may issue guidelines and regulations for minimum standards, the local agencies must ensure that those minimum standards are adapted and expanded as necessary to ensure the structural safety of bridges located in water within their area of responsibility.

Development of a comprehensive scope of work is critical to obtaining all desired inspection information, and can aid greatly in obtaining a safe and cost-effective underwater investigation. Underwater inspection work, while similar to other professional services, requires special contractual provisions to address the unique hazards and costs associated with it. Contractual provisions alone, however, cannot ensure quality underwater bridge inspections. Training of underwater inspectors, and managers of underwater inspection programs is essential.

8-1.2 Procurement Regulations

The solicitation and subsequent management of an underwater bridge inspection contract must be in conformance with the federal, state and local prescribed practices and procedures. It is important, however, for procurement personnel to be aware that special requirements peculiar to underwater operations, must also be addressed. Technical staff may have to provide guidance to procurement personnel to ensure that all technical aspects of the work are adequately covered in the procurement and contractual documents. In some instances, because underwater inspections have not been conducted on a wide scale, the technical staff may have to work closely with procurement personnel to ensure that administrative requirements peculiar to this work are included. Underwater inspection contracts are hybrid contracts involving aspects of professional service contracts, and provisions which are normally a part of maintenance and construction contracts.

The acquisition of underwater inspection services has been considered a maintenance department contract by some agencies and a professional engineering services contract by other agencies. As a result, procurement procedures will vary.

The 1988 Surface Transportation Act (P.L. 100-17) and the Brooks Act (P.L. 92-582) contain provisions requiring that when Federal funds are used for a project, either directly by a federal agency or through a local agency, the procurement of engineering services must be based on qualifications rather than on low bid unless a state has passed contrary legislation.

Underwater inspection procurements, because of the need for fully qualified diver-inspectors, evaluations of structural conditions, and recommendations for repair, often are recognized by agencies as professional engineering services.

SECTION 2. SCOPE OF WORK

8-2.1 General

The scope of work should define the extent of the required inspection; establish minimum standards for inspection personnel; describe the report format expected; and outline any known data or constraints which may affect the inspection. A scope of work or standard should be developed for in-house inspections as well as outside contract services to ensure there is a unity of objectives and agency-wide understanding of the work requirements. A sample scope of work is included in the Appendix.

8-2.2 Structure Description

A complete description of the bridge and its substructure should be provided. This should include the bridge configuration, location, length, type and number of substructure units in water, construction materials, past repairs or maintenance, name of the watercourse, maximum water depth, and water quality. Current velocity should also be included, if known. The special requirements discussed in Section 8-9, if applicable, should also be included.

8-2.3 Level of Inspection

The level of inspection to be to be performed should be clearly defined. FHWA has established minimum guidelines for routine underwater inspection as including the following:

Level I - Visual and tactile inspection of 100 percent of underwater members.

Level II - Detailed examination with cleaning and measurement of 10 percent of underwater members.

Inspection of channel bottom and sides for scour; cross-sections of alluvial channels and bottom probes of loose sediments.

If these minimum inspection requirements for a routine inspection do not permit a conclusive determination as to the safety of the structure, more extensive Level II and/or Level III inspections must be made.

For other than normally scheduled inspections, such as when specific problems are suspected, more extensive cleaning, measuring, and non-destructive testing may be needed. In determining the number of NDT measurements to require, it is important to gather sufficient data to achieve certainty of results, and in this area, reference to statistical survey methods may be useful.

Often, prior to initiating a routine inspection, it will be apparent that an inspection based on the minimum requirements will not yield sufficient data to make a determination with certainty of the structural integrity of the bridge; make major economic decisions regarding the future of the structure; or prepare detailed repair plans. In such cases, it is generally more cost-effective to initially include more Level II examinations, and include Level III examinations. Some owners routinely specify that 5 percent of all underwater members receive Level III inspections. For steel structures this could include ultrasonic measurements of the remaining thickness of the members, and for timber structures this could include boring and probing, coring, or ultrasonic testing. Initially including Level III inspections or collection of other detailed data as part of the routine inspection can reduce the overall inspection cost for a structure, by eliminating the cost of a second mobilization.

The scope of work should include a clear definition of what is required for each level of inspection. The definitions of the levels of inspection presented in Chapter 1 of this manual are generic definitions and as such include items which are not applicable to each bridge. Inclusion of inapplicable requirements can also increase the cost of the work unnecessarily.

It should also be recognized that the minimum inspection requisites listed above may not identify every defect, since Level II examinations are only a sampling.

The physical limits for the inspection of underwater members should be clearly defined. Generally, the mudline is the lower limit, but in some cases, probing or excavation below the present channel bottom may be warranted.

For the upper limit of the inspection; the waterline; some small distance above the waterline such as 3 feet; or the top of the entire element such as the pier or the pile may be specified. Including the entire element, both above and below water, as part of the underwater inspection has some advantages. It eliminates coordination problems between above and below water inspectors in recording data and evaluating the substructure unit; it reduces the cost of the inspection by eliminating the need for a second inspector to gain water access to the element for inspection above, but near, the waterline; and the inspector's report will summarize all inspection data together.

8-2.4 Soundings

Soundings should be made to provide a record of the bottom profile. Unless the water is too shallow for a boat, soundings should be taken using a continuous recording fathometer. The fathometer should be adjusted to account for the depth of the transducer below the water surface. Soundings, at least during the field work, will be referenced to the waterline at the time of the inspection. Later they may be adjusted to some other datum such as Mean Low Water in tidal areas or Normal Pool Elevation in reservoirs and controlled rivers. The water surface at the time of the inspection should be referenced to a point of known elevation on the bridge or to a local benchmark.

Soundings should be taken around all elements in water and along lines parallel to the bridge at the fascia. The pattern of soundings to be taken at a bridge will vary depending upon the channel size, flow characteristics and configuration of the bridge. Except for very small bridges, generally it would also include soundings along lines parallel to the face of the bridge, and at 50 feet, 100 feet and 200 feet upstream and downstream of the bridge. Additional soundings should be made as necessary to determine significant bottom features in the area. It is advantageous when reviewing soundings, particularly over a period of years, to have soundings made in a consistent pattern for all bridges under an agency's jurisdiction (Fig. 8-1).

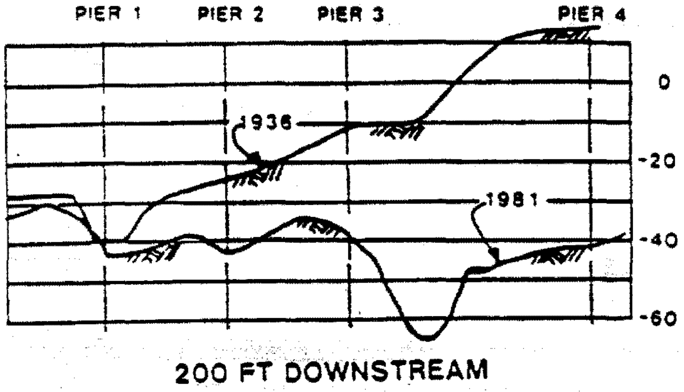

Figure 8-1 Comparison of soundings

8-2.5 Documentation

The type and extent of documentation of field conditions required should be clearly defined, as it can have significant effect on the cost of conducting an underwater investigation.

Detailed field notes should always be required. Documentation should include detailed notes of defects with location, height, width, and penetration. These notes should be sufficiently detailed to permit evaluation of the structure and preparation of repair documents and cost estimates.

Underwater color still photographs generally should be required showing both defective and sound areas of the structure. Still photography in clear, calm water is relatively inexpensive. In darker water where a clear water box must be used, or in high current, the cost increases. Pictures, however, can be extremely valuable to illustrate conditions in order to obtain funding, and to assist in the preparation of repair documents. The additional cost, for most inspections, is relatively small. Typical conditions should be photographed, but not every defect. A minimum number of pictures should be required at each bridge, such as at least two per pier, but there should be flexibility in the scope of work to permit reducing the number of pictures of good conditions if there is a corresponding increase in the number of photographs of defects.

Underwater video tape may be specified as documentation either alone or in combination with still photography. Video taping requires more diving time than still photography, as well as time to edit the tapes. This makes it particularly important to use video tape selectively. A competent trained diver-inspector should be able to judge those areas requiring taping during the investigation. When use must be made of an inspector who is inexperienced or not fully qualified to conduct bridge inspections, full video taping may be justified, but it must be emphasized that the value of the video is limited by the ability of the diver to recognize significant conditions and to point the camera at all such areas. Even under ideal conditions, video quality cannot match the human eye, and many variations of color and depth cannot be perceived when viewing a video tape. The video system should record both the diver's comments, and questions and comments of on-site observers. Later editing may also be used to add to or clarify these comments.

In video taping, there is much meaningless material recorded: starting; stopping; moving from substructure unit to substructure unit; adjusting lighting; and malfunctions. If an inspector is to review hours of tape, he will quickly become bored and inattentive. Video tapes should be edited to remove as much meaningless tape as possible. Video tapes should also be provided with an on-screen clock or counter, and titles to aid in reviewing the tape and finding specific units.

8-2.6 Report Requirements

The scope of work should state the type and number of copies of the report required. Since the report can range from a two or three page letter to a bound volume, costs of report preparation can vary widely. Factors which may influence the choice of report format and detail include agency standards, the size and importance of the bridge, anticipated bridge condition, prior inspection reports, the anticipated use of the final reports and the potential for litigation as would be present in an inspection following ship collision damage.

Though the length may vary, all reports should include the following sections:

(1) Description of the bridge (and appurtenant structures)
(2) Method of investigation
(3) Documentation of existing conditions
(4) Evaluation of conditions
(5) Recommendations

Additional report sections which may be required include:

(1) Cost estimates
(2) Details of equipment and procedures for special testing
(3) Appendices
(4) Color photographs (not photocopies)
(5) Drawings
(6) Sounding plans and sections
(7) Additional inspection forms

Drafts of inspection reports should generally be submitted to the owner for review and comment. Finally, the completed underwater inspection report should bear the signature and seal of a Registered Professional Engineer.

SECTION 3. QUALIFICATIONS OF INSPECTION PERSONNEL

8-3.1 General

It is the responsibility of the agency in charge of conducting underwater bridge inspections to establish the minimum qualifications for underwater bridge inspector-divers for each bridge where diving is required. The underwater inspection team should consist of a team leader and additional inspectors as required by the project scope and time frame, and safety considerations. Divers performing underwater inspections and evaluations should be fully qualified by training and experience in evaluating the types of degenerative underwater structural conditions that can exist at a given bridge. It is even more important for divers to be qualified to inspect bridges underwater than it is for above water inspectors. Above water, an area of concern can be more fully inspected by more than one person. Below water, the diver will usually be the only one to inspect a critical area. The inspector-diver must also be able to judge his own limitations, in evaluating structural conditions. If he encounters a situation which exceeds his qualifications, he must be able to recognize that fact and request better qualified assistance.

Some bridges, because of their complexity, substructure and superstructure interaction, or other site conditions, require a diver who is fully qualified as a bridge inspection team leader. For other bridges, a diver who is not a team leader might be used if that diver is fully trained and experienced in the structure and bed conditions at given bridge locations. Inspections made by divers not fully qualified as bridge inspectors or bridge inspection team leaders should be limited to specific bridge situations where simple measurements, verbal descriptions, underwater photography, etc. can provide conclusive evidence of underwater conditions to an on-site, fully qualified bridge inspection team leader.

8-3.2 Team Leader

The underwater bridge inspection team leader should meet the NBIS requirements for a bridge inspection team leader. He should also be certified as a diver by one of the several nationally recognized diver certification organizations or a commercial dive school so that, if necessary, he can verify or evaluate conditions reported by underwater inspectors. The team leader should be on-site at all times and perform a representative portion of the inspection since he must evaluate the structure. This individual will have overall responsibility for the inspection and should be experienced in planning and conducting diving operations.

8-3.3 Additional Inspectors

Additional inspectors used for the project should be fully trained and experienced to satisfy the requirements of the NBIS for bridge inspection team members, and should be certified divers trained by a nationally recognized organization. They should be able to document their training and experience in similar inspections and diving situations.

8-3.4 Additional Considerations

Employers must maintain records of medical examinations as required by OSHA regulations. Copies of these should be submitted to the agency as should copies of diver certification and training records.

The solicitation for underwater inspection services should clearly state the required qualifications of all members of the inspection team.

SECTION 4. INSURANCE REQUIREMENTS

8-4.1 General

Insurance requirements for underwater inspection contracts should be contained in the solicitation and normally will be consistent with the agency's standard contracting procedures. In addition to several coverages which are unique to underwater or marine work, underwater inspections may affect those insurance requirements considered standard. Since the need to obtain some insurance coverages in specific instances may be open to question, legal counsel should be consulted in developing final contract requirements.

8-4.2 Workers' Compensation

Workers' Compensation insurance covers a contractor's employees for lost time and medical expenses as a result of job related injuries. Specific requirements for Workers' Compensation insurance coverage and benefits are set by each state. In some states, the coverage must be purchased from a state agency. Because commercial diving activities are considered as high risks by insurance firms, rates for Workers' Compensation insurance for diving activities are very high, frequently approaching fifty percent of salary.

8-4.3 Longshoremen's and Harbor Workers' Compensation Insurance

This coverage is similar to Workers' Compensation, but covers work performed over and adjacent to water. Benefits provided under Longshoremen's insurance are usually greater than those provided by Workers' Compensation, and either an endorsement to a Worker's Compensation policy or a separate policy is necessary to secure Longshoreman's coverage. Because underwater operations involve work both below and above water, if an accident occurs there could be a dispute over which coverage applies. Partly for this reason, Longshoremen's insurance should be a requirement for all underwater inspection contracts.

8-4.4 Jones Act or Maritime Insurance

This insurance covers the crews of boats against occupational injuries. A requirement for such coverage where a small boat, particularly in non-navigable waters, is involved is debatable. In cases where larger boats are required, where work is to be performed in areas of commercial boat traffic, when diving is routinely done from a vessel or where separate hiring of a boat and crew is anticipated, this coverage may be required.

8-4.5 General Liability and Property Damage

Provision of this coverage is normally a requirement of government and private agencies for all contracts. General Liability and Property Damage Insurance provides coverage against suits brought by third parties, i.e., parties other than the bridge owner or diving contractor, for bodily injury and property damage.

Some General Liability/Property Damage policies do not extend coverage for work performed within a specified distance of a railroad, 200 feet, for example. In these cases, Railroad Protective Liability Insurance may be required. The need for this Railroad Protective Liability coverage, however, should be carefully evaluated with the railroad since it can be very expensive, and inspection activities should have minimal, if any, impact on adjacent rail operations.

8-4.6 Professional Liability

Sometimes termed "errors and omissions" insurance, this coverage is provided routinely by consulting firms in engineering and other professional fields. It provides liability coverage against malpractice suits brought for negligent services or failure to provide such services, such as might be brought by persons injured as the result of the failure of an underwater inspector to properly identify conditions which led to a bridge collapse. Professional liability coverage is required by many states in above-water and underwater inspection contracts.

SECTION 5. SCHEDULING

8-5.1 General

Underwater inspections should be correlated with the agency's overall bridge inspection program. Within that framework, economies may be realized by allowing the inspectors latitude for scheduling their field work.

8-5.2 Weather

Climatic conditions, especially in northern areas, affect schedules. While inspections can be conducted in cold weather and frozen rivers, such inspections are more costly because of reduced efficiency. Not only is it difficult for the diver to concentrate on the inspection, but topside support personnel are also hampered. In addition, while it is possible to break ice to provide access to the water for the diver, ice may cover large areas of the structure at the waterline where detailed inspection is important.

Where the divers must wear dry suits and full helmets, such as in polluted water, hot weather may also be a hindrance. The diver must be dressed quickly and cooled by immersion, and then unsuited at the end of the inspection to prevent overheating.

Whenever possible, therefore, work should be scheduled for mild weather.

River flows may vary with the season, generally being greatest in the spring and lowest in late summer or early fall. Inspections conducted during low flows can reduce costs. Where a bridge crosses a particularly deep river or a reservoir, it may be possible to eliminate the need for special deep diving techniques, such as decompression diving, by scheduling the underwater inspection for a period of minimum depth.

The clarity of water varies over the year, generally being poorest in the spring. Eroded material, plant life, and marine organisms can all contribute to reduced visibility.

8-5.3 Other Factors

In special cases, environmental constraints such as fish spawning and glacial runoff may need to be considered in establishing schedules.

SECTION 6. REPORT FORMS

A standard form should be developed for summarizing the results of the underwater inspection for inclusion in the agency's data bank and for providing input for the NBIS Inventory. This report should be completed by the inspector and submitted with the underwater inspection report.

Report forms for a system-wide program generally require that a numerical condition rating be assigned to each underwater substructure unit. Provisions should also be made to accommodate comments. Various report forms are discussed in greater detail in Chapter IX.

SECTION 7. REQUIREMENTS FOR PROPOSAL SUBMITTAL

8-7.1 General

The scope of work provided in a request for proposals for underwater bridge inspection services should indicate the minimum requirements for the proposer's submittal. Sufficient information should be requested to allow the bridge owner agency to assure itself that a competent firm will be selected at a reasonable fee.

8-7.2 Contractual Requirements

The submittal will normally require the contractor to complete various standard agreements and forms required by the agency's standard contracting and solicitation procedures. Such documents should be completed in full and bear authorized signatures as required. The length of time the proposal must remain valid should be clearly stated, keeping in mind that seasonal changes can significantly affect the costs of an underwater inspection.

General information on the firm and its personnel should be submitted unless the firm has previously been prequalified by the agency for underwater inspection work. Documentation of available insurance coverages including those in Section 8-4 should be provided.

8-7.3 Technical Requirements

a. Inspection Procedure. The contractor should submit an inspection execution plan or procedures indicating how he will undertake the work, equipment to be used, documentation techniques, and any special requirements.

b. Sample Reports. The submittal should include one or more sample reports similar in format to those required by the contracting agency. This is of particular importance if no specific report format has been specified in the Scope of Work.

SECTION 8. CONTRACTOR SELECTION

8-8.1 General

Many firms have both the technical and diving expertise to provide competent underwater inspections. Broadly speaking, the firms fall into two categories. The first, is a diving contractor who provides underwater construction as well as inspection services. The second is an engineering consulting firm which provides services in underwater inspection using its own staff, but does not perform construction. Both types of firms may have the qualifications for a particular project, and the bridge owner must evaluate the responding firms to determine which ones meet the agency's minimum requirements, and which one best meets those needs.

Solicitation for underwater inspection services may utilize a prequalification list developed by the agency, as well as advertisements in publications such as the Commerce Business Daily (CBD).

Engineering News Record (ENR), local construction publications, and newspapers. The use of such publications assures wide dissemination of the announcement and response by a number of qualified firms.

8-8.2 Personnel Experience

The experience of the inspection personnel is the single most important evaluation factor in selecting an inspection contractor, whether for underwater or above water projects. Project team members must meet agency requirements for both technical and diving expertise, and experience.

Resumes should be required for all proposed project personnel. Specific experience in underwater inspections and diving certification should be included for team leaders and all diver-inspectors. The submittal should include a breakdown of the proposed project team indicating their duties and qualifications.

A statement, or copies of records, indicating that divers meet OSHA requirements for training and medical examinations should be provided.

Underwater inspections are often performed in poor visibility, fast-moving rivers, and potentially hazardous surroundings. Divers should have experience in similar projects. Divers who dive infrequently and must concentrate more on diving aspects of the work may not be able to devote their full attention to the inspection effort, particularly in adverse conditions. While the individual inspector must be a competent diver, it should be emphasized that the sole purpose of his diving is to secure inspection data. The finest diver is of no value if he is not a technically competent inspector.

When specialized testing is to be utilized, the proposed personnel should have demonstrated experience in its proper use and interpretation of the data obtained.

8-8.3 Firm Stability

Considerable time may elapse between submission of a proposal and the actual conduct of an inspection. The owner agency should feel confident that the proposed inspection personnel will still be with the firm selected at the time of inspection, or that additional qualified personnel will be available. A review of the proposed staff's resumes should indicate if the same personnel have been with the firm for an extended length of time, if there is high turnover, or if the staff moves from firm to firm as jobs end.

An additional advantage of firm stability and staff retention is the ability of the owner to ask questions of a particular inspector at some time in the future. This requirement frequently occurs during the preparation of repair drawings.

8-8.4 Conflict of Interest

Some agencies, in order to eliminate any appearance of bias, preclude an inspection firm from submitting bids to complete any subsequent repairs. This may limit the interest and choice of underwater contracting firms in providing inspection services. Any appearance of a "biased" report may be a problem where an attempt is made to secure funding, or potential litigation is involved, as in a ship collision.

8-8.5 OSHA Requirements

All divers proposed for a project must satisfy requirements for training and medical examinations.

OSHA requires the firm to maintain a Safe Dive Practices Manual. The agency should request and review this document as it is one indication of the care a firm takes in safely conducting its operations. The agency should emphasize, however, that the request for this document in no way limits the contractor's responsibility for methods and safety.

8-8.6 References

A list of references for similar inspection projects completed by the contractor should be required and carefully reviewed. These projects should include work in similar conditions of water depth, visibility, current, and substructure type. The list should also include names, addresses and phone numbers of past client representatives who are familiar with the work of the firm on specific projects.

SECTION 9. SPECIAL REQUIREMENTS

8-9.1 General

In soliciting underwater inspection services, special situations sometimes arise which can significantly affect the effort, support equipment, and cost of the inspection. Some of these are difficult to foresee. Several more common considerations are addressed in the following paragraphs. The contract administrator should be alert to these conditions and provide any available information concerning special requirements in the request for proposal.

8-9.2 Decompression Dives

The amount of time a diver can spend at a given depth is dependent on various physiological factors. For deeper dives, or where prolonged bottom times are required, in water decompression or chamber decompression may be required. When decompression dives are required, additional cost must be expected for a recompression chamber, support equipment, and larger crew. When dives are made to depths greater than 100 feet of sea water or outside the "no-decompression" limits, a recompression chamber must be at the dive location for safety reasons whether or not a chamber decompression is anticipated. As a very general guideline, water depths greater than sixty feet should alert the contract administrator to the possibility of recompression requirements.

8-9.3 High Altitude

As the altitude at which a diving operation is conducted increases, the air pressure on the diver on the surface decreases. At altitudes above 1,000 feet mean sea level, modified decompression tables must be used to account for this change in ambient pressure. The effect of higher altitude is similar to increasing the depth of the dive. The effect of the altitude correction can be to move a no-decompression dive into the decompression range or require additional staff and equipment. Figure 8-3 illustrates the effect of altitude on a project. The altitude of the dive site should be included in a request for proposal for sites over 1000 feet above sea level.

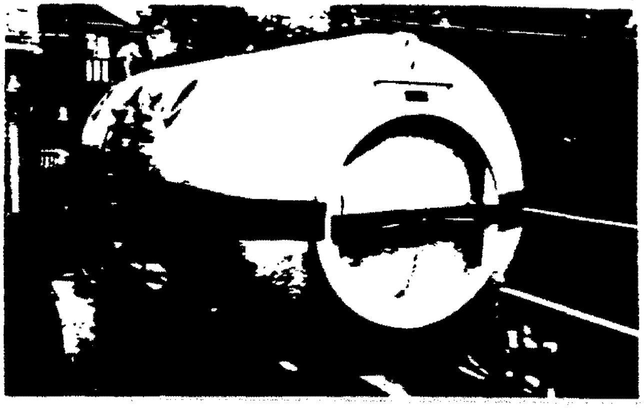

Figure 8-2 Portable Recompression Chamber

8-9.4 Penetration Dives

When divers are used to inspect flooded culverts or culverts with minimal available headroom where contaminated air may be present, safety must be carefully considered.

Where screens or debris are present which prevent or delay access and egress, they must be removed prior to diving. The party responsible for this removal work should be stated in the contract, and adequate funds provided to accomplish the removal.

Because a diver in distress cannot usually ascend to the surface in penetration dives, additional precautions and a larger dive team are usually needed. In addition to surface dive tenders, a diver-tender must be stationed at the point of entry to a confined space such as a submerged culvert mouth.

8-9.5 Pollution

While many waters are becoming cleaner, there is increased awareness of potential harmful effects of waters polluted with a variety of chemicals and wastes, even in very small amounts. Any available information on water quality should be supplied with a request for proposals. Some states are now classifying water

EXAMPLE OF ALTITUDE EFFECTS

Task: Inspection of Pier in 90 Feet of Water

	Location 1 Elev 800'	Location 2 Elev 6000'
Maximum Dive Depth	90'	90'
Maximum effective Dive Depth (Altitude corrected)	90'	112'
Maximum Bottom Time without Decompression (Per 24 hour period)	30 min.	30 min.
Dive Team Size:[1]		
Surface-Supplied Air	3	4
SCUBA	3	4
Decompression Chamber	Not required	Required on Site

Figure 8-3 Example of altitude effects.

quality at all bridge sites as part of their bridge record keeping process, and this is recommended for all agencies.

8-9.6 High Currents

Diving operations become increasingly difficult as currents increase. Currents above approximately 1 knot require the use of safety lines. In addition, heavy weights and other means may be needed so the diver can maintain his position during the inspection. In some cases, temporary diversion shields or walls may be required. These activities increase inspection time and cost.

River flows vary through the seasons and year. Whenever possible, ample time should be allowed in the contract for scheduling to allow inspection at low flow. At times, it is impossible to inspect at low flow periods, thus avoiding high currents. It is sometimes possible to reduce flows by temporary changes in the operation of an upstream dam. Flow data is generally available from several government agencies including the local office of the Corps of Engineers and state hydrologic survey agencies.

SECTION 10. QUALITY CONTROL OF UNDERWATER INSPECTIONS

8-10.1 General

Because those areas inspected during an underwater investigation are only accessible by persons with specialized training and equipment, quality control of the inspection is not easily based on random checks of previously inspected areas. This method has been used, however, by some states which utilize a combination of contract and in-house underwater inspection teams. In many cases, the agency will have to rely on an evaluation of above water

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[1] Dive team size must be determined in consideration of job factors, safety, and applicable governmental regulations.

procedures and a critical review of the product of the inspection.

8-10.2 Contractor Responsibility

It is the responsibility of the diving inspection team leader to assure the quality of his inspection effort. The quality control program should include the following:

(a) Assignment of qualified inspection team members.

(b) Establishment and adherence to standard inspection procedures.

(c) Development and use of standard inspection forms and checklists for recording inspection data.

(d) Preparation of reports using an established, comprehensive format.

(e) In-house, independent review of inspection reports.

8-10.3 Report Review

Agency technical staff should critically review the contractor's inspection report and compare it with previous reports when available. Any unusual findings should be discussed with the inspection team leader and the inspector-diver. Conditions which are not verifiable, not documentable, or not consistent with normal conditions may indicate an insufficient or inaccurate inspection requiring further action to confirm conditions.

SECTION 11. CONTRACTOR MONITORING AND COORDINATION

8-11.1 General

The type and extent of contract monitoring and coordination required depends on the scope of the underwater inspection effort. When a single small bridge is involved, coordination may simply involve notification of the owner by the inspector of the proposed inspection dates. For contracts for more than one bridge, a bridge by bridge schedule may be established that requires submission of periodic progress reports and completed inspection reports in a predetermined sequence.

8-11.2 Coordination With Above Water Inspection

When an above water inspection of a bridge is undertaken, scheduling of the underwater inspection at the same time should be considered. Performing both inspections simultaneously encourages communication to establish common points of reference. If the complete inspection of the substructure unit, both above and below water, is not done by the underwater inspection contractor, it also helps guard against misinterpretations of where one inspector stops and the other starts.

8-11.3 Observation and Monitoring

Some agencies provide an observer on-site during underwater inspections. In some cases the observer may view portions of the underwater structure by means of a video camera with a real-time surface monitor. This may be necessary if the diver conducting the inspection is not fully qualified.

If the observer is recording the inspection notes, as reported by the diver, the diver should review the notes immediately upon surfacing, verify their content, and attest to their completeness by initialling or signing them.

When the owner agency provides an on-site representative, his function should be limited to facilitating the inspection effort by providing any needed agency support and observing the inspection effort to assure that contractual obligations are met. All responsibility for the inspection itself, including notes and sketches, should be retained by the inspector. This should not hinder a competent inspection team and will eliminate any question of responsibility, should a later question arise as to the accuracy and completeness of the inspection or the inspection notes.

9-2.2 Notebook Format

The notebook format is often used for unique or complex structures. Information should be recorded systematically. The following summary describes a suggested content outline.

a. Title Page. The title page should contain the name of the structure, the structure identification number, the road section identification number, and the name of the crossing. The back of the title page should be used to note the names of the members of the inspection party, the person in charge of the party, the type of inspection, and the dates on which the inspection was made.

b. General Format. The left-hand page should contain the name of the member being inspected, its components, the evaluation of that member and its components, and an appropriate space for comments. The right-hand page should be reserved for sketches or drawings of the member. The format of each section of the notebook should be arranged so as to proceed from the general to specific, i.e., from a general lay-out of the substructure to individual drawings of the individual substructure units to the components of the substructure units.

9-2.3 Sketches

In most cases, it will be possible to insert reproductions of portions of the plans in the notebook. In some instances, it will be necessary to draw the sketches.

Sketches or drawings of each substructure unit should be included. In many cases it will be sufficient to draw typical units which identify the principal elements of the substructure. Each of the elements of a substructure unit should be annotated so that it can be cross-referenced to the information appearing on the data page on the left-hand side of the sketch. Items to be numbered include piling, footings, vertical supports, lateral bracing of members, and caps.

9-2.4 Numerical Evaluation

Numerical ratings of bridge components are useful for the evaluation of the bridge. Some agencies require the individual inspector to make numerical ratings of the bridge components. Other agencies prefer to assign numerical ratings in the office based on the detailed notes provided by the field inspector. The following system rates bridges on a "0" to "9" system with "9" being new condition and "0" being beyond repair. Note that ratings "0," "1," "2," "3," "4," and "6," apply only to major components and elements. A suggested rating system is as follows:

(a) "9" - Excellent condition.

(b) "8" - Very good condition. No problems noted.

(c) "7" - Good condition. Some minor problems.

(d) "6" - Satisfactory condition. Structural elements show some minor deterioration.

(e) "5" - Fair condition. All primary structural elements are sound but may have minor section loss, cracking, spalling or scour.

(f) "4" - Poor condition. Advanced section loss, deterioration, spalling or scour.

(g) "3" - Serious condition. Loss of section, deterioration, spalling or scour have seriously affected primary structural components. Local failures are possible. Fatigue cracks in steel or shear cracks in concrete may be present.

(h) "2" - Critical condition. Advanced deterioration of primary structural elements. Fatigue cracks in steel or shear cracks in concrete may be present or scour may have removed substructure support. Unless closely monitored it may be necessary to close the bridge until corrective action is taken.

(i) "1" - Imminent failure condition. Major deterioration or section loss present in critical structural components or obvious vertical or horizontal movement affecting structural stability. Bridge is closed to traffic but corrective action may put back in light service.

(j) "0" - Failed condition. Out of service, beyond corrective action.

(k) "N" - Not applicable.

9-2.5 Standard Forms

On large or complex bridges, the notebook format must be used to record inspection results. For small

CHAPTER IX

INSPECTION REPORTS

SECTION 1. INTRODUCTION

9-1.1 General

Inspection reports provide information which is essential to ensure the safety of public bridges. Reports supply information that allows evaluation of the current condition of the bridge, and the basis for determining future maintenance costs, scheduling and manpower requirements. Reports may also be used in litigation where damage has been caused by an outside party, or persons have been injured or property damaged as a consequence of bridge condition.

Reports should consist of written descriptions, with sketches as necessary, to identify areas of damage and distress.

Agencies also assign numerical values for various conditions or degrees of deterioration. The data is entered into a computer which can store and summarize the condition of all the structures throughout the state. Figures 9-1, 9-2, and 9-3 illustrate typical forms used by three states to record underwater inspection information.

9-1.2 Requirements of Inspection Forms

In order to be of value, an inspection report must be clear and complete. A report should include the following:

(a) Information about the configuration and construction of the structure (e.g., pier founded on piles or soil, pile lengths, etc.). This information is contained in design or as-built plans and previous reports.

(b) Any repairs made to the structure.

(c) Method of investigation (Scuba, surface supplied, wading, visual inspection, NDT testing, etc.).

(d) Inspection findings including the physical condition of the substructure, channel bottom conditions, and waterway observations. Drawings, photographs and soundings may be required.

(e) Conclusions as to how defects and conditions found have affected the substructure. This may include an analysis of the structure.

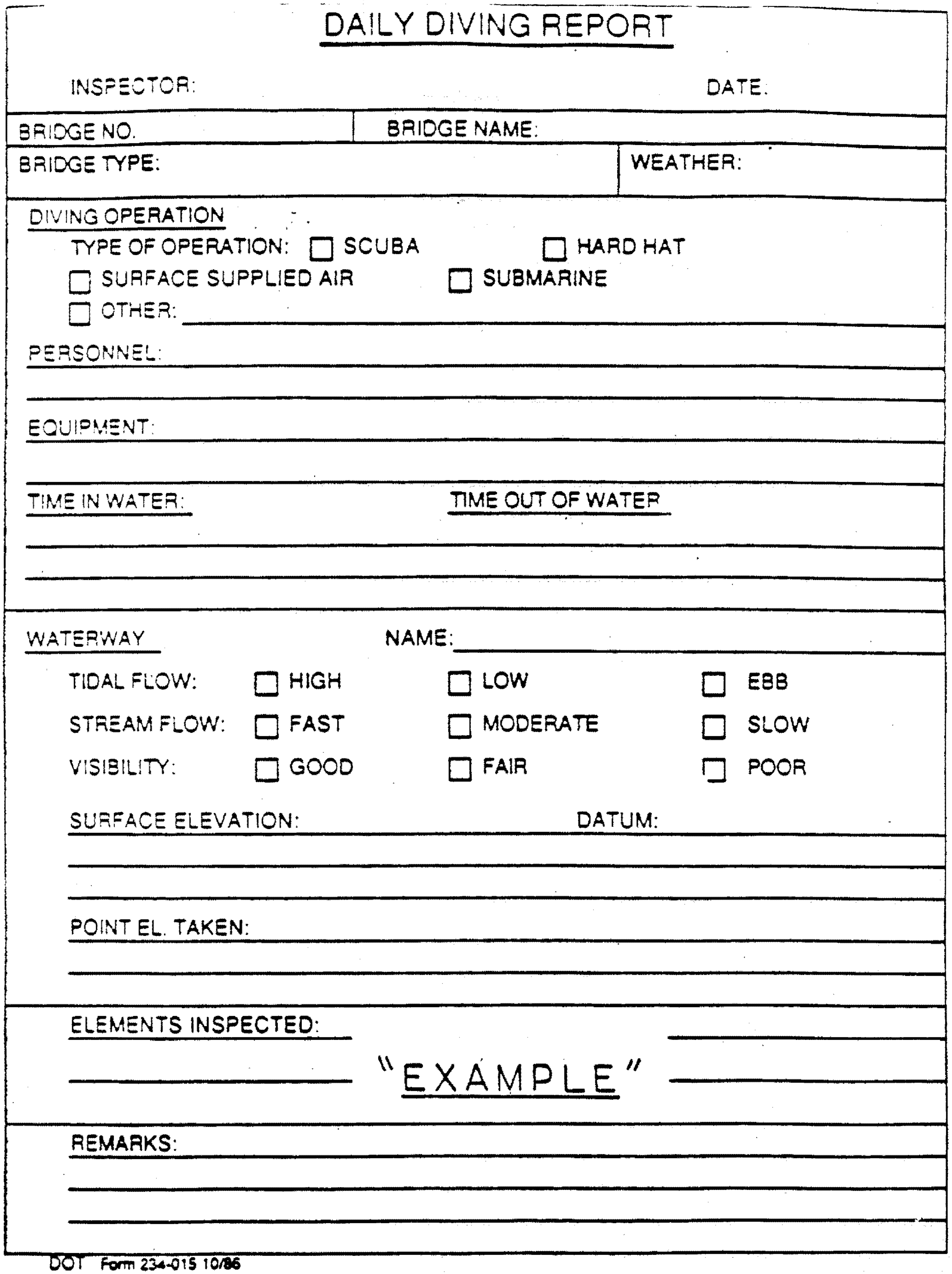
(f) Recommendations for repair, future maintenance or further inspection.

(g) Signature of bridge inspection team leader. Many states may require this to be a registered professional engineer attesting to the report's accuracy, completeness and sufficiency.

SECTION 2. RECORDING INSPECTION NOTES

9-2.1 General

Notes can be recorded in a notebook format, on standard forms or a combination of these. In order to make the notes clear, sketches should be drawn and photographs taken as needed.



DAILY DIVING REPORT

INSPECTOR: DATE:

BRIDGE NO. BRIDGE NAME:

BRIDGE TYPE: WEATHER:

DIVING OPERATION

TYPE OF OPERATION: ☐ SCUBA ☐ HARD HAT

☐ SURFACE SUPPLIED AIR ☐ SUBMARINE

☐ OTHER:

PERSONNEL:

EQUIPMENT:

TIME IN WATER: TIME OUT OF WATER

WATERWAY NAME:

TIDAL FLOW:	☐ HIGH	☐ LOW	☐ EBB
STREAM FLOW:	☐ FAST	☐ MODERATE	☐ SLOW
VISIBILITY:	☐ GOOD	☐ FAIR	☐ POOR

SURFACE ELEVATION: DATUM:

POINT EL. TAKEN:

ELEMENTS INSPECTED:

"EXAMPLE"

REMARKS:

DOT Form 234-015 10/86

Figure 9- Typical Form A

and simple bridges, however, it may be more convenient to use standard forms. When using standard forms, the evaluation numbers and comments may be recorded exactly as described in the section for notebooks. The reverse side of the forms can be used for drawing sketches and for additional comments.

If available, standard sketches should be attached to the forms with the coding of all members indicated. Where sketches and narrative descriptions cannot fully describe the deficiency or defect, photographs should be taken, and should be referred to appropriately in the narrative. All items on the forms may not always be filled out. Prior to the inspection, it should be determined which items are not applicable for the particular bridge to be inspected.

Figure 9-2 Typical Form B

"EXAMPLE"

Bridge Inspection Report Cont.

7S of 7

UNDERWATER BRIDGE INSPECTION SUPPLEMENT

STRUCTURE NO. A B L

INSPECTORS COLLINS ENGINEERS INC. INSP. DATE (Current) 10-11-88 (Next) 10-93

SYSTEMS NO. I - 25 MILEPOST 12.24 FEATURE NAME LAKE ABSARRACA

CONDITION RATING

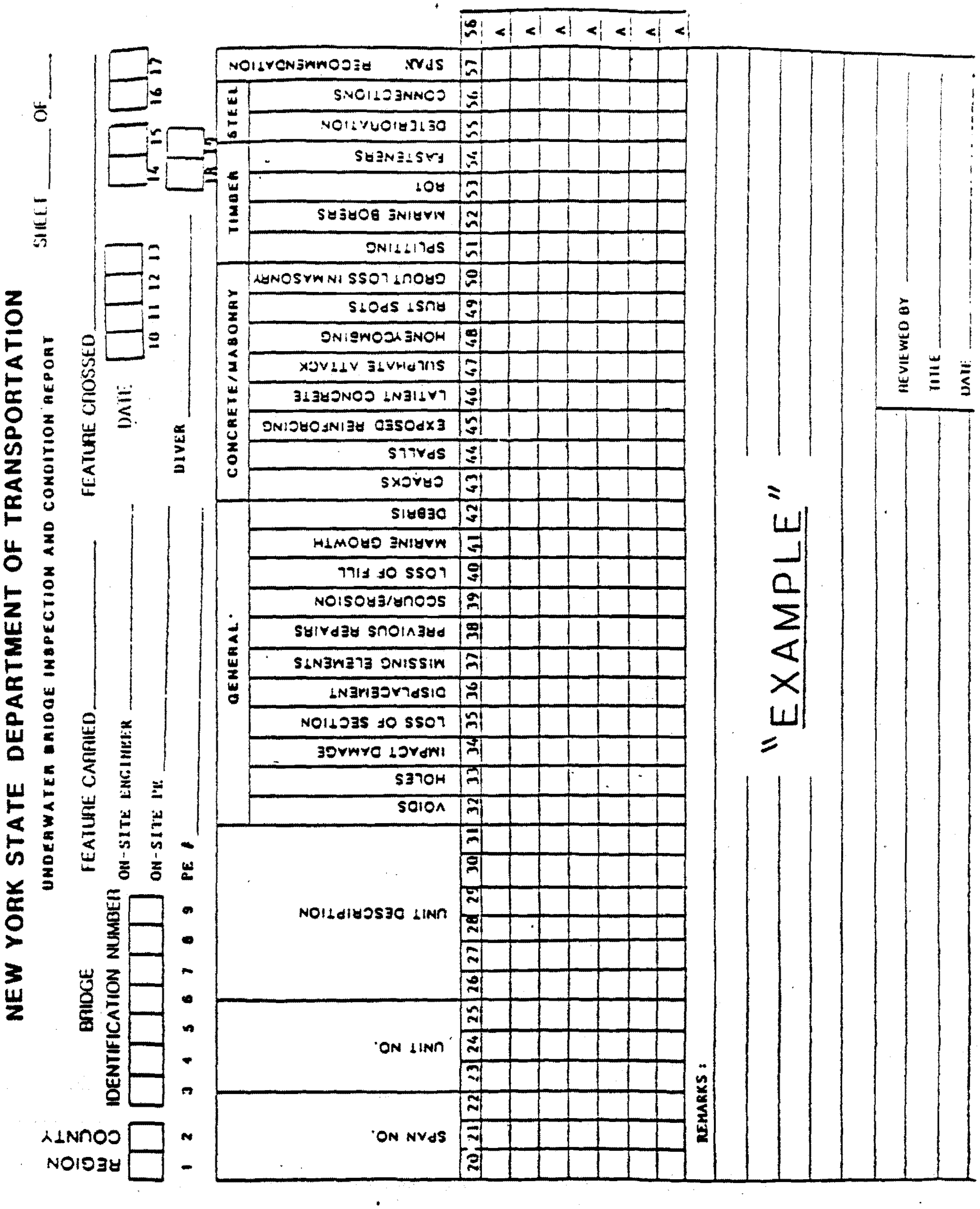
Unit Ref. No.	UNIT DESCRIPTION	Depth of Water (__ ft.)	ABUTS./PIERS/BENTS					CHANNEL				GENERAL					
			Piling .01	Column(s) or Shaft(s) .02	Footing(s) .03	Displacement .04	Other .05	Scour .06	Embankment Erosion .07	Embankment Protection .08	Other .09	Concrete(1) .10	Steel(2) .11	Timber(3) .12	Loss of Section(4) .13	Previous Repair/Maint. .14	Other .15
1	ABUT NO. 1	13.5	8	8	8	8	N	8	7	7	N	8	8	8	8	N	N
2	ABUT NO. 2	13.7	8	8	8	8	N	8	7	7	N	8	8	8	8	N	N
3																	
4																	
5																	
6																	
7																	
8																	

REMARKS

1 0 1	¢ 2.01 ; PILING NOT EXPOSED AND ASSUMED TO BE IN GOOD CONDITION
1 0 7	¢ 2.07 ; SOME MINOR EROSION AT BOTTOM OF SLOPE PAVING
1 0 8	¢ 2.08 ; SOME MINOR FREEZE-THAW DAMAGE TO SLOPE PAVING

Note: *Above condition ratings shall, as applicable, be represented in Items 60, 61 & 71.*

(1) Spalls, cracking, honeycomb, marine growth, exposed reinf., chem. attack, other
(2) Corrosion, cracks, marine growth, chem. attack, other
(3) Splits, rot, marine borers, chem. attack, other
(4) Rate based on % loss of x-sect. area. i.e., 0%(8) to ≥ 50%(3)



NEW YORK STATE DEPARTMENT OF TRANSPORTATION

UNDERWATER BRIDGE INSPECTION AND CONDITION REPORT

SHEET ______ OF ______

REGION ☐ 1 COUNTY ☐ 2

BRIDGE IDENTIFICATION NUMBER ☐☐☐☐☐☐☐ 3 4 5 6 7 8 9

FEATURE CARRIED ______

FEATURE CROSSED ______

DATE ☐☐☐☐ 10 11 12 13 ☐☐ 14 15 ☐☐ 16 17

ON-SITE ENGINEER ______

ON-SITE PE ______

DIVER ______ ☐☐ 18 19

PE # ______

SPAN NO.	20 21		
UNIT NO.	22 23 24 25		
UNIT DESCRIPTION	26 27 28 29 30 31		
GENERAL	VOIDS	32	
	HOLES	33	
	IMPACT DAMAGE	34	
	LOSS OF SECTION	35	
	DISPLACEMENT	36	
	MISSING ELEMENTS	37	
	PREVIOUS REPAIRS	38	
	SCOUR/EROSION	39	
	LOSS OF FILL	40	
	MARINE GROWTH	41	
	DEBRIS	42	
CONCRETE/MASONRY	CRACKS	43	
	SPALLS	44	
	EXPOSED REINFORCING	45	
	LATENT CONCRETE	46	
	SULPHATE ATTACK	47	
	HONEYCOMBING	48	
	RUST SPOTS	49	
	GROUT LOSS IN MASONRY	50	
TIMBER	SPLITTING	51	
	MARINE BORERS	52	
	ROT	53	
	FASTENERS	54	
STEEL	DETERIORATION	55	
	CONNECTIONS	56	
SPAN RECOMMENDATION		57	
		58	A A A A A A A

REMARKS:

"EXAMPLE"

REVIEWED BY ______

TITLE ______

DATE ______

Figure 9-3 Typical Form C

APPENDIX

OCCUPATIONAL SAFETY AND HEALTH ADMINISTRATION

DIVING STANDARDS

Subpart T—Commercial Diving Operations

AUTHORITY: Secs. 4, 6, 8, Occupational Safety and Health Act of 1970 (29 U.S.C. 653, 655, 657); Sec. 107, Contract Work Hours and Safety Standards Act (Construction Safety Act) (40 U.S.C. 333); Sec. 41, Longshoremen's and Harbor Workers' Compensation Act (33 U.S.C. 941); Secretary of Labor's Order No. 8-76 (41 FR 25059) or 9-83 (48 FR 35736), as applicable; 29 CFR Part 1911.

SOURCE: 42 FR 37668, July 22, 1977, unless otherwise noted.

GENERAL

§ 1910.101 Scope and application.

(a) *Scope.* (1) This subpart (standard) applies to every place of employment within the waters of the United States, or within any State, the District of Columbia, the Commonwealth of Puerto Rico, the Virgin Islands, American Samoa, Guam, the Trust Territory of the Pacific Islands, Wake Island, Johnston Island, the Canal Zone, or within the Outer Continental Shelf lands as defined in the Outer Continental Shelf Lands Act (67 Stat. 462, 43 U.S.C. 1331), where diving and related support operations are performed.

(2) This standard applies to diving and related support operations conducted in connection with all types of work and employments, including general industry, construction, ship repairing, shipbuilding, shipbreaking and longshoring. However, this standard does not apply to any diving operation:

(i) Performed solely for instructional purposes, using open-circuit, compressed-air SCUBA and conducted within the no-decompression limits;

(ii) Performed solely for search, rescue, or related public safety purposes by or under the control of a governmental agency; or

(iii) Governed by 45 CFR Part 46 (Protection of Human Subjects, U.S. Department of Health, Education, and Welfare) or equivalent rules or regulations established by another federal agency, which regulate research, development, or related purposes involving human subjects.

(iv) Defined as scientific diving and which is under the direction and control of a diving program containing at least the following elements:

(A) Diving safety manual which includes at a minimum: Procedures covering all diving operations specific to the program; procedures for emergency care, including recompression and evacuation; and criteria for diver training and certification.

(B) Diving control (safety) board, with the majority of its members being active divers, which shall at a minimum have the authority to: Approve and monitor diving projects; review and revise the diving safety manual; assure compliance with the manual; certify the depths to which a diver has been trained; take disciplinary action for unsafe practices; and, assure adherence to the buddy system (a diver is accompanied by and is in continuous contact with another diver in the water) for SCUBA diving.

(b) *Application in emergencies.* An employer may deviate from the requirements of this standard to the extent necessary to prevent or minimize a situation which is likely to cause death, serious physical harm, or major environmental damage, provided that the employer:

(1) Notifies the Area Director, Occupational Safety and Health Administration within 48 hours of the onset of the emergency situation indicating the nature of the emergency and extent of the deviation from the prescribed regulations; and

(2) Upon request from the Area Director, submits such information in writing.

(c) *Employer obligation.* The employer shall be responsible for compliance with:

(1) All provisions of this standard of general applicability; and

(2) All requirements pertaining to specific diving modes to the extent diving operations in such modes are conducted.

(42 FR 37668, July 22, 1977, as amended at 47 FR 53365, Nov. 26, 1982)

§ 1910.402 Definitions.

As used in this standard, the listed terms are defined as follows:

"Acfm": Actual cubic feet per minute.

"ASME Code or equivalent": ASME (American Society of Mechanical Engineers) Boiler and Pressure Vessel Code, Section VIII, or an equivalent code which the employer can demonstrate to be equally effective.

"ATA": Atmosphere absolute.

"Bell": An enclosed compartment, pressurized (closed bell) or unpressurized (open bell), which allows the diver to be transported to and from the underwater work area and which may be used as a temporary refuge during diving operations.

"Bottom time": The total elasped time measured in minutes from the time when the diver leaves the surface in descent to the time that the diver begins ascent.

"Bursting pressure": The pressure at which a pressure containment device would fail structurally.

"Cylinder": A pressure vessel for the storage of gases.

"Decompression chamber": A pressure vessel for human occupancy such as a surface decompression chamber, closed bell, or deep diving system used to decompress divers and to treat decompression sickness.

"Decompression sickness": A condition with a variety of symptoms which may result from gas or bubbles in the tissues of divers after pressure reduction.

"Decompression table": A profile or set of profiles of depth-time relationships for ascent rates and breathing mixtures to be followed after a specific depth-time exposure or exposures.

"Dive location": A surface or vessel from which a diving operation is conducted.

"Dive-location reserve breathing gas": A supply system of air or mixed gas (as appropriate) at the dive location which is independent of the primary supply system and sufficient to support divers during the planned decompression.

"Dive team": Divers and support employees involved in a diving operation, including the designated person-in-charge.

"Diver": An employee working in water using underwater apparatus which supplies compressed breathing gas at the ambient pressure.

"Diver-carried reserve breathing gas": A diver-carried supply of air or mixed gas (as appropriate) sufficient under standard operating conditions to allow the diver to reach the surface, or another source of breathing gas, or to be reached by a standby diver.

"Diving mode": *A type of diving requiring specific equipment, procedures and techniques (SCUBA, surface supplied air, or mixed gas).*

"Fsw": Feet of seawater (or equivalent static pressure head).

"Heavy gear": Diver-worn deep-sea dress including helmet, breastplate, dry suit, and weighted shoes.

"Hyperbaric conditions": Pressure conditions in excess of surface pressure.

"Inwater stage": A suspended underwater platform which supports a diver in the water.

"Liveboating": The practice of supporting a surfaced-supplied air or mixed gas diver from a vessel which is underway.

"Mixed gas diving": A diving mode in which the diver is supplied in the water with a breathing gas other than air.

"No-decompression limits": The depth-time limits of the "no-decompression limits and repetitive dive group designation table for no-decompression air dives", U.S. Navy Diving Manual or equivalent limits which the employer can demonstrate to be equally effective.

"Psi(g)": Pound per square inch (gauge).

"Scientific diving" means diving performed solely as a necessary part of a scientific, research, or educational activity by employees whose sole purpose for diving is to perform scientific research tasks. Scientific diving does not include performing any tasks usually associated with commercial diving such as: Placing or removing heavy objects underwater; inspection of pipelines and similar objects; construction; demolition; cutting or welding, or the use of explosives.

"SCUBA diving": A diving mode independent of surface supply in which the diver uses open circuit self-contained underwater breathing apparatus.

"Standby diver": A diver at the dive location available to assist a diver in the water.

"Surface-supplied air diving": A diving mode in which the diver in the water is supplied from the dive location with compressed air for breathing.

"Treatment table": A depth-time and breathing gas profile designed to treat decompression sickness.

"Umbilical": The composite hose bundle between a dive location and a diver or bell, or between a diver and a bell, which supplies the diver or bell with breathing gas, communications, power, or heat as appropriate to the diving mode or conditions, and includes a safety line between the diver and the dive location.

"Volume tank": A pressure vessel connected to the outlet of a compressor and used as an air reservoir.

"Working pressure": The maximum pressure to which a pressure containment device may be exposed under standard operating conditions.

[42 FR 37668, July 22, 1977, as amended at 47 FR 53365, Nov. 26, 1982]

PERSONNEL REQUIREMENTS

§ 1910.410 Qualifications of dive team.

(a) *General.* (1) Each dive team member shall have the experience or training necessary to perform assigned tasks in a safe and healthful manner.

(2) Each dive team member shall have experience or training in the following:

(i) The use of tools, equipment and systems relevant to assigned tasks;

(ii) Techniques of the assigned diving mode: and

(iii) Diving operations and emergency procedures.

(3) All dive team members shall be trained in cardiopulmonary resuscitation and first aid (American Red Cross standard course or equivalent).

(4) Dive team members who are exposed to or control the exposure of others to hyperbaric conditions shall be trained in diving-related physics and physiology.

(b) *Assignments.* (1) Each dive team member shall be assigned tasks in accordance with the employee's experience or training, except that limited additional tasks may be assigned to an employee undergoing training provided that these tasks are performed under the direct supervision of an experienced dive team member.

(2) The employer shall not require a dive team member to be exposed to hyperbaric conditions against the employee's will, except when necessary to complete decompression or treatment procedures.

(3) The employer shall not permit a dive team member to dive or be otherwise exposed to hyperbaric conditions for the duration of any temporary physical impairment or condition which is known to the employer and is likely to affect adversely the safety or health of a dive team member.

(c) *Designated person-in-charge.* (1) The employer or an employee designated by the employer shall be at the dive location in charge of all aspects of the diving operation affecting the safety and health of dive team members.

(2) The designated person-in-charge shall have experience and training in the conduct of the assigned diving operation.

GENERAL OPERATIONS PROCEDURES

§ 1910.420 Safe practices manual.

(a) *General.* The employer shall develop and maintain a safe practices manual which shall be made available at the dive location to each dive team member.

(b) *Contents.* (1) The safe practices manual shall contain a copy of this standard and the employer's policies for implementing the requirements of this standard.

(2) For each diving mode engaged in, the safe practices manual shall include:

(i) Safety procedures and checklists for diving operations;

(ii) Assignments and responsibilities of the dive team members;

(iii) Equipment procedures and checklists; and

(iv) Emergency procedures for fire, equipment failure, adverse environmental conditions, and medical illness and injury.

(The information collection requirements contained in paragraph (b) were approved by the Office of Management and Budget under control number 1218-0069)

[42 FR 37668, July 22, 1977, as amended at 49 FR 18295, Apr. 30, 1984]

§ 1910.421 Pre-dive procedures.

(a) *General.* The employer shall comply with the following requirements prior to each diving operation, unless otherwise specified.

(b) *Emergency aid.* A list shall be kept at the dive location of the telephone or call numbers of the following:

(1) An operational decompression chamber (if not at the dive location);

(2) Accessible hospitals;

(3) Available physicians;

(4) Available means of transportation; and

(5) The nearest U.S. Coast Guard Rescue Coordination Center.

(c) *First aid supplies.* (1) A first aid kit appropriate for the diving operation and approved by a physician shall be available at the dive location.

(2) When used in a decompression chamber or bell, the first aid kit shall be suitable for use under hyperbaric conditions.

(3) In addition to any other first aid supplies, an American Red Cross standard first aid handbook or equivalent, and a bag type manual resuscitator with transparent mask and tubing shall be available at the dive location.

(d) *Planning and assessment.* Planning of a diving operation shall include an assessment of the safety and health aspects of the following:

(1) Diving mode;

(2) Surface and underwater conditions and hazards;

(3) Breathing gas supply (including reserves);

(4) Thermal protection;

(5) Diving equipment and systems,

(6) Dive team assignments and physical fitness of dive team members (including any impairment known to the employer);

(7) Repetitive dive designation or residual inert gas status of dive team members;

(8) Decompression and treatment procedures (including altitude corrections); and

(9) Emergency procedures.

(e) *Hazardous activities.* To minimize hazards to the dive team, diving operations shall be coordinated with other activities in the vicinity which are likely to interfere with the diving operation.

(f) *Employee briefing.* (1) Dive team members shall be briefed on:

(i) The tasks to be undertaken;

(ii) Safety procedures for the diving mode;

(iii) Any unusual hazards or environmental conditions likely to affect the safety of the diving operation; and

(iv) Any modifications to operating procedures necessitated by the specific diving operation.

(2) Prior to making individual dive team member assignments, the employer shall inquire into the dive team member's current state of physical fitness, and indicate to the dive team member the procedure for reporting physical problems or adverse physiological effects during and after the dive.

(g) *Equipment inspection.* The breathing gas supply system including reserve breathing gas supplies, masks, helmets, thermal protection, and bell handling mechanism (when appropriate) shall be inspected prior to each dive.

(h) *Warning signal.* When diving from surfaces other than vessels in areas capable of supporting marine traffic, a rigid replica of the international code flag "A" at least one meter in height shall be displayed at the dive location in a manner which allows all-round visibility, and shall be illuminated during night diving operations.

(The information collection requirements contained in paragraphs (b)(1) and (b)(5) were approved by the Office of Management and Budget under control number 1218-0058)

[42 FR 37668, July 22, 1977, as amended at 47 FR 14706, Apr. 6, 1982]

§ 1910.422 Procedures during dive.

(a) *General.* The employer shall comply with the following requirements which are applicable to each diving operation unless otherwise specified.

(b) *Water entry and exit.* (1) A means capable of supporting the diver shall be provided for entering and exiting the water.

(2) The means provided for exiting the water shall extend below the water surface.

(3) A means shall be provided to assist an injured diver from the water or into a bell.

(c) *Communications.* (1) An operational two-way voice communication system shall be used between:

(i) Each surface-supplied air or mixed-gas diver and a dive team member at the dive location or bell (when provided or required); and

(ii) The bell and the dive location.

(2) An operational, two-way communication system shall be available at the dive location to obtain emergency assistance.

(d) *Decompression tables.* Decompression, repetitive, and no-decompression tables (as appropriate) shall be at the dive location.

(e) *Dive profiles.* A depth-time profile, including when appropriate any breathing gas changes, shall be maintained for each diver during the dive including decompression.

(f) *Hand-held power tools and equipment.* (1) Hand-held electrical tools and equipment shall be de-energized before being placed into or retrieved from the water.

(2) Hand-held power tools shall not be supplied with power from the dive location until requested by the diver.

(g) *Welding and burning.* (1) A current supply switch to interrupt the current flow to the welding or burning electrode shall be:

(i) Tended by a dive team member in voice communication with the diver performing the welding or burning; and

(ii) Kept in the open position except when the diver is welding or burning.

(2) The welding machine frame shall be grounded.

(3) Welding and burning cables, electrode holders, and connections shall be capable of carrying the maximum current required by the work, and shall be properly insulated.

(4) Insulated gloves shall be provided to divers performing welding and burning operations.

(5) Prior to welding or burning on closed compartments, structures or pipes, which contain a flammable vapor or in which a flammable vapor may be generated by the work, they shall be vented, flooded, or purged with a mixture of gases which will not support combustion.

(h) *Explosives.* (1) Employers shall transport, store, and use explosives in accordance with this section and the applicable provisions of § 1910.109 and § 1926.912 of Title 29 of the Code of Federal Regulations.

(2) Electrical continuity of explosive circuits shall not be tested until the diver is out of the water.

(3) Explosives shall not be detonated while the diver is in the water.

(i) *Termination of dive.* The working interval of a dive shall be terminated when:

(1) A diver requests termination;

(2) A diver fails to respond correctly to communications or signals from a dive team member;

(3) Communications are lost and can not be quickly re-established between the diver and a dive team member at the dive location, and between the designated person-in-charge and the person controlling the vessel in live-boating operations; or

(4) A diver begins to use diver-carried reserve breathing gas or the dive-location reserve breathing gas.

§ 1910.423 Post-dive procedures.

(a) *General.* The employer shall comply with the following requirements which are applicable after each diving operation, unless otherwise specified.

(b) *Precautions.* (1) After the completion of any dive, the employer shall:

(i) Check the physical condition of the diver;

(ii) Instruct the diver to report any physical problems or adverse physiological effects including symptoms of decompression sickness;

(iii) Advise the diver of the location of a decompression chamber which is ready for use; and

(iv) Alert the diver to the potential hazards of flying after diving.

(2) For any dive outside the no-decompression limits, deeper than 100 fsw or using mixed gas as a breathing mixture, the employer shall instruct the diver to remain awake and in the vicinity of the decompression chamber which is at the dive location for at least one hour after the dive (including decompression or treatment as appropriate).

(c) *Recompression capability.* (1) A decompression chamber capable of recompressing the diver at the surface to a minimum of 165 fsw (6 ATA) shall be available at the dive location for:

(i) Surface-supplied air diving to depths deeper than 100 fsw and shallower than 220 fsw;

(ii) Mixed gas diving shallower than 300 fsw; or

(iii) Diving outside the no-decompression limits shallower than 300 fsw.

(2) A decompression chamber capable of recompressing the diver at the surface to the maximum depth of the dive shall be available at the dive location for dives deeper than 300 fsw.

(3) The decompression chamber shall be:

(i) Dual-lock;

(ii) Multiplace; and

(iii) Located within 5 minutes of the dive location.

(4) The decompression chamber shall be equipped with:

(i) A pressure gauge for each pressurized compartment designed for human occupancy;

(ii) A built-in-breathing-system with a minimum of one mask per occupant;

(iii) A two-way voice communication system between occupants and a dive team member at the dive location;

(iv) A viewport; and

(v) Illumination capability to light the interior.

(5) Treatment tables, treatment gas appropriate to the diving mode, and sufficient gas to conduct treatment shall be available at the dive location.

(6) A dive team member shall be available at the dive location during and for at least one hour after the dive to operate the decompression chamber (when required or provided).

(d) *Record of dive.* (1) The following information shall be recorded and maintained for each diving operation:

(i) Names of dive team members including designated person-in-charge;

(ii) Date, time, and location;

(iii) Diving modes used;

(iv) General nature of work performed;

(v) Approximate underwater and surface conditions (visibility, water temperature and current); and

(vi) Maximum depth and bottom time for each diver.

(2) For each dive outside the no-decompression limits, deeper than 100 fsw or using mixed gas, the following additional information shall be recorded and maintained:

(i) Depth-time and breathing gas profiles;

(ii) Decompression table designation (including modification); and

(iii) Elapsed time since last pressure exposure if less than 24 hours or repetitive dive designation for each diver.

(3) For each dive in which decompression sickness is suspected or symptoms are evident, the following additional information shall be recorded and maintained:

(i) Description of decompression sickness symptoms (including depth and time of onset); and

(ii) Description and results of treatment.

(e) *Decompression procedure assessment.* The employer shall:

(1) Investigate and evaluate each incident of decompression sickness based on the recorded information, consideration of the past performance of decompression table used, and individual susceptibility;

(2) Take appropriate corrective action to reduce the probability of recurrence of decompression sickness; and

(3) Prepare a written evaluation of the decompression procedure assessment, including any corrective action taken, within 45 days of the incident of decompression sickness.

(The information collection requirements contained in paragraphs (d) and (e) were approved by the Office of Management and Budget under control number 1218-0069)

[42 FR 37668, July 22, 1977, as amended at 49 FR 18295, Apr. 30, 1984]

Specific Operations Procedures

§ 1910.424 SCUBA diving.

(a) *General.* Employers engaged in

SCUBA diving shall comply with the following requirements, unless otherwise specified.

(b) *Limits.* SCUBA diving shall not be conducted:

(1) At depths deeper than 130 fsw;

(2) At depths deeper than 100 fsw or outside the no-decompression limits unless a decompression chamber is ready for use;

(3) Against currents exceeding one (1) knot unless line-tended; or

(4) In enclosed or physically confining spaces unless line-tended.

(c) *Procedures.*

(1) A standby diver shall be available while a diver is in the water.

(2) A diver shall be line-tended from the surface, or accompanied by another diver in the water in continuous visual contact during the diving operations.

(3) A diver shall be stationed at the underwater point of entry when diving is conducted in enclosed or physically confining spaces.

(4) A diver-carried reserve breathing gas supply shall be provided for each diver consisting of:

(i) A manual reserve (J valve); or

(ii) An independent reserve cylinder with a separate regulator or connected to the underwater breathing apparatus.

(5) The valve of the reserve breathing gas supply shall be in the closed position prior to the dive.

§ 1910.425 Surface-supplied air diving.

(a) *General.* Employers engaged in surface-supplied air diving shall comply with the following requirements, unless otherwise specified.

(b) *Limits.* (1) Surface-supplied air diving shall not be conducted at depths deeper than 190 fsw, except that dives with bottom times of 30 minutes or less may be conducted to depths of 220 fsw.

(2) A decompression chamber shall be ready for use at the dive location for any dive outside the no-decompression limits or deeper than 100 fsw.

(3) A bell shall be used for dives with an inwater decompression time greater than 120 minutes, except when heavy gear is worn or diving is conducted in physically confining spaces.

(c) *Procedures.* (1) Each diver shall be continuously tended while in the water.

(2) A diver shall be stationed at the underwater point of entry when diving is conducted in enclosed or physically confining spaces.

(3) Each diving operation shall have a primary breathing gas supply sufficient to support divers for the duration of the planned dive including decompression.

(4) For dives deeper than 100 fsw or outside the no-decompression limits:

(i) A separate dive team member shall tend each diver in the water;

(ii) A standby diver shall be available while a diver is in the water;

(iii) A diver-carried reserve breathing gas supply shall be provided for each diver except when heavy gear is worn; and

(iv) A dive-location reserve breathing gas supply shall be provided.

(5) For heavy-gear diving deeper than 100 fsw or outside the no-decompression limits:

(i) An extra breathing gas hose capable of supplying breathing gas to the diver in the water shall be available to the standby diver.

(ii) An inwater stage shall be provided to divers in the water.

(6) Except when heavy gear is worn or where physical space does not permit, a diver-carried reserve breathing gas supply shall be provided whenever the diver is prevented by the configuration of the dive area from ascending directly to the surface.

§ 1910.426 Mixed-gas diving.

(a) *General.* Employers engaged in mixed-gas diving shall comply with the following requirements, unless otherwise specified.

(b) *Limits.* Mixed-gas diving shall be conducted only when:

(1) A decompression chamber is ready for use at the dive location; and

(i) A bell is used at depths greater than 220 fsw or when the dive involves inwater decompression time of greater than 120 minutes, except when heavy gear is worn or when diving in physically confining spaces; or

(ii) A closed bell is used at depths greater than 300 fsw, except when diving is conducted in physically confining spaces.

(c) *Procedures.* (1) A separate dive team member shall tend each diver in the water.

(2) A standby diver shall be available while a diver is in the water.

(3) A diver shall be stationed at the underwater point of entry when diving is conducted in enclosed or physically confining spaces.

(4) Each diving operation shall have a primary breathing gas supply sufficient to support divers for the duration of the planned dive including decompression.

(5) Each diving operation shall have a dive-location reserve breathing gas supply.

(6) When heavy gear is worn:

(i) An extra breathing gas hose capable of supplying breathing gas to the diver in the water shall be available to the standby diver; and

(ii) An inwater stage shall be provided to divers in the water.

(7) An inwater stage shall be provided for divers without access to a bell for dives deeper than 100 fsw or outside the no-decompression limits.

(8) When a closed bell is used, one dive team member in the bell shall be available and tend the diver in the water.

(9) Except when heavy gear is worn or where physical space does not permit, a diver-carried reserve breathing gas supply shall be provided for each diver:

(i) Diving deeper than 100 fsw or outside the no-decompression limits; or

(ii) Prevented by the configuration of the dive area from directly ascending to the surface.

§ 1910.427 Liveboating.

(a) *General.* Employers engaged in diving operations involving liveboating shall comply with the following requirements.

(b) *Limits.* Diving operations involving liveboating shall not be conducted:

(1) With an inwater decompression time of greater than 120 minutes;

(2) Using surface-supplied air at depths deeper than 190 fsw, except that dives with bottom times of 30 minutes or less may be conducted to depths of 220 fsw;

(3) Using mixed gas at depths greater than 220 fsw;

(4) In rough seas which significantly impede diver mobility or work function; or

(5) In other than daylight hours.

(c) *Procedures.* (1) The propeller of the vessel shall be stopped before the diver enters or exits the water.

(2) A device shall be used which minimizes the possibility of entanglement of the diver's hose in the propeller of the vessel.

(3) Two-way voice communication between the designated person-in-charge and the person controlling the vessel shall be available while the diver is in the water.

(4) A standby diver shall be available while a diver is in the water.

(5) A diver carried reserve breathing gas supply shall be carried by each diver engaged in liveboating operations.

Equipment Procedures and Requirements

§ 1910.430 Equipment.

(a) *General.* (1) All employers shall comply with the following requirements, unless otherwise specified.

(2) Each equipment modification, repair, test, calibration or maintenance service shall be recorded by means of a tagging or logging system, and include the date and nature of work performed, and the name or initials of the person performing the work.

(b) *Air compressor system.* (1) Compressors used to supply air to the diver shall be equipped with a volume tank with a check valve on the inlet side, a pressure gauge, a relief valve, and a drain valve.

(2) Air compressor intakes shall be located away from areas containing exhaust or other contaminants.

(3) Respirable air supplied to a diver shall not contain:

(i) A level of carbon monoxide (CO) greater than 20 p/m;

(ii) A level of carbon dioxide (CO_2) greater than 1,000 p/m;

(iii) A level of oil mist greater than 5 milligrams per cubic meter; or

(iv) A noxious or pronounced odor.

(4) The output of air compressor systems shall be tested for air purity every 6 months by means of samples taken at the connection to the distribution system, except that non-oil lubricated compressors need not be tested for oil mist.

(c) *Breathing gas supply hoses.* (1) Breathing gas supply hoses shall:

(i) Have a working pressure at least equal to the working pressure of the total breathing gas system;

(ii) Have a rated bursting pressure at least equal to 4 times the working pressure;

(iii) Be tested at least annually to 1.5 times their working pressure; and

(iv) Have their open ends taped, capped or plugged when not in use.

(2) Breathing gas supply hose connectors shall:

(i) Be made of corrosion-resistant materials;

(ii) Have a working pressure at least equal to the working pressure of the hose to which they are attached, and

(iii) Be resistant to accidental disengagement.

(3) Umbilicals shall:

(i) Be marked in 10-ft. increments to 100 feet beginning at the diver's end, and in 50 ft. increments thereafter;

(ii) Be made of kink-resistant materials; and

(iii) Have a working pressure greater than the pressure equivalent to the maximum depth of the dive (relative to the supply source) plus 100 psi.

(d) *Buoyancy control.* (1) Helmets or masks connected directly to the dry suit or other buoyancy-changing equipment shall be equipped with an exhaust valve.

(2) A dry suit or other buoyancy-changing equipment not directly connected to the helmet or mask shall be equipped with an exhaust valve.

(3) When used for SCUBA diving, a buoyancy compensator shall have an inflation source separate from the breathing gas supply.

(4) An inflatable flotation device capable of maintaining the diver at the surface in a face-up position, having a manually activated inflation source independent of the breathing supply, an oral inflation device, and an exhaust valve shall be used for SCUBA diving.

(e) *Compressed gas cylinders.* Compressed gas cylinders shall:

(1) Be designed, constructed and maintained in accordance with the applicable provisions of 29 CFR 1910.101 and 1910.169 through 1910.171.

(2) Be stored in a ventilated area and protected from excessive heat;

(3) Be secured from falling; and

(4) Have shut-off valves recessed into the cylinder or protected by a cap, except when in use or manifolded, or when used for SCUBA diving.

(f) *Decompression chambers.* (1) Each decompression chamber manufactured after the effective date of this standard, shall be built and maintained in accordance with the ASME Code or equivalent.

(2) Each decompression chamber manufactured prior to the effective date of this standard shall be maintained in conformity with the code requirements to which it was built, or equivalent.

(3) Each decompression chamber shall be equipped with:

(i) Means to maintain the atmosphere below a level of 25 percent oxygen by volume;

(ii) Mufflers on intake and exhaust lines, which shall be regularly inspected and maintained;

(iii) Suction guards on exhaust line openings; and

(iv) A means for extinguishing fire, and shall be maintained to minimize sources of ignition and combustible material.

(g) *Gauges and timekeeping devices.* (1) Gauges indicating diver depth which can be read at the dive location shall be used for all dives except SCUBA.

(2) Each depth gauge shall be deadweight tested or calibrated against a master reference gauge every 6 months, and when there is a discrepancy greater than two percent (2 percent) of full scale between any two equivalent gauges.

(3) A cylinder pressure gauge capable of being monitored by the diver during the dive shall be worn by each SCUBA diver.

(4) A timekeeping device shall be available at each dive location.

(h) *Masks and helmets.* (1) Surface-supplied air and mixed-gas masks and helmets shall have:

(i) A non-return valve at the attachment point between helmet or mask and hose which shall close readily and positively; and

(ii) An exhaust valve.

(2) Surface-supplied air masks and helmets shall have a minimum ventilation rate capability of 4.5 acfm at any depth at which they are operated or the capability of maintaining the diver's inspired carbon dioxide partial pressure below 0.02 ATA when the diver is producing carbon dioxide at the rate of 1.6 standard liters per minute.

(i) *Oxygen safety.* (1) Equipment used with oxygen or mixtures containing over forty percent (40%) by volume oxygen shall be designed for oxygen service.

(2) Components (except umbilicals) exposed to oxygen or mixtures containing over forty percent (40%) by volume oxygen shall be cleaned of flammable materials before use.

(3) Oxygen systems over 125 psig and compressed air systems over 500 psig shall have slow opening shut off valves.

(j) *Weights and harnesses.* (1) Except when heavy gear is worn, divers shall be equipped with a weight belt or assembly capable of quick release.

(2) Except when heavy gear is worn or in SCUBA diving, each diver shall wear a safety harness with:

(i) A positive buckling device;

(ii) An attachment point for the umbilical to prevent strain on the mask or helmet; and

(iii) A lifting point to distribute the pull force of the line over the diver's body.

(The information collection requirements contained in paragraph (a)(2) were approved by the Office of Management and Budget under control number 1218 0069)

(39 FR 23502, June 27, 1974, as amended at 49 FR 18295, Apr. 30, 1984; 51 FR 33033, Sept. 18, 1986)

RECORDKEEPING

§ 1910.440 Recordkeeping requirements.

(a) [Reserved]

(2) The employer shall record the occurrence of any diving-related injury or illness which requires any dive team member to be hospitalized for 24 hours or more, specifying the circumstances of the incident and the extent of any injuries or illnesses.

(b) *Availability of records.* (1) Upon the request of the Assistant Secretary of Labor for Occupational Safety and Health, or the Director, National Institute for Occupational Safety and Health, Department of Health, Education and Welfare of their designees, the employer shall make available for inspection and copying any record or document required by this standard.

(2) Records and documents required by this standard shall be provided upon request to employees, designated representatives, and the Assistant Secretary in accordance with 29 CFR 1910.20 (a)-(e) and (g)-(i). Safe practices manuals (§ 1910.420), depth-time profiles (§ 1910.422), recordings of dives (§ 1910.423), decompression procedure assessment evaluations (§ 1910.423), and records of hospitalizations (§ 1910.440) shall be provided in the same manner as employee exposure records or analyses using exposure or medical records. Equipment inspections and testing records which pertain to employees (§ 1910.430) shall also be provided upon request to employees and their designated representatives.

(3) Records and documents required by this standard shall be retained by the employer for the following period:

(i) Dive team member medical records (physician's reports) (§ 1910.411)—5 years;

(ii) Safe practices manual (§ 1910.420)—current document only;

(iii) Depth-time profile (§ 1910.422) until completion of the recording of dive, or until completion of decompression procedure assessment where there has been an incident of decompression sickness;

(iv) Recording of dive (§ 1910.423)—1 year, except 5 years where there has been an incident of decompression sickness;

(v) Decompression procedure assessment evaluations (§ 1910.423)—5 years;

(vi) Equipment inspections and testing records (§ 1910.430)—current entry or tag, or until equipment is withdrawn from service;

(vii) Records of hospitalizations (§ 1910.440)—5 years.

(4) After the expiration of the retention period of any record required to be kept for five (5) years, the employer shall forward such records to the National Institute for Occupational Safety and Health, Department of Health and Human Services. The employer shall also comply with any additional requirements set forth at 29 CFR 1910.20(h).

(5) In the event the employer ceases to do business:

(i) The successor employer shall receive and retain all dive and employee medical records required by this standard; or

(ii) If there is no successor employer, dive and employee medical records shall be forwarded to the National Institute for Occupational Safety and Health, Department of Health, Education, and Welfare.

(Approved by the Office of Management and Budget under control number 1218 0058)

(42 FR 37668, July 22, 1977, as amended at 45 FR 35281, May 23, 1980; 47 FR 14706, Apr. 6, 1982; 51 FR 34562, Sept. 29, 1986)

§ 1910.441 Effective date.

This standard shall be effective on October 20, 1977, except that for provisions where decompression chambers or bells are required and such equipment is not yet available, employers shall comply as soon as possible thereafter but in no case later than [illegible] months after the effective date of the standard.

APPENDIX A—EXAMPLES OF CONDITIONS WHICH MAY RESTRICT OR LIMIT EXPOSURE TO HYPERBARIC CONDITIONS

The following disorders may restrict or limit occupational exposure to hyperbaric conditions depending on severity, presence of residual effects, response to therapy, number of occurrences, diving mode, or degree and duration of isolation.

History of seizure disorder other than early febrile convulsions.

Malignancies (active) unless treated and without recurrence for 5 yrs.

Chronic inability to equalize sinus and/or middle ear pressure.

Cystic or cavitary disease of the lungs.

Impaired organ function caused by alcohol or drug use.

Conditions requiring continuous medication for control (e.g., antihistamines, steroids, barbiturates, moodaltering drugs, or insulin).

Meniere's disease.

Hemoglobinopathies.

Obstructive or restrictive lung disease.

Vestibular end organ destruction.

Pneumothorax.

Cardiac abnormalities (e.g., pathological heart block, valvular disease, intraventricular conduction defects other than isolated right bundle branch block, angina pectoris, arrhythmia, coronary artery disease).

Juxta-articular osteonecrosis.

APPENDIX B—GUIDELINES FOR SCIENTIFIC DIVING

This appendix contains guidelines that will be used in conjunction with § 1910.401(a)(2)(iv) to determine those scientific diving programs which are exempt from the requirements for commercial diving. The guidelines are as follows:

1. The Diving Control Board consists of a majority of active scientific divers and has autonomous and absolute authority over the scientific diving program's operations.

2. The purpose of the project using scientific diving is the advancement of science; therefore, information and data resulting from the project are non-proprietary.

3. The tasks of a scientific diver are those of an observer and data gatherer. Construction and trouble-shooting tasks traditionally associated with commercial diving are not included within scientific diving.

4. Scientific divers, based on the nature of their activities, must use scientific expertise in studying the underwater environment and, therefore, are scientists or scientists in training.

[50 FR 1050, Jan. 9, 1985]

SAMPLE SCOPE OF WORK

I. Introduction

This statement of work is intended to describe the scope of work of the Firm in providing the engineering and inspection services for the preparation of underwater Bridge Inspection Reports for the structures listed herein. It also provides schedules for the different tasks, and other contractual obligations of the Firm and the Agency.

II. Project

Underwater Bridge Inspections for, 25 bridges, agency wide.

III. Location and Description

The project consists of 25 bridges, listed on the attached "Exhibit A", located in regions throughout the Agencie's area of responsibility. These bridges are owned and maintained by the Agency.

IV. Scope of Work

All work performed under this contract shall be in accordance with the National Bridge Inspection Standard and the Manual for Maintenance Inspection of Bridges issued by AASHTO. All diving operations shall be conducted in conformance with the requirements of Subpart T, Commercial Diving Operations, Occupational Safety and Health Administration Standards. The Firm shall supply at his own expense, all equipment, labor, licenses, permits, and insurance necessary for the completion of this contract.

V. Underwater Inspection

A. Underwater Inspection - The Firm shall perform a thorough visual and tactile inspection of each structure listed on Exhibit A, and identify the substructure and foundation deficiencies, and the need for any indepth inspections that may be required as a result of suspected deficiencies that cannot be identified by visual/tactile inspection. Ten percent of the structure elements shall be well cleaned of any marine growth to facilitate the inspection. Piles shall be cleaned in bands approximately one foot wide at the waterline, mudline and midheight. Piers, abutments, etc. shall have one foot square areas cleaned at the nose, sides and tail at the waterline, mudline and midheight. In-depth investigations are not part of this contract. Once identified, a separate contract may be developed to address these needs.

B. The inspection of substructure and foundation elements shall extend from the waterline to the mudline and include, but not be limited to the following:

   a. Concrete Pile and/or Solid Piers: Check all concrete for erosion, wear, abrasion, scaling, spalling, exposure and deterioration of any exposed reinforcing steel, and all cracking.

   b. Steel Pile and/or Steel Encased Piers: Check all steel for corrosion, misalignment, and loss of section.

   c. Timber Pile and/or Crib Piers: Check all timber for vermin such as marine borer, shipworm attack, termites, and powder-post beetles, etc.; for evidence of fungus decay; for damage by collision or overstressing; and for excessive weathering. All timber shall be sounded and probed with a heavy duty 6 inch (min.) blade icepick or awl.

   d. Dolphins and Fenders: Examine for same deterioration as substructure units.

C. The inspection shall include depth soundings around each pier, along the fascia, and at 100' and 200' intervals upstream and downstream. Soundings shall be obtained using a continuous reading strip chart fathometer unless water conditions preclude use of a boat, in which case sounding poles or lead lines may be utilized. Elevations shall be referenced to a point of know elevations, such as a bridge seat.

The channel bottom, particularly around piers or abutments, shall be probed and the presence, size and condition of any riprap shall be noted.

D. Still color photography shall be utilized to document underwater conditions. A "clear water" box shall be available on site for use if needed to secure photographs.

E. If, in the opinion of the Inspection Team Leader, a dangerous or critical situation exists, he shall immediately notify _______________, Bridge Engineer, at _________, of the situation and follow up with an accurate written report.

VI. Schedule

The Firm shall submit a proposed schedule of inspections to the Agency, at least 5 days prior to commencement of inspection work. The Firm shall also inform the Agency of any changes to the proposed schedule.

VII. Personnel

Qualifications of inspection personnel shall conform to the requirements of the NBIS and the following:

A. The Engineer in charge of the inspection and preparation of the inspection report must possess the following minimum qualifications:

   1. Be a registered professional engineer in the state where the bridges are located.

   2. Have a minimum of 5 years experience in underwater structure inspection assignments in a responsible capacity.

   3. Be a certified diver by a recognized diving authority.

B. The diver(s) who will perform the underwater inspection shall meet the qualifications as a bridge inspector in accordance with the NBIS requirements and be a certified diver, with at least two years experience in underwater bridge inspection.

The Firm shall submit for approval a detailed resume of each inspection team member.

VIII. Report

A separate report shall be prepared for each bridge inspected. The report shall include a description of the condition of the bridge units inspected and the adjacent channel bottom. Recommendations for repairs or further investigations shall be included as appropriate.

The report shall include plots of the channel bottom elevations and original color photographs, clearly labeled. Two copies of the report, signed by the registered professional engineer responsible for the inspection, shall be submitted.

The inspection team shall also complete appropriate sections of bridge rating forms if so furnished by the Agency.

IX. Insurance

Before starting work, the Firm shall submit evidence of the required insurance coverages.

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GLOSSARY

A

Abutment. A substructure unit composed of stone, concrete, brick, or timber supporting the end of a single span or the extreme end of a multispan superstructure, and, in general, retaining or supporting the approach embankment placed in contact therewith. (See also WING WALL.)

Aggregate. The sand, gravel, broken stone, or combinations thereof with which the cementing material is mixed to form a mortar or concrete. The fine material used to produce mortar for stone and brick masonry and for the mortar component of concrete is commonly termed "fine aggregate" while the coarse material used in concrete only is termed "coarse aggregate."

Anode. A metallic surface on which oxidation occurs, giving up electrons with metal ions going into solution or forming an insoluble compound of the metal.

Apron. A waterway bed protection consisting of timber, concrete, riprap, paving or other construction placed adjacent to substructure abutments and piers to prevent undermining by scour.

Ascent Time. The time interval between leaving the deepest point of the dive and returning to the surface

B

Backfill. Material placed adjacent to an abutment, pier, retaining wall or other structure or part of a structure to fill the unoccupied portion of the foundation excavation.

Soil, usually granular, placed behind and within the abutment and wingwalls.

Backwater. The water of a stream retained at an elevation above its normal level through the controlling effect of a condition existing at a downstream location such as a flood, an ice jam or other obstruction.

The increase in the elevation of the water surface above normal produced primarily by the stream width contraction beneath a bridge. The wave-like effect is most pronounced at and immediately upstream from an abutment or pier but extends downstream to a location beyond the body of the substructure part.

Base Metal, Structure Metal, Parent Metal. The metal at and closely adjacent to the surface to be incorporated in a welded joint which will be fused, and by coalescence and interdiffusion with the weld will produce a welded joint.

Batter. The inclination of a surface in relation to a horizontal or vertical plane or occasionally in relation to an inclined plane. Batter is commonly designated upon bridge detail plans as so many inches to one foot.

Batter Pile. A pile driven in an inclined position to resist forces which act in other than a vertical direction. It may be computed to withstand these forces or, instead, may be used as a subsidiary part or portion of a structure to improve its general rigidity.

Bearing Seat. Top of masonry supporting bridge bearing.

Bed Load. Sediment that moves by rolling, sliding, or skipping along the bed and is essentially in contact with the streambed.

Bed Rock. (Ledge Rock.) A natural mass formation of igneous, sedimentary, or metamorphic rock material either outcropping upon the surface, uncovered in a foundation excavation, or underlying an accumulation of unconsolidated earth material.

Bent. A supporting unit of a trestle or a viaduct type structure made up of two or more column or column-like members connected at their topmost ends by a cap, strut, or other member holding them in their correct positions. This connecting member is commonly designed to distribute the superimposed loads upon the bent, and when combined with a system of diagonal and horizontal bracing attached to the columns, the entire construction functions somewhat like a truss distributing its loads into the foundation.

When piles are used as the column elements, the entire construction is designated a "pile bent" and, correspondingly, when those elements are framed, the assemblage is termed a "frame bent."

Berm. (Berme.) The line, whether straight or curved, which defines the location where the top surface of an approach embankment or causeway is intersected by the surface of the side slope. This term is synonymous with "Roadway Berm."

A horizontal bench located at the toe of slope of an approach cut, embankment or causeway to strengthen and secure its underlaying material against sliding or other displacement into an adjacent ditch, borrow pit, or other artificial or natural lower lying area.

Blanket. A protection against stream scour placed adjacent to abutments and piers, and covering the streambed for a distance from these structures considered adequate for the stream flow and streambed conditions. The streambed covering commonly consists of a deposit of stones of varying sizes which, in combination, will resist the scour forces. A second type consists of a timber framework so constructed that it can be ballasted and protected from displacement by being loaded with stones or with pieces of wrecked concrete structures or other adaptable ballasting material.

Bottom Time. The total elapsed time measured in minutes from the time when the diver leaves the surface in descent to the time that the diver begins ascent.

Bracing. A system of tension or compression members, or a combination of these, forming with the part or parts to be supported or strengthened, a truss or frame. It transfers wind, dynamic, impact, and vibratory stresses to the substructure and gives rigidity throughout the complete assemblage.

Breathing Mixture. Air or a mixture of gases breathed by a diver which contains a physiologically appropriate proportion of oxygen.

Breast Wall. (Face Wall, Stem.) The portion of an abutment between the wings and beneath the bridge seat. The breast wall supports the superstructure loads, and retains the approach fill.

Bridge Pad. The raised, levelled area upon which the pedestal, shoe, sole, plate or other corresponding element of the superstructure takes bearing by contact. Also called Bridge Seat Bearing Area.

Bridge Seat. The top surface of an abutment or pier upon which the superstructure span is placed and supported. For an abutment it is the surface forming the support for the superstructure and from which the backwall rises. For a pier it is the entire top surface.

Bulkhead. 1. A retaining wall-like structure commonly composed of driven piles supporting a wall or a barrier of wooden timbers or reinforced concrete members functioning as a constraining structure resisting the thrust of earth or other material bearing against the assemblage. 2. A retaining wall-like structure composed of timber, steel, or reinforced concrete members commonly assembled to form a barrier held in a vertical or an inclined position by members interlocking therewith and extending into the restrained material to obtain the anchorage necessary to prevent both sliding and overturning of the entire assemblage.

Butt Weld. A weld joining two abutting surfaces by depositing weld metal within an intervening space. This weld serves to unite the abutting surfaces of the elements of a member or to join members or their elements abutting upon or against each other.

C

Cap. (Cap Beam, Cap Piece.) The topmost piece or member of a viaduct, trestle, or frame bent serving to distribute the loads upon the columns and to hold them in their proper relative positions.

The topmost piece or member of a pile bent in a viaduct or trestle serving to distribute the loads upon the piles and to hold them in their proper relative positions.

Capillary Action. The process by which water is drawn from a wet area to a dry area through the pores of a material.

Capstone. 1. The topmost stone of a masonry pillar, column or other structure requiring the use of a single capping element. 2. One of the stones used in the construction of a stone parapet to make up its topmost or "weather" course. Commonly this course projects on both the inside and outside beyond the general surface of the courses below it.

Cathode. A surface that accepts electrons and does not corrode.

Cement Paste. The plastic combination of cement and water that supplies the cementing action in concrete.

Cement Matrix. The binding medium in a mortar or concrete produced by the hardening of the cement content of the mortar, concrete mixture of inert aggregates, or hydraulic cement and water.

Channel Profile. Longitudinal section of a channel.

Cofferdam. In general, an open box-like structure constructed to surround the area to be occupied by an abutment, pier, retaining wall or other structure and permit unwatering of the enclosure so that the excavation for the preparation of a foundation and the abutment, pier, or other construction may be effected in the open air. In its simplest form, the dam consists of interlocking steel sheet piles.

Commercial Diver. A person who receives renumeration for diving activities.

Concrete. A composite material consisting essentially of a binding medium within which are embedded particles or fragments of a relatively inert mineral filler. In portland cement concrete, the binder or matrix, either in the plastic or the hardened state, is a combination of portland cement and water. The filler material, called aggregate, is generally graded in size from fine sand to pebbles or stones which may, in some concrete, be several inches in diameter.

Consolidation. The time-dependent change in volume of a soil mass under compressive load caused by pore-water slowly escaping from the pores or voids of the soil. The soil skeleton is unable to support the load by itself and changes structure, reducing its volume and usually producing vertical settlements.

Continuous Spans. A beam, girder, or truss type superstructure designed to extend continuously over one or more intermediate supports.

Creep. An inelastic deformation that increases with time while the stress is constant.

Cribbing. A construction consisting of wooden, metal or reinforced concrete units so assembled as to form an open cellular-like structure for supporting a superimposed load or for resisting horizontal or overturning forces acting against it.

Cylinder. A pressure vessel for the storage of gases.

D

Decompression. The reduction of environmental or ambient pressure to atmospheric pressure.

Decompression Chamber. A pressure vessel for human occupancy such as a surface decompression chamber, closed bell, or deep diving system used to decompress divers and to treat decompression sickness.

Decompression Schedule. A time-depth profile with a specified bottom time and depth, whose application is calculated to reduce the pressure on a diver safely.

Decompression Sickness. A condition with a variety of symptoms which may result from the formation of gas or gas bubbles in the blood or other tissues of divers during or subsequent to ascent or other pressure reduction. Residual audio-vesticular or neurological symptoms involve permanent damage to the hearing or balance system, or to the peripheral or central nervous system, respectively. Serious symptoms involve the sensory or neurological systems significantly, and include numbness, paralysis, visual and hearing disturbances, choking, shock, and unconsciousness. Pain-only symptoms are limited to localized joint and muscle pain, minor muscle weakness and skin itching, tingling, or redness. Pain-only symptoms which recur during or after recompression therapy are classified as serious symptoms.

Debris. Any material including floating woody materials and other trash, suspended sediment, or bed load, moved by a flowing stream.

Degradation. General, progressive lowering of the stream channel by erosion.

Diaphragm Wall (cross wall). A wall built transversely to the longitudinal centerline of a spandrel arch serving to tie together and reinforce the spandrel walls together with providing a support for the floor system in conjunction with the spandrel walls. To provide means for the making of inspections the diaphragms of an arch span may be provided with manholes.

The division walls of a reinforced concrete caisson dividing its interior space into compartments and reinforcing its walls. A wall serving to subdivide a box-like structure or portion of a structure into two or more compartments, or sections.

Dike. (Dyke). An earthen embankment constructed to provide a barrier to the inundation of an adjacent area which it encloses entirely or in part.

When used in conjunction with a bridge, its functions are commonly those of preventing stream erosion and localized scour and/or to so direct the stream current that debris will not accumulate upon bottom land adjacent to approach embankments, abutments, piers, towers, or other portions of the structure.

This term is occasionally misapplied to crib construction used to accomplish a like result.

Spur Dike. A projecting jetty-like construction placed adjacent to an abutment of the "U," "T," block or arched type upon the upstream and downstream sides, but sometimes only on the upstream side, to secure a gradual contraction of the stream width and induce a free, even flow of water adjacent to, and beneath a bridge. They may be constructed in extension of the wing wall or a winged abutment.

The common types of construction used for water wings are: (1) Wooden cribs filled with stones; (2) embankments riprapped on the waterway side; and (3) wooden and metal sheet piling.

Spur dikes serve to prevent stream scour and undermining of the abutment foundation, and to relieve the condition which otherwise would tend to gather and hold accumulations of stream debris and adjacent to the upstream side of the abutment.

Dimension Stone. A stone of relatively large dimensions, the face surface of which is either chisel or margin drafted but otherwise rough and irregular; commonly called either "rock face" or "quarry face."

Stones quarried with the dimensions large enough to provide cut stones with given finished dimensions.

Diver. An employee engaged in work using underwater apparatus which supplies compressed breathing gas at ambient pressure from a self-contained or remote source.

Dolphin. A group or cluster of piles driven in one to two circles about a center pile and drawn together at their top ends around the center pile to form a buffer or guard for the protection of channel span piers or other portions of a bridge exposed to possible injury by collision with waterbound traffic. The tops of the piles are secured with a wrapping consisting of several plies of wire, rope, coil, twist link, or stud link anchor chain, which, by being fastened at its ends only, renders itself taut by the adjustments of the piles resulting from service contact with ships, barges, or other craft. The center pile may project above the others to serve as a bollard for restraining and guiding the movements of water-borne traffic units. Single steel and concrete piles of large size may also be used as dolphins.

Dry Suit (variable volume). A diving suit capable of being inflated for buoyancy or insulation which keeps the diver's body essentially dry.

E

Efflorescence. A white deposit on concrete or brick caused by crystallization of soluble salts brought to the surface by moisture in the masonry.

Electrolyte. Moisture or a liquid carrying ionic current between two metal surfaces, the anode and the cathode.

Element. Metal Structures. An angle, beam, plate or other rolled, forged or cast piece of metal forming a part of a built piece. For wooden structures, a board, plank, joist, or other fabricated piece forming a part of a built piece.

Epoxy. A synthetic resin which cures or hardens by chemical reaction between components which are mixed together shortly before use.

Erosion. (Stream) Wearing away of the streambed by flowing water.

F

Factor of Safety. A factor or allowance predicated by common engineering practice upon the failure stress or stresses assumed to exist in a structure or a member or part thereof. Its purpose is to provide a margin in the strength, rigidity, deformation and endurance of a structure or its component parts compensating for irregularities existing in structural materials and workmanship, uncertainties involved in mathematical analysis and stress distribution, service deterioration and other unevaluated conditions.

Falsework. A temporary wooden or metal framework built to support without appreciable settlement and deformation the weight of a structure during the period of its construction and until it becomes self-supporting. In general, the arrangement of its details are devised to facilitate the construction operations and provide for economical removal and the salvaging of material suitable for reuse.

Fascia. An outside, covering member designed on the basis of architectural effect rather than strength and rigidity although its function may involve both.

Fascia Girder. An exposed outermost girder of a span sometimes treated architecturally or otherwise to provide an attractive appearance.

Fender. 1. A structure placed at an upstream location adjacent to a pier to protect it from the striking force, impact and shock of floating stream debris, ice floes, etc. This structure is sometimes termed an "ice guard" in latitudes productive of lake and river ice to form ice flows. 2. A structure commonly consisting of dolphins, capped and braced rows of piles, or wooden cribs either entirely or partially filled with rock ballast, constructed upstream and downstream from the center and end piers (or abutments) of a fixed or movable superstructure span to fend off water-borne traffic from collision with these substructure parts, and in the case of a swing span, with the span while in its open position.

Fender Pier. A pier-like structure which performs the same service as a fender but is generally more substantially built. These structures may be constructed entirely or in part of stone or concrete masonry.

Fill. (Filling.) Material, usually earth, used for the purpose of raising or changing the surface contour of an area, or for constructing an embankment.

Filler Metal. Metal prepared in wire, rod, electrode or other adaptable form to be fused with the structure metal in the formation of a weld.

Flange. The part of a rolled I-shaped beam or of a built-up girder extending transversely across the top and bottom edges of the web. The flanges are considered to carry the compressive and tensile forces that comprise the internal resisting moment of the beam, and may consist of angles, plates, or both.

Floating Bridge. In general, this term means the same as "Pontoon Bridge." However, its parts providing buoyancy and supporting power may consist of logs or squared timbers, held in position by lashing pieces, chains or ropes, and floored over with planks, or the bridge itself may be of hollow cellular construction.

Flood Frequency. The average time interval in years in which a flow of a given magnitude, taken from an infinite series, will recur.

Footing. (Footing Course, Plinth.) The enlarged, or spread-out lower portion of a substructure, which distributes the structure load either to the earth or to supporting piles. The most common footing is the concrete slab, although stone piers also utilize footings. Plinth refers to stone work as a rule. "Footer" is a local term for footing.

Forms. (Form Work, Lagging, Shuttering.) The constructions, either wooden or metal, providing means for receiving, molding and sustaining in position the plastic mass of concrete placed therein to the dimensions, outlines and details of surfaces planned for its integral parts throughout its period of hardening.

The terms "forms" and "form work" are synonymous. The term "lagging" is commonly applied to the surface shaping areas of forms producing the intradoses of arches or other curved surfaces, especially when strips are used.

Foundation. The supporting material upon which the substructure portion of a bridge is placed. A foundation is "natural" when consisting of natural earth, rock or near-rock material having stability adequate to support the superimposed loads without lateral displacement or compaction entailing appreciable settlement or deformation. Also, applied in an imprecise fashion to a substructure unit.

Pile or Piled Foundation. A foundation reinforced by driving piles in sufficient number and to a depth adequate to develop the bearing power required to support the foundation load.

Foundation Grillage. A construction consisting of steel, timber, or concrete members placed in layers. Each layer is normal to those above and below it and the members within a layer are generally parallel, producing a crib or grid-like effect. Grillages are usually placed under very heavy concentrated loads.

Foundation Load. The load resulting from traffic, superstructure, substructure, approach embankment, approach causeway, or other incidental load increment imposed upon a given foundation area.

Foundation Pile. A pile, whether of wood, reinforced concrete, or metal used to reinforce a foundation and render it satisfactory for the supporting of superimposed loads.

Foundation Seal. A mass of concrete placed underwater within a cofferdam for the base portion of an abutment, pier, retaining wall or other structure to close or seal the cofferdam against incoming water from foundation springs, fissures, joints or other water carrying channels.

Foundation Stone. The stone or one of the stones of a course having contact with the foundation of a structure.

FSW. A foot of seawater; a unit of pressure generally defined as 1/33 of a standard atmosphere, which represents the pressure exerted by a foot of seawater having a specific gravity of 1.027, equal to approximately .445 pounds per square inch.

G

Grillage. A platform-like construction or assemblage used to insure distribution of loads upon unconsolidated soil material.

Grout. A mortar having a sufficient water content to render it a free-flowing mass, used for filling (grouting) the interstitial spaces between the stones or the stone fragments (spalls) used in the "backing" portion of stone masonry; for fixing anchor bolts and for filling cored spaces in castings, masonry, or other spaces where water may accumulate.

Guard Pier. (Fender Pier.) A pier-like structure built at right angles with the alignment of a bridge or at an angle therewith conforming to the flow of the stream current and having adequate length, width, and other provisions to protect the swing span in its open position from collision with passing vessels or other water-borne equipment and materials. It also serves to protect the supporting center pier of the swing-span from injury and may or may not be equipped with a rest pier upon which the swing span in its open position may be latched. The type of construction varies with navigation and stream conditions from a simple pile and timber structure or a wooden crib-stone ballasted structure to a solid masonry one, or to a combination construction. In locations where ice floes or other water-borne materials may accumulate upon the upstream pier end, a cutwater or a starling is an essential detail.

H

H-Beam. (H-Pile.) A rolled steel bearing pile having an H-shaped cross section.

Head. A measure of water pressure expressed in terms of an equivalent weight or pressure exerted by a column of water. The height of the equivalent column of water is the head.

Heavy Gear Diving. Diving which uses standard deep sea dress, including helmet and brass breastplate, suit of rubberized canvas, and heavy weighted shoes.

Helmet. **(open-circuit and/or surface-supplied)** Breathing and protective equipment which encloses the diver's head.

Hyperbaric Conditions. Pressure conditions in excess of surface pressure (1 ATA).

M

Mask. **(open-circuit and/or surface-supplied)** Breathing and protective equipment which covers a diver's face.

Masonry. A general term applying to abutments, piers, retaining walls, arches and allied structures built of stone, brick or concrete and known correspondingly as stone, brick or concrete masonry.

Meander. The tortuous channel that characterizes the serpentine curvature of a slow flowing stream in a flood plain.

Mortar. An intimate mixture, in a plastic condition, of cement, or other cementitious material with fine aggregate and water, used to bed and bind together the quarried stones, bricks, or other solid materials composing the major portion of a masonry construction or to produce a plastic coating upon such construction.

The indurated jointing material filling the interstices between and holding in place the quarried stones or other solid materials of masonry construction. Correspondingly, this term is applied to the cement coating used to produce a desired surface condition upon masonry constructions and is described as the "mortar finish," "mortar coat," "floated face or surface," "parapet," etc.

The component of concrete composed of cement, or other indurating material with sand and water when the concrete is a mobile mass and correspondingly this same component after it has attained a rigid condition through hardening of its cementing constituents.

N

No-decompression Diving. Diving which involves depths and times shallow and short enough so that controlled ascent can be made without stops or stages, e.g., dives within the time-depth limits of the no-decompression table in the U.S. Navy Diving Manual.

P

Pier. A structure composed of stone, concrete, brick, steel or wood and built in shaft or block-like form to support the ends of the spans of a multi-span superstructure at an intermediate location between its abutments.

The following types of piers are adapted to bridge construction. The first three are functional distinctions, while the remaining types are based upon form or shape characteristics.

Anchor Pier. A pier functioning to resist an uplifting force, as for example: The end reaction of an anchor arm of a cantilever bridge. This pier functions as a normal sickness when applied to a diver in a pressure vessel for human occupancy as therapy.

Riprap. Brickbats, stones, blocks of concrete or other protective covering material of like nature deposited upon river and stream beds and banks, lake, tidal or other shores to prevent erosion and scour by water flow, waves or other movement.

Run-Off. As applied to bridge design, the portion of the precipitation upon a drainage (catchment) area which is discharged quickly by its drainage stream or streams and which, therefore, becomes a factor in the design of the effective water discharge area of a bridge. Run-off is dependent upon soil porosity (varied by saturated or frozen condition), slope or soil surfaces, intensity of rainfall or of melting snow conditions, and other pertinent factors.

S

Scour. An erosion of a river, stream, tidal inlet, lake or other water bed area by a current, wash or other water in motion, producing a deepening of the overlying water, or a widening of the lateral dimension of the flow area.

Scuba Diving. A diving mode independent of surface supply in which the diver uses open circuit self-contained underwater breathing apparatus.

Sheet Pile Cofferdam. In general, a wall-like, watertight or nearly watertight barrier composed of driven timber or metal sheet piling constructed to surround the area to be occupied by an abutment, pier, retaining wall or other structure and permit unwatering of the enclosure so that the excavation for the preparation of a foundation and the abutment, pier or other construction may be produced in the open air. The alignment of the piles may be facilitated by the use of walers, struts and ties.

This type of dam is adapted to construction located in still or slow flowing shallow water. Its watertightness is sometimes rendered more complete by depositing earth material against the exterior side of the dam.

Sheet Piling. (Sheeting.) A general or collective term used to describe a number of sheet piles taken together to form a crib, cofferdam, bulkhead, etc.

Silt. Very finely divided siliceous or other hard and durable rock material derived from its mother rock through attritive or other mechanical action rather than chemical decomposition. In general, its grain size shall be that which will pass a Standard No. 200 sieve.

Slope. A term commonly applied to the inclined surface of an excavated cut or an embankment.

Slope Pavement. (Slope Protection.) A thin surfacing of stone, concrete or other material deposited upon the sloped surface of an approach cut, embankment or causeway to prevent its disintegration by rain, wind or other erosive action.

Standby Diver. A diver available to go to the aid of another diver in the water.

Starling. An extension at the upstream end only, or at both the upstream and downstream ends of a pier built with surfaces battered thus forming a cutwater to divide and deflect the stream waters and floating debris and, correspondingly, when on the downstream end, functioning to reduce crosscurrents, swirl and eddy action which are productive of depositions of sand, silt and detritus downstream from the pier.

Stem. The vertical wall portion of an abutment retaining wall, or solid pier.

Stone Facing. (Stone Veneer, Brick Veneer.) A stone or brick surface covering or sheath laid in imitation of stone or brick masonry but having a depth thickness equal to the width dimension of one stone or brick for stretchers and the length dimension for headers. The backing portion of a wall or the interior portion of a pier may be constructed of rough stones imbedded in mortar or concrete, cyclopean concrete, plain or reinforced concrete, brick bats imbedded in mortar, or even of mortar alone. The backing and interior material may be deposited as the laying of the facing material progresses to secure interlocking and bonding with it, or the covering material may be laid upon its preformed surface.

Substructure. The abutments, piers, grillage or other constructions built to support the span or spans of above water or from a bell, with compressed air for breathing.

Suspended Load. Sediment that is supported by the upward components of the turbulent currents in a stream and that stays for an appreciable length of time.

pier structure when subjected to certain conditions of superstructure loading.

Cylinder Pier. A type of pier produced by sinking a cylindrical steel shell to a desired depth and filling it with concrete. The foundation excavation may be made by open dredging within the shell and the sinking of the shell may proceed simultaneously with the dredging.

Dumbbell Pier. A pier consisting essentially of two cylindrical or rectangular shaped piers joined by a web constructed integrally with them.

Hammerhead Pier. (Tee Pier.) A pier with a cylindrical or rectangular shaft, and a relatively long, transverse cap.

Pedestal Pier. A structure composed of stone, concrete or brick built in block-like form--supporting a column of a bent or tower of a viaduct. Foundation conditions or other practical considerations may require that two or more column supports be placed upon a single base or footing section. To prevent accumulation of stream debris at periods of high water or under other conditions the upstream piers may be constructed with cut-waters and in addition the piers may be connected by an integrally built web between them. When composed only of a wide block-like form, it is called a wall or solid pier.

Pile Pier or Bent. A pier composed of driven piles capped or decked with a timber grillage, concrete cap, or steel beam; or with a reinforced concrete slab forming the bridge seat.

Pivot Pier. Center Pier. A term applied to the center bearing pier supporting a swing span while operating throughout an opening-closing cycle. This pier is commonly circular in shape but may be hexagonal, octagonal or even square in plan.

Rest Pier. A pier supporting the end of a movable bridge span when in its closed position.

Rigid Frame Pier. Pier with two or more columns and a horizontal beam on top constructed to act like a frame.

Pier Cap. (Pier Top.) The topmost portion of a pier. On rigid frame piers, the term applies to the beam across the column tops. On hammerhead and tee piers, the cap is a continuous beam.

Pile. A rod or shaft-like linear member of timber, steel, concrete, or composite materials driven into the earth to carry structure loads thru weak strata of soil to those strata capable of supporting such loads. Piles are also used where loss of earth support due to scour is expected.

Sheet Piles. Commonly used in the construction of bulkheads, cofferdams, and cribs to retain earth and prevent the inflow of water, liquid mud, and fine grained sand with water, are of three general types, viz.: (1) Timber composed of a single piece or of two or more pieces spiked or bolted together to produce a compound piece either with a lap or a tongued and grooved effect. (2) Reinforced concrete slabs constructed with or without lap or tongued and grooved effect. (3) Rolled steel shapes with full provision for rigid interlocking of the edges.

Pile Cap. Concrete footings for a pier or abutment supported on piles. Also applied to the concrete below the pile tops when footing reinforcing steel is placed completely above the piles.

Pile Splice. One of the means of joining one pile upon the end of another to provide greater penetration length.

Piling. (Sheet Piling.) General terms applied to assemblages of piles in a construction.

Plinth Course. The course or courses of stone forming the base portion of an abutment, pier, parapet or retaining wall and having a projection or extension beyond the general surface of the main body of the structure.

Pneumofathometer. A depth measuring device indicating depth in FSW, consisting of an open-ended hose fixed to the diver, with the other end connected to an air supply and pressure gauge at the surface.

Pointing. The operations incident to the compacting of the mortar in the outermost portion of a joint and the troweling or other treatment of its exposed surface to secure water tightness or desired architectural effect or both.

Pressure. Force per unit of area. In diving, pressure denotes an exposure greater than surface pressure (1 ATM).

R

Recompression. An increase in pressure which is calculated to eliminate the symptoms of decompression

T

Tail Water. Water ponded below the outlet of a culvert, pile, or bridge waterway, thereby reducing the amount of flow through the waterway. Tailwater is expressed in terms of its depth.

Toe of Slope. The location defined by the intersection of the sloped surface of an approach cut, embankment or causeway or other sloped area with the natural or an artificial ground surface existing at a lower elevation.

Toe Wall. (Footwall.) A relatively low retaining wall placed near the "toe-of-slope" location of an approach embankment or causeway to produce a fixed termination or to serve as a protection against erosion and scour or, perhaps, to prevent the accumulation of stream debris.

Trestle. A bridge structure consisting of beam, girder or truss spans supported upon bents. The bents may be of the piled or of the framed type, composed of timber, reinforced concrete or metal. When of framed timbers, metal or reinforced concrete they may involve two or more tiers in their construction. Trestle structures are designated as "wooden," "frame," or "framed," "metal" "concrete," "wooden pile," "concrete pile," etc., depending upon or corresponding to the material and characteristics of their principal members.

U

Umbilical. The composite hose bundle between a dive location and a diver or bell, or between a diver and a bell, which supplies the diver or bell with breathing gas, communications, power, or heat as appropriate to the diving mode or conditions, and includes a safety line between the diver and the dive location.

V

Volume Tank. A pressure vessel connected to the outlet of a compressor and used as an air reservoir.

W

Wale. (Wale-Piece, Waler.) A wooden or metal piece or an assemblage of pieces placed either inside or outside, or both inside and outside, the wall portion of a crib, cofferdam or similar structure, usually in a horizontal position, to maintain its shape and increase its rigidity, stability, and strength.

Waterway. The available width for the passage of stream tidal or other water beneath a bridge, if unobstructed by natural formations or by artificial constructions beneath or closely adjacent to the structure. For a multiple span bridge the available width is the total of the unobstructed waterway lengths of the spans.

Wing Wall. The retaining wall extension of an abutment intended to restrain and hold in place the side slope material of an approach causeway or embankment. When flared at an angle with the breast wall it serves also to deflect stream water and floating debris into the waterway of the bridge and thus protects the approach embankment against erosion. The general forms of wing walls are:

(1) Straight--in continuation of the breast wall of the abutment.

(2) U-type--placed parallel to the alignment of the approach roadway.

(3) Flared--forming an angle with the alignment of the abutment breast wall by receding therefrom.

(4) Curved--forming either a convex or concave arc flaring from the alignment of the abutment breast wall.

The footing of a full abutment height wing wall is usually a continuation of the base portion of the breast wall but may be stepped to a higher or lower elevation to obtain acceptable foundation conditions.

A stub type of straight wing wall is sometimes used in connection with a pier-like or bent-like abutment placed within the end of an embankment. This type, serves to retain the top portion of the embankment from about the elevation of the bridge seat upward to the roadway elevation. The top surface is battered to conform with the embankment side slope.

Work Site. A vessel or surface structure from which dives are supported and/or the underwater location where work is performed.

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