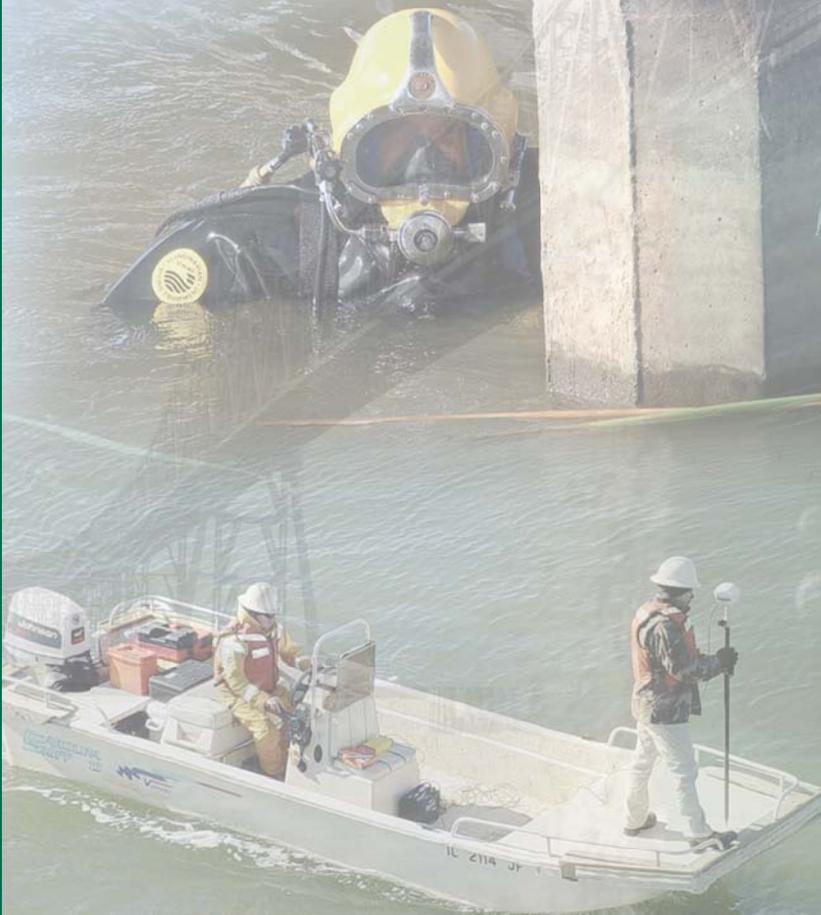


# Underwater Bridge Inspection

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U.S. Department of Transportation  
**Federal Highway Administration**



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The conduct of underwater bridge inspections may frequently require the use of divers. While this manual contains information on diving equipment and diver inspection techniques, it is neither intended to train personnel in diving nor enumerate all diving safety concerns and regulations. Actual diving inspections can be extremely hazardous and should be undertaken only by personnel adequately trained to cope with the conditions that may be encountered.



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# Underwater Bridge Inspection

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## CHAPTER I

# MANAGING AN UNDERWATER INSPECTION PROGRAM

### SECTION 1. IDENTIFICATION OF BRIDGES FOR UNDERWATER INSPECTION

#### 1-1.1 Need for Underwater Inspections

The National Bridge Inventory (NBI)\* of the United States includes geometric and condition data for approximately 603,000 highway bridges. Of those, approximately 502,000 bridges, or about 83 percent, are built over waterways. While many of these bridges do not have foundation elements actually located in water, a great many do and most bridge failures occur because of underwater issues. Underwater inspections are an integral part of a comprehensive bridge safety program to ensure the safety of the travelling public, and can be a vital part of a cost-effective bridge maintenance and management program.

The Federal Highway Administration (FHWA), through the National Bridge Inspection Standards (NBIS), and through guidance provided in Technical Advisories, specifies that underwater members 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 underwater inspection techniques. These techniques may include visual and tactile inspections by wading, diving, remotely operated vehicles (ROVs), underwater cameras, underwater imaging, depth sounding equipment, material sampling equipment, and other specialized inspection equipment as needed to determine underwater structural and streambed conditions.



Figure 1-1 I-90 Bridge over Schoharie Creek, New York (1987)

Bridges that cross waterways often have foundation elements located in water to provide the most economical total design. When these elements are continuously submerged or submerged during periods of significant flow, underwater inspection techniques and management procedures are used to establish their condition so that failures can be avoided. Figures 1-1 and 1-2 illustrate two water-related bridge failures which resulted in significant loss of life.

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\*The NBI includes bridge information from the 50 states, the District of Columbia, and Puerto Rico.

Underwater inspection of submerged bridge components, in conjunction with channel bottom surveys, is only the first step in a comprehensive safety inspection of an in-service bridge. Evaluation of the inspection results by qualified engineers is the next step. All bridges located over water should be evaluated by a multi-disciplinary team including structural, hydraulic, and geotechnical engineers.



Figure 1-2 US 51 Bridge over Hatchie River, Tennessee (1989)

Underwater inspections can play an important part in an overall bridge maintenance and management program. Underwater material damage and deterioration, and scour-related undermining may not be apparent above water until the damage has become so severe that remedial actions are extremely expensive. Early detection of underwater distress allows implementation of cost-effective repairs.

Underwater inspections can also reduce the cost of in-water repair work. Engineers can better design repairs when the exact extent of damage is available in detailed underwater inspection reports. Better delimitation of repairs below water reduces the number of unknown conditions a contractor must consider in bidding, thus reducing risk to the contractor, and generally resulting in lower bid prices and less contract modifications during the repair work for the bridge owner.

### 1-1.2 National Bridge Inspection Standards

The National Bridge Inspection Standards (NBIS) define the minimum requirements for the proper safety inspection and evaluation of all highway bridges in the United States. The standards can be found in Title 23, Code of Federal Regulations, Part 650, Subpart C (23 CFR Part 650). The regulation addresses the inspection of publicly-owned highway bridges longer than 20 feet located on public roads.

Since 1988, the NBIS has required that the submerged elements of all bridges with substructures located in water be inspected at regular intervals not to exceed 60 months. Bridge owners must prepare and maintain an inventory of all bridges subject to the NBIS, and must identify all bridges requiring underwater inspection. For bridges requiring underwater inspection, owners must identify the location of underwater

elements, including a description of the underwater elements; establish the inspection frequency and the procedures for conducting the inspection of each bridge requiring underwater inspection; and conduct the inspections of those elements requiring underwater inspections according to those established procedures. Those bridges which require underwater inspection must be noted on individual inspection and inventory records.

The NBIS requires procedures to assure critical findings are addressed in a timely manner. For bridges located in water, one approach could be an agency process that recognizes critical situations; standard procedures to be followed depending on the severity of the situation; and preplanned incident management activities. The discovery of specific underwater conditions, or condition ratings below a predetermined level, should initiate remedial actions for cautiously managing the safety of the structure and protecting the public. The in-place protocols should authorize, when warranted, immediate closure of an unsafe bridge by the on-site bridge inspector.

Additionally, in accordance with the NBIS, owners must identify all bridges that are scour critical, i.e., bridges with a foundation element that has been determined to be unstable for the observed or evaluated scour conditions.

Since 2005, the NBIS has specified that a qualified team leader must be present at the bridge for all underwater bridge inspections, and all inspection divers must have successfully completed an FHWA approved comprehensive bridge inspection training course or an FHWA approved underwater diver bridge inspection training course.

For bridges that are scour critical, bridge owners must prepare a plan of action to monitor known and potential deficiencies and to address critical findings. Bridges that are scour critical must be monitored in accordance with the plan of action.

To maintain a high degree of accuracy and consistency in their bridge inspection program, bridge owners are required to establish systematic quality control (QC) and quality assurance (QA) procedures including periodic review of inspection teams, periodic bridge inspection training, and independent review of inspection reports. Many bridge program managers have developed comprehensive documentation covering all aspects of their bridge inspection programs, including requirements that are unique to their organizations.

While this manual is specifically intended to address the requirements contained in the NBIS for the underwater inspection of publicly owned highway bridges located on public roads, the recommendations and procedures contained in this manual should serve as a prudent approach and generally be applicable to railroad bridges, pedestrian bridges, privately owned bridges, and other structures located in water.

There are also other guidelines which provide information related to general underwater inspection and contain useful information that is applicable to

underwater bridge inspection methods, equipment, and techniques. Refer to the Appendix for a list of related references.

## SECTION 2. UNDERWATER INSPECTION

### 1-2.1 Levels of Inspection

Originating in the offshore diving industry, and adopted by the U.S. Navy, the designation of standard levels of inspection intensity has gained widespread acceptance. 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. The levels might, more correctly, be referred to as levels of inspection effort or intensity, but are commonly referred to as levels of inspection. Three levels of inspection have been adopted for underwater bridge inspection. These levels, 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) or Partially Destructive Testing (PDT)

A routine underwater bridge inspection normally includes a 100% Level I inspection and a 10% Level II inspection. It may also include additional Level II inspections and Level III inspections if necessary to determine the structural condition of the submerged substructure elements with certainty.

- a. Level I Inspection. A Level I inspection includes a close visual examination of the entire submerged portions of a bridge. Although the Level I inspection is often referred to as a "swim-by" inspection, it is to be detailed enough to detect obvious damage or deterioration. 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 substructure element, whether it be a pier, abutment, retaining wall, bulkhead, or pile bent. In many environments, handheld lights are needed to make observations. A Level I inspection may also include limited probing of the substructure and adjacent channel bottom.

Where water clarity is so poor that a diving inspector cannot visually inspect the structure, a tactile inspection is made and can be accomplished using systematic sweeping motions of the hands and arms to cover the entire submerged structure.

The results of the Level I inspection provide a general overview of the substructure condition and verification of the actual construction with 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 of, and in selecting the location of, more detailed inspections.

- b. Level II Inspection. A Level II inspection is a detailed inspection which requires that portions of the structure be cleaned of marine or aquatic growth. Cleaning in salt water and brackish water can be time-consuming and should be restricted to critical areas of the structure. In fresh water, aquatic coatings can often be removed with limited effort by wiping the structural element with gloved hands.

For pile type structures, a 6-inch to 12-inch-high band—preferably a 10-inch to 12-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 octagonal pile, at least six sides; on a round pile, at least three-fourths of the perimeter; and on an H-pile, at least the outside faces of the flanges, one inside face of a flange, and one side of the web.

Where a 10% Level II inspection is specified for a pile type structure, it is not the intention that 10 percent of the entire substructure be cleaned, but rather that 10 percent of the piles be cleaned in three 6-inch to 12-inch-high bands.

On large solid-faced elements such as piers and abutments, one foot by one foot areas should be cleaned at three levels on each exposed face and end of the element. For a structure length that is greater than about 50 feet, it is general practice to clean an additional line at three levels on each exposed face. The selection of the locations for cleaning should be made so as to minimize the potential for damage to the structure, and should target, when possible, more critical locations. After cleaning, damaged areas should be measured, and the extent and severity of the damage documented.

Level II inspections are intended to detect and identify damaged and deteriorated areas which may be hidden by surface biofouling or products of corrosion. The thoroughness of cleaning should be governed by what is necessary to discern the condition of the underlying material. Complete removal of all biofouling growth or corrosion products is generally not needed. Figure 1-3 illustrates a Level II cleaning of a steel H-pile.



Figure 1-3 Level II Cleaning of a Steel H-Pile

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 generally limited to key structural areas, areas which are suspect, or areas which may be representative of the entire underwater structure. Figure 1-4 shows an inspector measuring the remaining thickness of a steel pile using an underwater ultrasonic thickness measuring device. Non-destructive and partially destructive testing is described in further detail in Chapter V.



Figure 1-4 Level III Inspection of a Steel Pile with an Ultrasonic Thickness Measuring Device

## 1-2.2 Types of Inspection

The NBIS recognizes seven types of bridge inspections: routine, initial, damage, in-depth, underwater, special, and fracture critical inspections. These types of inspection apply to both above water and underwater inspections. Bridge owners should establish criteria to determine the level and frequency of each of these types of inspection for underwater elements.

a. Routine Inspections. A routine inspection is a regularly scheduled inspection consisting of observations and measurements needed to determine the physical and functional condition of the bridge, to identify any changes from initial or previously recorded conditions, and to ensure that the structure continues to satisfy present service requirements. A routine inspection should incorporate Level I and Level II inspections, and a scour investigation as summarized in Figure 1-5. A basic scour investigation should include sounding and probing the channel bottom adjacent to the structure, and determining channel cross sections in the area of the bridge.

The routine inspection may indicate that an in-depth inspection is needed 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.

Level I inspection (Visual, tactile, "swim-by" overview)	100% of all underwater elements.
Level II inspection (Limited measurements and cleaning in bands or areas at designated locations)	10% of all underwater elements.
Scour investigation	Cross sections of channel. Sound and probe bottom near underwater elements.

Figure 1-5 Summary Guidelines for Routine Underwater Inspection

- b. Initial Inspections. An initial, or inventory, inspection is the first inspection of a bridge as it becomes a part of the bridge file. It provides all structure appraisal and inventory data, and other relevant data to determine the baseline structural condition. An inventory inspection may also be required when there has been a change in the configuration of the structure such as widening, lengthening or strengthening, bridge replacement, or change in ownership. An initial inspection typically incorporates Level I and Level II inspections, and a scour investigation as required for a routine inspection.

The initial inspection may indicate that an in-depth inspection 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.

- c. Damage Inspections. A damage inspection is an unscheduled inspection to assess structural damage resulting from environmental factors or human actions. The scope of the inspection should be sufficient to determine the need for emergency load restrictions and to assess the level of effort to accomplish needed repairs.
- d. In-Depth Inspections. An in-depth inspection is a close-up inspection of one or more members above or below water to identify any deficiencies not readily detectable using routine inspection procedures. For underwater elements, this may include additional Level II inspections or Level III inspections. 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 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 techniques as part of routine inspections.

- e. Special Inspections. A special inspection is an inspection scheduled at the discretion of the bridge owner, used to monitor a particular known or suspected deficiency.

Some of the conditions or events that may trigger the need for damage, in-depth, or special underwater inspections 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. Bridges which are scour critical should be inspected in accordance with their plans of action.

Bridges should also be inspected underwater following the installation of scour protective devices to assure their effectiveness and to detect any unforeseen consequences.

- (2) Vessel Impact. Bridges should be inspected underwater after any vessel impact, especially if there is visible damage above water that extends below water. This should be done in order to evaluate the safety of the bridge and to determine the extent of damage for design of repairs. It may be especially important to inspect vessel impact damage in busy channels in a timely manner so that damage can be attributed to the proper vessel impact event. See Figure 1-6.



Figure 1-6 Vessel Impact Damage at I-40 Bridge over Arkansas River, Oklahoma (2002)

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

of substructure materials. Some waterways also promote active microbial induced corrosion (MIC) on submerged steel elements.

- (6) Floating and Build-Up of Debris at Piers or Abutments. This material can place significant loads on structures and the build-up effectively widens the substructure element and may cause scouring currents or increase the depth of scour. See Figure 1-7 for an example of damage caused by floating debris.

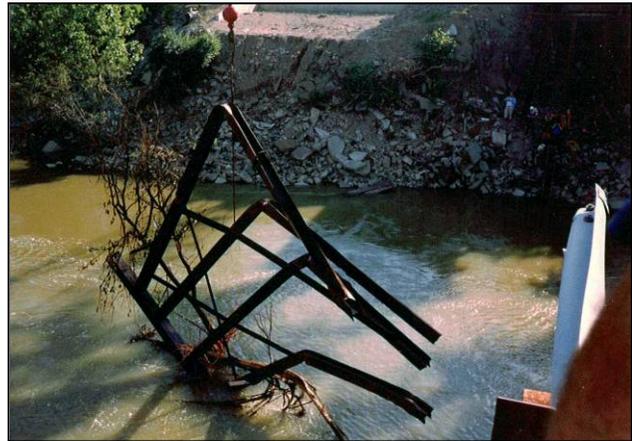


Figure 1-7 Temporary Bridge Pier Collapsed by Floating Debris

- (7) Above Water 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, or other major natural events.

### 1-2.3 Frequency of Inspection

Routine inspections of substructures in water must be conducted at least every 60 months. Sixty months is a maximum interval which is only appropriate for a structure in excellent condition, or for a structure with current conditions deemed acceptable for that timeframe and with no concerns warranting more frequent monitoring. Certain underwater structural elements will require inspections at less than 60-month intervals. Each agency should establish criteria to determine the level and frequency to which these members are inspected considering such factors as construction material, environment, age of the structure, scour characteristics, condition rating from past inspections, and known deficiencies. Thus, structures having underwater members which are partially deteriorated or which are located in unstable channels or aggressive environments require shorter inspection intervals.

The NBIS also provides that certain underwater structural elements may be eligible to be inspected at greater than 60-month intervals, not to exceed 72 months, with written FHWA approval. This may be appropriate when past inspection findings and analysis justify the increased inspection interval. States requesting the extended underwater inspection interval must develop a 72-month underwater inspection frequency policy for their bridges and submit it to FHWA for approval. If approved, FHWA will monitor the 72-month underwater inspection policy as part of the normal NBIS program review process. The State, working with FHWA, may use the policy to select structures, on a case-by-case basis, eligible for the increased underwater inspection frequency. FHWA indicates that guidance for developing a 72-month

underwater inspection frequency policy can be found in the American Society of Civil Engineers (ASCE) manual, *Underwater Inspection of Bridges*. FHWA also suggests that to be eligible, the substructure should be in at least good to fair condition; should not be unprotected steel or unwrapped timber in an aggressive environment or fast currents; should not have stream stability or scour issues; and should have a known foundation type.

For routine underwater bridge inspections, factors to consider in establishing the inspection frequency and the normal levels of inspection effort include:

- (1) Structure 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

Some bridge owners shorten the underwater inspection interval to 24 months or 48 months to coincide with the date for the above water inspections. Refer to Figure 1-8 for a summary of the NBIS above water bridge inspection frequency requirements.

<b>Above Water Bridge Inspection Frequency</b> In accordance with the NBIS:
<p><b>Routine Inspections</b></p> <p>Inspect each bridge at intervals not to exceed 24 months.* Certain bridges may be inspected at greater than 24-month intervals, not to exceed 48 months, with written FHWA approval.</p>
<p><b>Fracture Critical Member (FCM) Inspections</b></p> <p>Inspect FCMs at intervals not to exceed 24 months.*</p>
<p>*Certain bridges and FCMs require inspection at less than 24 months based on factors such as age, traffic characteristics, and known deficiencies.</p>

Figure 1-8 Summary of Above Water Bridge Inspection Frequency Requirements

#### 1-2.4 Dive Safety

In conducting underwater inspections with diving equipment, the persons performing the inspections must be qualified both as an inspector and a diver. The NBIS specifies the bridge inspector qualifications and inspection procedures in some detail. It does not, however, address diving qualifications or dive procedures.

Diving is an inherently dangerous activity that requires significant training, specialized equipment, and experience operating in the hostile underwater environments often found at bridges. As a minimum, all diving operations are regulated by the U.S. Occupational Safety and Health Administration (OSHA) regulations, 29 Code of Federal Regulations, Part 1910 (29 CFR 1910), Subpart T-Commercial Diving Operations with applicable updates and directives. Local jurisdictions may also impose additional safety regulations.

This manual contains information on diving equipment, diving inspection operations and techniques, and dive hazard analyses, but it is not intended to cover all dive situations that may be encountered during underwater bridge inspections. Proper training as a commercial diver and appropriate experience is essential to safely conduct underwater bridge inspections.



## CHAPTER II

### THE UNDERWATER INSPECTION TEAM

#### SECTION 1. INTRODUCTION

##### 2-1.1 General

The underwater inspection team is composed of individuals that meet the bridge inspection team member qualifications specified by the National Bridge Inspection Standards (NBIS), and the minimum diving qualifications required by the Occupational Safety and Health Administration (OSHA) regulations, Commercial Diving Operations (29 CFR 1910 Subpart T). In addition, the particular bridge to be inspected may dictate the inclusion of personnel with enhanced inspection or diving capabilities. In selecting team members and assigning duties, the team leader evaluates both inspection and diving qualifications to ensure the work will be accomplished safely and accurately.

The overall composition of the underwater inspection team should be determined by the type of structure to be inspected and the waterway conditions where the bridge is located. Each team member must have the necessary experience, qualifications, and skills for the demands of the inspection project. For most underwater bridge inspections, the size of the team and the selection of the diving equipment should be dictated by all applicable considerations necessary to ensure safe diving operations.

The person in charge of a bridge inspection program is responsible for ensuring the diver-inspectors who will be conducting underwater bridge inspections meet the minimum qualifications mandated by the NBIS, and that the underwater inspections are carried out in accordance with the NBIS and Federal Highway Administration (FHWA) guidelines.

The employer of the bridge inspection team members, whether that be a private company or the bridge owner, is responsible for ensuring that the underwater inspection is carried out in accordance with applicable safety laws and regulations. The employer could be subject to significant civil and criminal penalties for noncompliance.

##### 2-1.2 Qualifications

- a. General. The success of any inspection program depends on the training and professionalism 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 as it relates to the safety of lives and protection of property, and the dedication to do a professional job are essential prerequisites.

The underwater inspector needs to be a trained diver and meet the NBIS training requirements of an underwater bridge inspector. Training in only one of these areas will not suffice. Comprehensive technical training of underwater inspectors may be even more important than the training of above water inspectors since the underwater inspector is often the only person who can or will see a structure underwater. The underwater inspector must have the ability to recognize the structural significance of conditions encountered underwater; the judgment to expend inspection effort commensurate with the indicators of defects present; and the technical competence and vocabulary to relate inspection findings to someone on the surface.

Diving conditions are usually adverse at bridge sites. Bridges are often built at the narrowest point in a channel where waterway velocity is greatest, and in areas where water may be dark and polluted. Marine traffic, floating timber, and construction debris are commonly observed underwater hazards. The underwater inspector must have the necessary diving knowledge and skills to safely access the structure and then remain there comfortably in order to conduct a thorough and accurate inspection.

- b. Bridge Inspection Training. The NBIS requires that at least one team leader who meets the minimum qualifications, as described below, be present at the bridge site at all times during each underwater inspection.

There are five ways to qualify as a team leader. A team leader must, as a minimum, satisfy one of the following criteria:

- 1) Have five years bridge inspection experience and have successfully completed an FHWA approved comprehensive bridge inspection course;\* or
- 2) Be certified as a Level III or IV Bridge Safety Inspector under the National Society of Professional Engineers' (NSPE) program for National Certification in Engineering Technologies (NICET), and have successfully completed an FHWA approved comprehensive bridge inspection training course;\* or
- 3) Have a bachelor's degree in engineering, have successfully passed the National Council of Examiners for Engineering and Surveying (NCEES) Fundamentals of Engineering examination, have two years of bridge inspection experience, and have successfully completed an FHWA approved comprehensive bridge inspection training course;\* or
- 4) Have an associate's degree in engineering or engineering technology, have four years of bridge inspection experience, and have successfully completed an FHWA approved comprehensive bridge inspection training course;\* or
- 5) Be a registered professional engineer and have successfully completed an FHWA approved comprehensive bridge inspection training course.\*

\*National Highway Institute Course No. 130055 Safety Inspection of In-Service Bridges is one option. Information on this and other NHI courses can be found at [www.nhi.fhwa.gov](http://www.nhi.fhwa.gov). States or Federal agencies are permitted to develop their own "comprehensive inspection training" programs subject to approval by FHWA.

The NBIS also requires that all divers performing underwater bridge inspections have successfully completed either an FHWA approved comprehensive bridge inspection training course based on FHWA's Bridge Inspector's Reference Manual (BIRM) or an FHWA approved underwater diver bridge inspection training course\*\*.

- c. Optional Owner Requirements. Some bridge owners also require that underwater bridge inspection team members successfully complete both an FHWA approved comprehensive bridge inspection training course\* and an FHWA approved underwater diver bridge inspection training course.\*\*

Some states further require that underwater bridge inspections be conducted by divers who are licensed professional engineers.

Standby divers, tenders, and note takers who do not conduct any part of the diving inspection do not have to meet the training requirements of the NBIS for divers conducting underwater inspections. State and local regulations may, however, require additional training and qualifications.

Because bridge inspectors, including inspector-divers, must have a basic knowledge of how loads are distributed throughout the bridge, understand the importance of the various components of bridges to safety, and possess a general understanding of the effects of deterioration upon the safe load carrying capacity, each bridge inspector should participate in a continuing education training program. Many agencies, as part of their NBIS mandated quality control and quality assurance programs, require that team leaders successfully complete a bridge inspection refresher training course at least every five years.\*\*\*

- d. Commercial Dive Training. At present, there is no national commercial diver licensing program in the United States. OSHA, however, has recognized certain types of formal diver training as meeting the minimum requirements prescribed by the Commercial Diving Operations standard. These include commercial dive schools, military dive schools, and other accredited dive schools. Documented employer-provided training may also meet the OSHA requirements.

Recreational diving is not covered by the OSHA Commercial Diving Operations standard. Recreational diving certification organizations, such as PADI, NAUI, and YMCA, provide scuba dive training for recreational diving, and the training does not meet the minimum requirements of OSHA for commercial dive training. Recreational divers are not routinely exposed to and are not trained for severe water conditions, temperature extremes, accumulated debris, great depths, strong currents, poor visibility, or sustained workloads such as those experienced by divers conducting underwater bridge inspections. In addition, recreational dive

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\*National Highway Institute Course No. 130055 Safety Inspection of In-Service Bridges is one option. Information on this and other NHI courses can be found at [www.nhi.fhwa.gov](http://www.nhi.fhwa.gov). States or Federal agencies are permitted to develop their own "comprehensive inspection training" programs subject to approval by FHWA.

\*\*National Highway Institute Course No. 130091 Underwater Inspection of Bridges

\*\*\* National Highway Institute Course No. 130053 Bridge Inspection Refresher Training is one option.

training programs typically do not provide training in the following areas: decompression diving (in-water and surface decompression techniques); omitted decompression events; recompression chamber operations; and treatment of diving-related illnesses, including hyperbaric treatments.

Search, rescue, and related public-safety diving by or under the control of a governmental agency is also excluded from the OSHA Commercial Diving Operations standard, but the exclusion does not apply to underwater bridge inspection work\*.

Likewise, scientific diving is excluded from the OSHA Commercial Diving Operations standard. Such diving includes the study of fish behavior, ecological surveys, and benthic surveys. Thus, tasks performed by a scientific diver are light and short in duration. Scientific divers must use scientific expertise in studying the underwater environment and, therefore, are scientists or scientists in training. Divers who are trained and certified as scientific divers by the National Oceanic and Atmospheric Administration (NOAA) do not meet the requirements of the OSHA Commercial Diving Operations standard\*.

Military dive training can vary greatly—from scuba diving training for rescue divers to the use of many advanced techniques and types of diving equipment. The training records of military divers should therefore be examined to ensure they meet the OSHA training requirements for commercial divers.

Graduates of commercial diving schools are taught various types of diving methods, equipment maintenance, and how to perform mechanical tasks underwater. Some schools also provide specialty courses in Non-Destructive 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. Training conducted in accordance with the American National Standards Institute's (ANSI) "Commercial Diver Training—Minimum Standards" is commonly accepted as meeting the minimum requirements for commercial dive school training.

None of the dive training alternatives described above, however, qualifies a commercial diver as an underwater bridge inspector without the additional NBIS technical training described above.

In general, OSHA enforces its diving standards wherever diving operations are being conducted by private sector employees. Some states, however, have an OSHA-approved state diving standard, which is identical to or at least as effective as the Federal OSHA, and will govern diving operations in the particular state.

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\*Appendix A and Appendix B, 29CFR Part 1910, Subpart T—Commercial Diving Standard

Federal employees are also covered by the OSHA diving standard, and may also be subject to additional agency-specific diving regulations. Federal OSHA does not have authority over state and local government employees. State and local government employees are only covered by a commercial diving standard in states with OSHA-approved state plans.

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 and physically demanding underwater situation.

## SECTION 2. DIVE SAFETY STANDARDS

### 2-2.1 Occupational Safety and Health Administration (OSHA)

The Occupational Safety and Health Administration's Commercial Diving Operations standard applies to all diving and related support operations conducted in connection with all types of work and employments, except as previously noted. All divers, regardless of their training, if receiving remuneration for their diving services, are considered commercial divers. A copy of the OSHA Commercial Diving Operations standard (29 CFR 1910 Subpart T) is included in the Appendix. The latest changes to the standard and directives related to the standard may be found at [www.OSHA.gov](http://www.OSHA.gov).

The OSHA standard delineates minimum personnel requirements, general operations procedures, specific operations procedures, equipment procedures and requirements, and recordkeeping requirements. All persons procuring, supervising, or conducting commercial diving operations should be cognizant of its provisions.

Many of the provisions of the standard are described in the 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:

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

- 1) An employer designated person-in-charge of the operation, who is qualified by training and experience, must conduct pre-dive and post-dive briefings.
- 2) The use of scuba diving is not allowed at depths greater than 130 feet sea water (fsw).

- 3) The use of scuba is not allowed in currents exceeding one knot unless the diver is line tended.
- 4) The use of surface-supplied air is not allowed at depths greater than 220 fsw.
- 5) For dives to depths in excess of 100 fsw or for dives outside the no-decompression limits, a recompression chamber must be on-site ready for use.
- 6) The minimum size dive team for conducting commercial scuba diving operations with one line tended diver in the water is three, but additional personnel may be required for specific operations.
- 7) The minimum size dive team for conducting surface supplied diving operations is three, but additional personnel may be required for specific operations.

#### Equipment Procedures:

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

#### Recordkeeping Requirements:

The standard requires recording and retaining documents related to diving related injuries, illness, or fatalities; diving exposure, decompression evaluations, and medical treatment; equipment inspection and testing; and depth-time profiles.

### 2-2.2 U.S. Army Corps of Engineers, Contract Diving Operations

Another dive safety standard commonly used for government diving projects is the U.S. Army Corps of Engineers Safety and Health Requirements, Chapter 30, Diving Operations, EM 385-1-1. It contains provisions similar to the OSHA standard, but provides more specific guidance as to minimum dive team staffing for various diving conditions as shown in Figure 2-1. It also provides more definitive requirements for diving qualifications and requires divers be certified in the emergency administration of oxygen.

Minimum Staffing Levels for Dive Teams in Accordance with EM 385-1-1*	
Operation Type	Minimum Team Size
Scuba—untethered, 0 to 100 ft.	4
Scuba—tethered, 0 to 100 ft.	4
Surface Supplied Air, 0 to 100 ft.	6
Surface Supplied Air, 0 to 100 ft., requiring decompression	8
Surface Supplied Air, 101 to 190 ft.	8
*Refer to EM 385-1-1 for details and further conditions.	

Figure 2-1 EM 385-1-1 Minimum Dive Team Size

### 2-2.3 Other Safety Standards

There are other OSHA standards, besides those related to diving, that must be followed when working at a dive site. These might include:

- Work requiring confined space entry
- Work requiring fall protection
- Work requiring personal flotation devices
- Work requiring high visibility safety clothing
- Work requiring personal protection equipment such as a hardhat, eye protection, hearing protection, and foot protection

Local government jurisdictions or private bridge owners may also have additional or more stringent safety standards that must be followed. Some states have, with OSHA approval, opted to establish their own safety standards which are at least as restrictive as the OSHA standard. It is important to be aware of such standards because they may place additional requirements on the inspection team. For example, the diving standard for at least one state requires annual diver medical examinations which are not required by OSHA.

## SECTION 3. PLANNING UNDERWATER BRIDGE INSPECTION OPERATIONS

The primary goals of every underwater inspection project should be to complete the work safely and to provide a thorough and accurate inspection. Proper planning is essential to achieving these goals. Inspection teams must plan for safety; plan for conducting the inspection; plan for what is expected; and plan for what is unexpected.

Many underwater inspection teams use standard forms to ensure a systematic approach to planning. A multi-page example of such a form is included at the end of this chapter.

- a. Preliminary Planning. The first step in the planning is to determine the goal of the inspection, and to decide what information will be gathered and in what detail. It is important that every member of the team understand the objectives of the underwater bridge inspection project. A project kick-off meeting for the team is useful to define and refine the scope and limits of the work. Personnel for the team should be initially selected based on the technical knowledge that is required for a particular project, and an initial evaluation of the characteristics of the dive environment. Team members should know what to look for, be able to evaluate what is important, and be able to communicate their findings.

- b. Data Collection and Research. If possible, design drawings and as-built drawings of the bridge should be obtained to determine the configuration of the structure, construction materials, and type of foundation. Records of past repairs should also be reviewed. Previous inspection reports should be obtained and may indicate the progression of defects, deterioration of repairs, waterway conditions, and access points. Prior scour data and any plans of action should also be reviewed.

Waterway information may be obtained from sources such as topographical maps and flow data from the Corps of Engineers, tidal charts from the National Oceanic and Atmospheric Administration (NOAA), and internet mapping and satellite services.

At this time in the planning process, local agencies should be contacted to inform them of the intended inspection. The parties to be contacted may include the U.S. Coast Guard, Department of Homeland Security, and local, county, and state authorities.

- c. Hazard Analysis. Every project site will have hazards. In planning an underwater bridge inspection, the site must be examined to identify all potential hazards so that they can be mitigated. Methods of mitigation may include avoidance of the hazard, removal of the hazard, the selection of appropriate operational methods, the choice of appropriate inspection and diving equipment, and the use of special protective equipment.

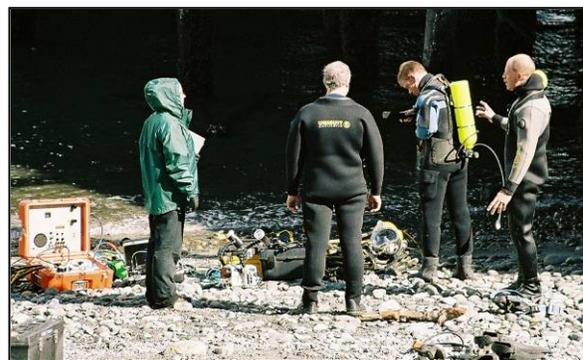


Figure 2-2 Divers Conducting Pre-Dive Briefing and Equipment Check

In underwater bridge inspection operations, common hazards may include:

- Swift currents (riverine and tidal)
- Deep water
- High altitudes
- Extreme water temperatures
- Limited or no visibility
- Marine wildlife
- Contaminated water
- Ice floes or fixed ice
- Floating or accumulated debris
- Watercraft operations
- Construction operations

- d. Dive Inspection Operations Plan. After the hazard analysis is completed, the staffing of the inspection team can be finalized, taking into consideration both the inspection qualifications and the diving qualifications required for the team members.

The operations plan should include team member assignments and responsibilities, inspection procedures and objectives, equipment requirements, emergency information and procedures, and a review of potential hazards and mitigation techniques to be employed.

Every organization providing underwater bridge inspection services should establish a system to ensure that underwater inspections are conducted safely, thoroughly, and in accordance with the requirements of the NBIS. Refer to Chapter VIII for a detailed discussion of the quality control and quality assurance process.

- e. Risk Assessment. Risk assessment is essentially a qualitative process to evaluate the hazardousness of a proposed underwater inspection based on parameters that relate to the characteristics of the inspection team and the demands of diving operations. The sample Risk Assessment worksheet included at the end of this chapter was developed to compare the relative effect of various parameter choices on the overall risk of a project. Use of a tool such as this, with parameters selected to reflect appropriate operating characteristics, can be useful in identifying more hazardous operations.

**SAMPLE DIVE INSPECTION OPERATIONS PLAN**

The following, except for the 'Take 5 for Safety' Briefing, shall be completed, either electronically or by hand, by the Dive Supervisor and submitted to the Company Diving Coordinator for approval prior to mobilizing for any Company dive-related activity. The 'Take 5 for Safety' Briefing shall be completed by the Dive Team under the direction of the Dive Supervisor just prior to conducting any dive operation. After completion of the dive-related activity, the fully completed Dive Operations Plan shall be submitted to the Company Diving Coordinator.

<b>DIVE SUPERVISOR</b>		<b>DATE PREPARED</b>	
<b>PROJECT NAME AND JOB NUMBER</b>			
<b>WATERWAY NAME</b>		<b>LOCATION</b>	
<b>DIVE OBJECTIVE</b>			
<b>JOB SPECIFIC EQUIPMENT</b>			
Type of Operation	<input type="checkbox"/> SCUBA (30 cf bailout req'd w/separate regulator)	<input type="checkbox"/> Surface-supplied Air (30 cf bailout req'd)	
Diver's Dress	<input type="checkbox"/> Dry <input type="checkbox"/> Wet <input type="checkbox"/> Hot Water		
Boat Required	<input type="checkbox"/> Pontoon <input type="checkbox"/> 20'/22' V-hull <input type="checkbox"/> 18'/20' Skiff	<input type="checkbox"/> 16' John	<input type="checkbox"/> 14' John <input type="checkbox"/> 14' V-Hull
LP Compressor	<input type="checkbox"/> Quincy <input type="checkbox"/> Honda		
HP Compressor	<input type="checkbox"/> Bauer (8hp) <input type="checkbox"/> Bauer (5.5hp) <input type="checkbox"/> Bauer (Gas/Elec.)		
Other Air Source/Reserve	<input type="checkbox"/> Volume Tank <input type="checkbox"/> Lrg Cylinders <input type="checkbox"/> Bank of Tanks	<input type="checkbox"/> _____	
Air Console/Comm. System	<input type="checkbox"/> DCS Box 1 <input type="checkbox"/> DCS Box 2	<input type="checkbox"/> _____	
Umbilical	<input type="checkbox"/> 70' <input type="checkbox"/> 100' <input type="checkbox"/> 150'	<input type="checkbox"/> 300'	Number Req'd _____
Helmet/Mask	<input type="checkbox"/> EXO 57 <input type="checkbox"/> Auga Mask <input type="checkbox"/> Superlite 17	<input type="checkbox"/> Superlite 27	Number Req'd _____
UW Camera	<input type="checkbox"/> Nikonos <input type="checkbox"/> Digital <input type="checkbox"/> Video	<input type="checkbox"/> Clearwater Box	<input type="checkbox"/> _____
First Aid	<input type="checkbox"/> EMT Kit <input type="checkbox"/> O2 Kit		
<b>Other Equipment:</b>			
Standard Equipment: Personal Gear, Dive Knife, Dive Flag, Dry Box, Extra Keys, Radio, Cell Phone, Tool Box, Film, Paper, Pencils, Field Forms			
<b>ANTICIPATED CONDITIONS</b>			
Depth _____ ft.	TBT _____	No. of Dives _____	
Water <input type="checkbox"/> Salt <input type="checkbox"/> Fresh	<input type="checkbox"/> Fresh	Temperature _____ F	Visibility _____ ft.
Surface <input type="checkbox"/> Calm <input type="checkbox"/> Choppy	<input type="checkbox"/> Choppy	<input type="checkbox"/> Rough	
Surf <input type="checkbox"/> Small <input type="checkbox"/> Medium	<input type="checkbox"/> Medium	<input type="checkbox"/> Large	
Tide <input type="checkbox"/> High <input type="checkbox"/> Low	<input type="checkbox"/> Low	_____	
Current <input type="checkbox"/> Fast <input type="checkbox"/> Moderate	<input type="checkbox"/> Moderate	<input type="checkbox"/> Slow	Velocity _____ ft./sec.
Weather <input type="checkbox"/> Sunny <input type="checkbox"/> Cloudy	<input type="checkbox"/> Cloudy	Air Temperature _____ F	
<b>DIVE PLAN AND PROCEDURES:</b>			
<b>Points of Contact:</b>			
Enter text			
<b>Scope of Work:</b> (possible attachments: client scope, proposal, workplan, contract, etc.)			
Enter text			
<b>Governing Regulations:</b>			
Enter text			
<b>Special Site Conditions:</b>			
Enter text			
<b>Site-specific Hazard Analysis:</b> (potential hazards: water temperature, water conditions, water current, weather patterns, exit/entry points, penetrations/obstructions, drift/debris, marine life, watercraft/port operations, other contractor operations, lock-out/tag-out)			
Enter text			

**SAMPLE DIVE INSPECTION OPERATIONS PLAN**

<b>Dive Team Members</b>					
Diver Name	Position	CPR Date	First Aid Date	O <sub>2</sub> Date	ADC Number

**EMERGENCY INFORMATION**

Dive Site Location: \_\_\_\_\_

Decompression Chamber Location: \_\_\_\_\_ Phone: \_\_\_\_\_

Hospital Location: \_\_\_\_\_ Phone: \_\_\_\_\_

Physician Location: \_\_\_\_\_ Phone: \_\_\_\_\_

Transportation: \_\_\_\_\_

Emergency Notification  U.S. Coast Guard Ch 16 (Duty Officer)  Local Emergency 911 (non-coastal)

Nearest Rescue Center (Coast Guard, Fire Dept., etc.):

Location: \_\_\_\_\_ Phone: \_\_\_\_\_

National Diving Accident Network:

Duke University Medical Center  
Emergency Assistance: 919/684-8111U.S. Navy Experimental Diving Unit  
Panama City, Florida  
Duty Phone: 904/234-4355

Be ready with: Name of Patient, Location of Incident, and Nature of Injury.

If you receive a busy signal, call the Operator and state that this is a life or death situation. Request that the circuit be broken.

**Location Map (site/facility plan, driving directions, boat launch info, etc.)**

**SAMPLE DIVE INSPECTION OPERATIONS PLAN  
Risk Assessment**

Planning	Risk Value		SCORE _____
	<b>Preparatory Time</b>		
<b>Contract Type</b>	Optimum	Adequate	Minimal
Emergency	3	4	5
New Contract	2	3	4
Ongoing Contract or Repeat	1	2	3
Organization and Equipment	Risk Value		SCORE _____
	<b>Equipment Available</b>		
<b>Project Organization</b>	Internal Equip	Leased Equipment	Another Company's
Working for Contractor	2	3	4
Subconsultant	1	2	3
Prime	1	2	3
Physical Requirements of Divers	Risk Value		SCORE _____
	<b>Employee Preparation</b>		
<b>Environment</b>	Optimum	Adequate	Minimal
Non-acclimated	3	4	5
Partially Acclimated	2	3	4
Acclimated	1	2	3
Team Members	Risk Value		SCORE _____
	<b>Diver Experience</b>		
<b>Task</b>	Very Experienced	Moderate Experience	Minimal Experience
Complex	3	4	5
Routine	2	3	4
Simple	1	2	3
Weather	Risk Value		SCORE _____
<b>Water</b>	<b>Rain and Weather</b>		
<b>Temperature °F</b>	Clear	Drizzle or High Humidity	Rain/Snow/Ice/Dust
<45° or >86°	3	4	5
45° - 65°	2	3	4
66°-85°	1	2	3
Waterway	Risk Value		SCORE _____
	<b>Current</b>		
<b>Type Visibility</b>	No Current	Moderate Current	Fast Current
Zero Visibility	4	5	6
1 ft visibility	3	4	5
3 ft visibility	2	3	4
6 ft visibility	1	2	3
Project Duration	Risk Value		SCORE _____
	<b>Team Experience Together</b>		
<b>Duration in Weeks</b>	Much	Some	Little
3	3	4	5
2	2	3	4
1	1	2	3

**Add all scores for a total risk value of \_\_\_\_\_**

Page 4 of (adjust page numbers and total as required)

## SAMPLE DIVE INSPECTION OPERATIONS PLAN

### Risk Assessment Values

**Low Risk = 0 to 12**  
**Caution = 13 to 25**  
**High Risk = 26 to 35**

\*High-risk operations assigned a value of 20-35 require consultation and further approval by Company Diving Coordinator and a more detailed dive plan. When two or more areas are assigned a risk factor of 5, the overall rating is to be considered high risk.

### Action(s) to be Taken to Reduce Assigned Risk Values if Total Assigned Operations Risk is Over 15

**Planning:**

**Organization and Equipment:**

**Physical Requirements:**

**Team Members:**

**Weather:**

**Waterway:**

**Duration:**

### Additional Hazard Analysis for High-Risk Assessment

### Attachment Checklist

- Dive Physicals
- Diver Resumes
- CPR, First Aid, O2 Certifications
- Compressor Air Test Certificates
- Scuba Cylinder Maintenance Logs
- Other:

**SAMPLE DIVE INSPECTION OPERATIONS PLAN**

**'Take 5 for Safety' Briefing** (to be conducted on site just prior to dive operations to review hazards, dive plan, dive team assignments and responsibilities, and emergency procedures to be followed)

**Starting Date/Time:** \_\_\_\_\_

**Planned Duration (bottom time):** \_\_\_\_\_

**Summary of Discussion:**

**Team Member Signatures:**

_____	<b>Position</b> _____

**Ending Date/Time:** \_\_\_\_\_ **Actual Bottom Time:** \_\_\_\_\_

**Maximum Water Depth Range:** \_\_\_\_\_ ft. to \_\_\_\_\_ ft.

**Post-Dive Operation Comments**

Fully completed Dive Operations Plan to be submitted to Company Diving Coordinator after dive-related activity has been completed.

## CHAPTER III IDENTIFICATION OF UNDERWATER STRUCTURAL DEFECTS

### SECTION 1. INTRODUCTION

In order to thoroughly and efficiently inspect and evaluate the condition of a structure located in water, the inspector must be able to recognize the various types of substructure configurations, likely locations and types of commonly encountered defects, and understand the causes and mechanisms of deterioration. The principal causes of underwater structure distress are deterioration of the structural materials, damage from vessels and floating debris, and undermining or loss of lateral and vertical soil support due to scour.

Structures located underwater, at the waterline, and in the splash zone above water are generally subject to similar types of distress and deterioration. For convenience in the manual, except where described in more detailed terms, “underwater structures” and similar terms will be used to refer to portions of structures which are at, under, or immediately above the waterline.

The environment at the waterline is especially conducive to structural damage and distress. With warm temperatures at least part of the time, a ready supply of oxygen, solutions of chlorides and other chemicals in contact with the substructure, and floating debris, the waterline environment can be ideal for accelerated deterioration of all types of foundation materials.

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. Without an underwater inspection, however, the extent of damage cannot be known with certainty, nor can the overall structural condition be properly evaluated.

### 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, composites, or a combination of these, are used both as intermediate supports and as abutments. Figure 3-1 shows the variety of pile materials and pile types commonly used for load bearing piles in pile bents, and fendering and sheet piles in other structures. Figures 3-2 and 3-3 illustrate typical concrete and timber pile bents, respectively.

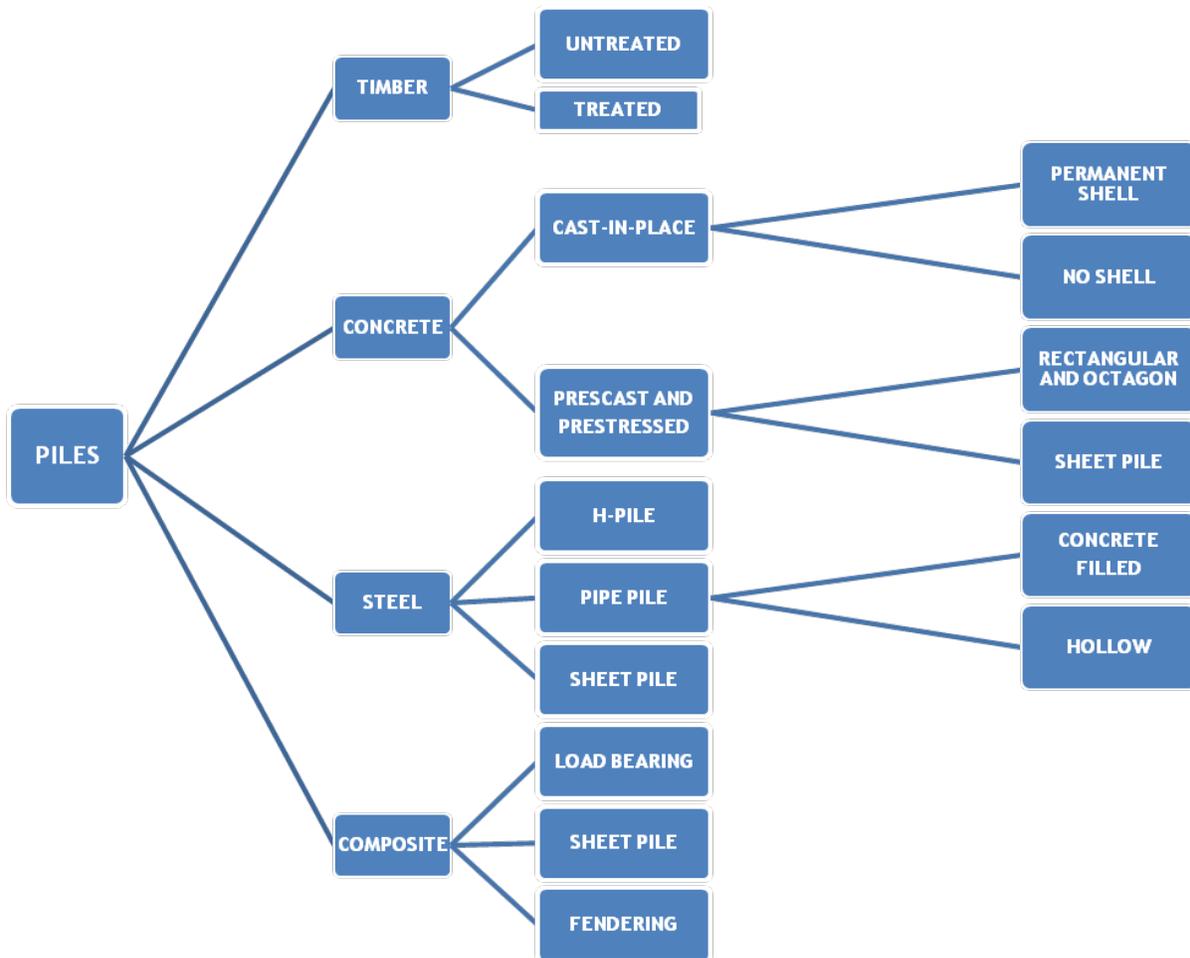


Figure 3-1 Typical Pile Types



Figure 3-2 Concrete Pile Bent at Low Water



Figure 3-3 Timber Pile Bents and Timber Pile Abutment

Piles can also be used as supports for piers and abutments where soil conditions are such that the piers and abutments cannot be supported by spread footings on the in situ soil. Figure 3-4 shows a bridge abutment supported by timber piles.

Timber piles may be untreated or may be pressure treated with preservatives. The use of preservatives, such as creosote and creosote-coal tar, and arsenate solutions has a commercial history dating back to the mid-1800s. Local and national environmental laws, however, may preclude the future use of some preservatives. 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. Figure 3-5 shows an untreated timber pile supporting a concrete pier.

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 steel 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 to 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 with or without a shell to support massive bridge elements. These shafts may also support formed columns from near the channel bottom to the underside of the bridge deck.

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 inches wide. Some of these piles



Figure 3-4 Exposed Timber Piles at Scoured Abutment

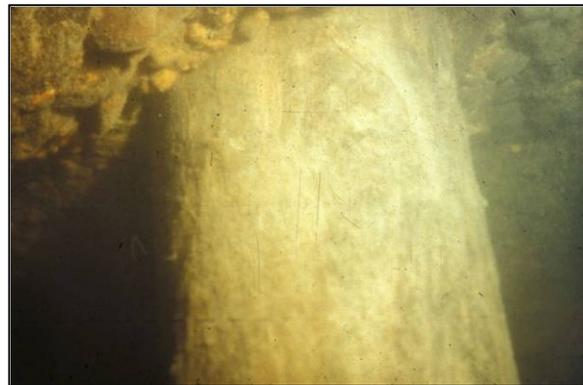


Figure 3-5 Timber Pile at Underside of Concrete Pier

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. Figure 3-6 illustrates the use of steel H-piles to support a bridge pier. Steel sheet piles are also often used as stay-in-place forms for foundations of piers and abutments.

Piles that are a combination of materials are also used. Often, timber and steel piles are partially or totally encased in concrete for protection or as a part of a pile repair.

Composite piles can be produced from a variety of materials, and their design and manufacture are typically proprietary. Those composite piles containing polymers are referred to as polymeric piles and different classes of polymer piles may be reinforced or unreinforced.



Figure 3-6 Concrete Pier Supported by Steel H-Piles

Composite piles are often categorized by their use as load bearing, fendering, or sheet piles.

Figure 3-7 shows a cross section of load bearing polymeric pile. Figure 3-8 illustrates the use of composite materials for both the piles and wales of a fender system. Figure 3-9 shows the installation of a composite sheet pile waterfront bulkhead.



Figure 3-7 Cross Section of Load Bearing Composite Pile



Figure 3-8 Composite Pile and Wale Fender System



Figure 3-9 Composite Sheet Piling

### 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.

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. Figure 3-10 illustrates a pier constructed of two large columns and a connecting web wall.

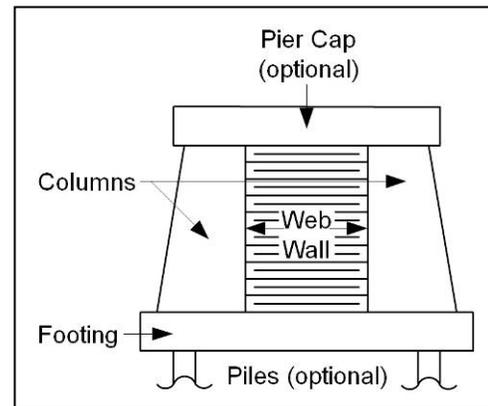


Figure 3-10 Typical Concrete Pier

### 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.

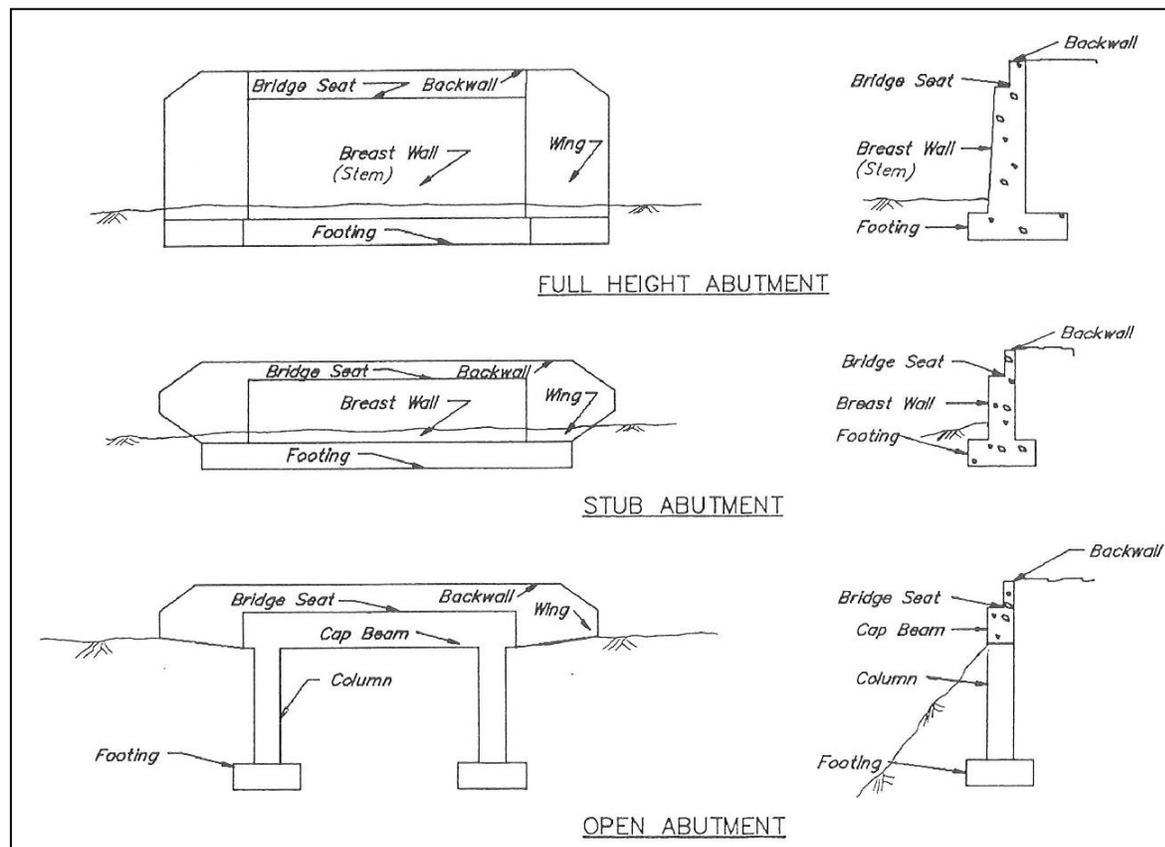


Figure 3-11 Abutment Types and Nomenclature

Abutments, classified according to their locations, are full height (closed), stub, or open (spill-through). Pile bents are also used as abutments. Wing walls are abutment extensions on the sides of an abutment which enclose the approach fill. Figure 3-11 illustrates three common abutment types.

### 3-2.4 Caissons

A caisson is an enclosure used to build a pier's foundation and carry superstructure and substructure loads through poor soil and water to sound soil or rock. In bridges designed over rivers, a floating caisson (close-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 floating 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 at the proper elevation, it is filled, generally with concrete, and the bridge pier is built on it. Figure 3-12 depicts a floating caisson in place on the channel bottom supporting a masonry pier atop it.

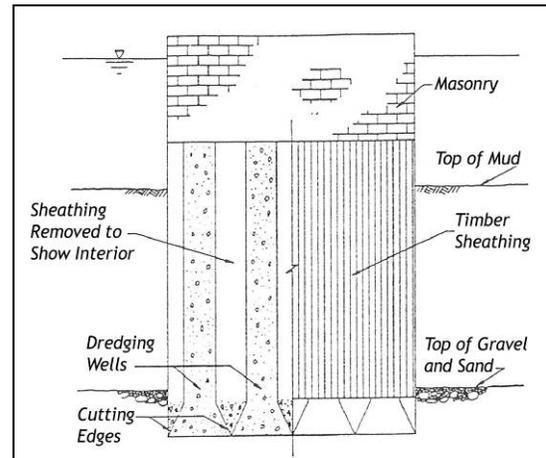


Figure 3-12 Floating Caisson

### 3-2.4 Cofferdams and Foundation Seals

Bridge piers and abutments are often constructed in the dry using cofferdams and foundation seals. Cofferdams are typically constructed of steel sheet piling. After the foundation construction is completed, the sheeting may be removed or cut-off near the channel bottom. It may be separated from the foundation material or the sheeting may be used as a form against which concrete is cast making the sheeting an integral part of the foundation. Figure 3-13 depicts the construction of a concrete pier within a cofferdam.

In many situations, before a cofferdam is dewatered, a concrete seal must be placed below water on top of the soil to prevent uplift and flooding of the dewatered cofferdam due to hydrostatic pressure. The concrete of the seal is often placed underwater with a tremie or by pumping, and may be somewhat irregular in shape or of inferior quality when compared to the portion of the foundation cast in the dry. Special care is needed in placing the underwater concrete seal so that weak layers, cold joints, or areas of laitance are not included. Figure 3-14 shows a concrete footing cast atop a foundation seal.

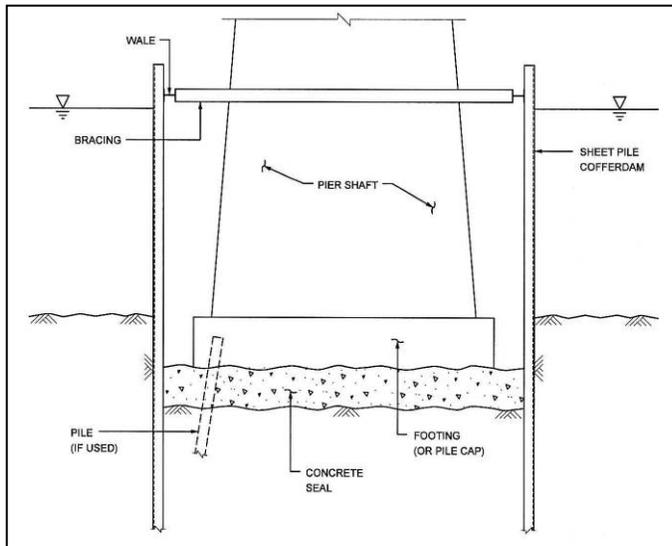


Figure 3-13 Pier Construction within Cofferdam



Figure 3-14 Foundation Seal Under Pier Exposed by Scour

Internal horizontal cofferdam bracing, typically steel, is often used in deeper cofferdams. The concrete for the new foundation may be cast directly around the bracing, in which case, the bracing will be cut off at the face of the member when the cofferdam is removed. Corrosion of exposed bracing steel may also be present.

The new foundation may also be constructed with a formwork box around the bracing so that the bracing may be removed when the rest of the cofferdam is removed. The resulting void through the new foundation may be left open or patched with concrete.

### 3-2.5 Protection Devices

Dolphins, fenders, and shear fences are placed around substructure units to protect them from vessels. These devices may be designed to absorb some of the energy of physical contact with a vessel, and may be able to protect the bridge from more 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 the forces from smaller vessel impacts.

Dolphins are generally constructed of a group of timber piles. Steel and composite piles may also be used. The piles are driven into the channel bottom and the tops of the piles are pulled together and wrapped tightly with steel cables or chains as shown in Figure 3-15. Figure 3-16 illustrates the use of steel piles with a concrete cap to act as a dolphin.

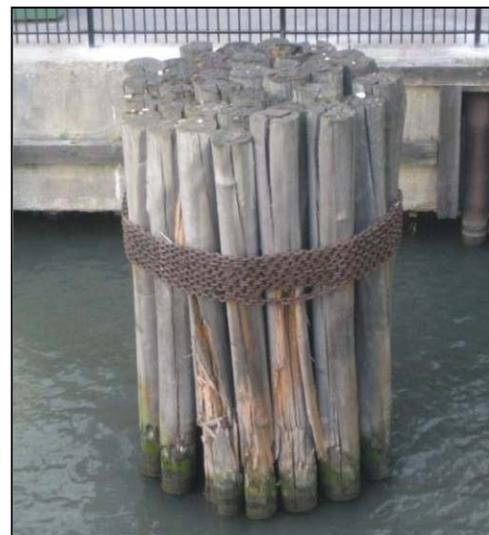


Figure 3-15 Timber Dolphin

Dolphins can also be constructed of steel sheet piling driven to form a cylinder that is filled with stone or sand, and capped with a concrete slab as shown in Figure 3-17. Large diameter steel cylinders, in place of sheet piles, may also be driven into the channel bottom and filled with aggregate and concrete.

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. Figure 3-18 shows a pile supported fender system used to protect a movable bridge pier.

A shear fence is generally an extension of a fender system, consisting of a series of timber piles supporting timber wales and sheeting as shown in Figure 3-19. Steel piles are sometimes used instead of timber.

### 3-2.7 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. Culverts may have one or multiple openings, and may be constructed of concrete, steel, or timber. Structures with over a 20-foot clear span, measured parallel to the centerline of the roadway, are commonly referred to as bridges for NBIS purposes rather than culverts; and structures with less than a 20-foot clear span are usually called culverts even though they may directly support traffic loads, and may be constructed similarly to larger structures. Refer to FHWA's Bridge Inspector's Reference Manual (BIRM) for an in-depth discussion of culverts and their 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 underwater inspection of culverts by diving presents special considerations because of their confining nature and the operational and safety requirements for confined space entry penetration dives.



Figure 3-16 Steel Pipe Pile Dolphin with Concrete Cap



Figure 3-17 Timber Fender System Attached to Pier with Steel Sheet Pile Cell Dolphins



Figure 3-18 Pile Supported Fender System



Figure 3-19 Timber Shear Fence

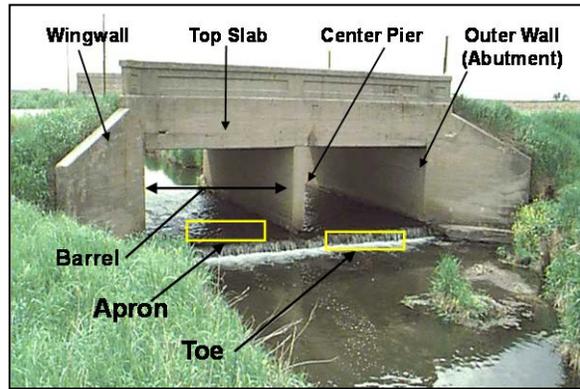


Figure 3-20 Culvert Nomenclature

## SECTION 3. DETERIORATION OF STRUCTURAL MATERIALS

### 3-3.1 Concrete

There are basically three types of concrete structures: plain, reinforced, and prestressed. Although current bridge design 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 non-isotropic material with great compressive strength, but relatively little tensile strength. The compressive strength of concrete commonly used in bridges varies from 3 to 11 kips per square inch (ksi). The addition of reinforcing steel or prestressing steel to the concrete gives the member high tensile or flexural strength.

There are four main types of concrete deterioration: cracking, scaling, spalling, and chemical attack. Concrete structures are also subject to damage from external forces.

a. Cracking. Almost all concrete cracks. Cracks are common in both new and old concrete. Cracks may be due to structural and non-structural causes. 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, providing an avenue through which water and deleterious substances can enter the concrete.



Figure 3-21 Cracked Concrete Pile

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 that is often hidden below water as shown in Figure 3-21.

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. The most common form of scaling is caused by freeze-thaw action and, therefore, is generally 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 as illustrated by the bridge pier in Figure 3-22.

The Bridge Inspector's Reference Manual classifies scaling in the following categories:

- (1) Light Scale. Loss of surface mortar; up to one-quarter inch penetration, with surface exposure of coarse aggregates.
- (2) Medium Scale. Loss of surface mortar; one-quarter inch to one-half inch penetration, with some added mortar loss between aggregates.
- (3) Heavy Scale. Loss of surface mortar surrounding aggregate particles; one-half inch to one 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 one inch.



Figure 3-22 Scaling of Pier at Waterline

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, with the waterline referenced to a fixed elevation on the substructure unit. 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.

c. Spalling. Spalling is a depression in the surface of concrete which exposes corroded reinforcing steel as shown in Figure 3-23. It is primarily the result of internal pressures within the concrete caused by corrosion of the steel.

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

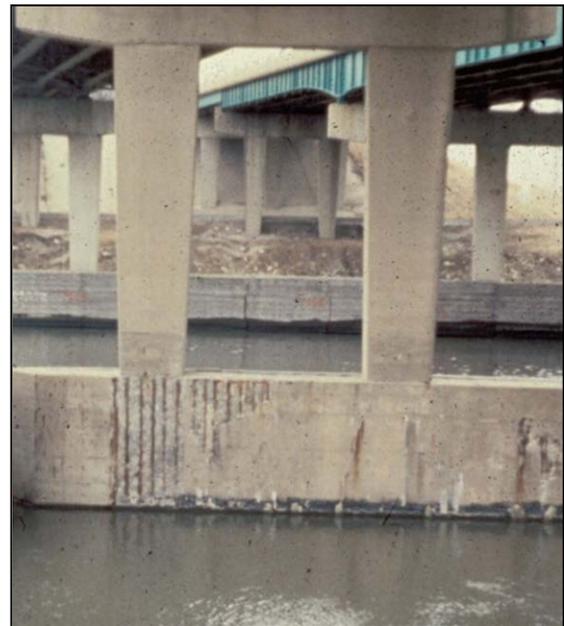


Figure 3-23 Spalling of Concrete at Waterline

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. These expansive forces crack the concrete and “pop-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 fresh surface for rapid corrosion. In colder climates, water freezing in small cracks also expands, enlarges the crack, 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 areas are also known as closed spalls or delaminations, and 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 and tie wires protruding from concrete structures below water. It is also common to find steel rods used to tie formwork 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 sometimes subjected to chemicals that attack the concrete. The forms of chemicals vary and may be present in the concrete, in the water, or in the adjacent soil. The principal forms of attack are related to chlorides, alkali-aggregate reaction, sulfates, and delayed ettringite formation (DEF), and generally involve volumetric changes.

The penetration of chlorides into concrete can cause corrosion of the reinforcing steel. Chlorides may enter the concrete from salt water, deicing agents, or admixtures. Chlorides make water a better electrolyte, and spalling is likely to eventually occur when chlorides are present.

Alkali-aggregate reaction deterioration occurs in the presence of aggregates that react with alkali hydroxides in the concrete. The most common type of alkali-aggregate reaction is alkali-silica reaction (ASR). The reaction occurs between the alkalis present in the cement paste and reactive forms of silica contained in certain types of aggregate. The reaction forms a gel that swells when it absorbs water, and causes expansive forces that damage the concrete. The damage is usually evident in the form of map cracking in areas where there is a continuing source of water, such as piers at the water line.

Sulfates are present in seawater and are common in ground waters, especially where there are high proportions of certain clays 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. Sulfates react with tri-calcium aluminate to form ettringite which swells and causes cracks. Sulfates also react with calcium hydroxide to form gypsum. With further deterioration, the surface ravel as material is easily chipped away. The newly exposed surface is often white in color. Figure 3-24 shows an area of sulfate attack on a submerged corner of a bridge pier in a salt water environment.

Ettringite is formed in concrete when gypsum and sulfates react with calcium aluminate in the cement paste. During the normal curing process, this reaction occurs while the concrete is still somewhat plastic, and the formation and expansion of ettringite does not cause damage to the concrete. If concrete is cured at high temperatures, for example, when concrete piles are steam cured, the normal ettringite formation process is prevented. Later, however, in the presence of moisture, when the concrete is rigid, ettringite forms and can cause cracking of the concrete. Figure 3-25 shows a concrete pile that has suffered severe deterioration due to delayed ettringite formation (DEF).

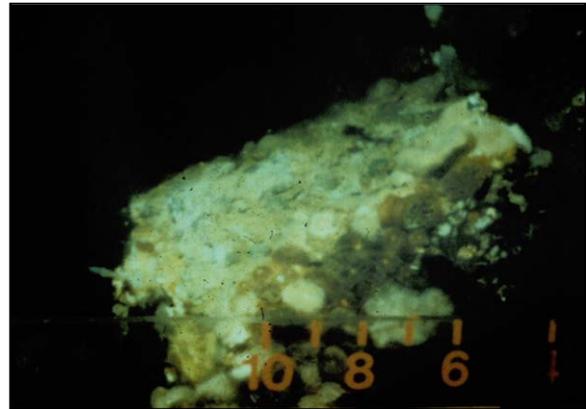


Figure 3-24 Sulfate Attack of Concrete Pier



Figure 3-25 Pile Damaged by Delayed Ettringite Formation

### 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. Galvanic Corrosion. Corrosion of steel H-piles in salt water 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 underside of the concrete or near the waterline as illustrated in Figure 3-26.

A common remedial action is to encase the piles 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 location of the loss of metal is shifted to just below the concrete encasement. This repair may, in fact, make the situation worse, as the upper cathodic area becomes more massive and the anodic exposed steel pile becomes smaller. Rapid and severe corrosion of steel piles has been noted below the concrete encasement as shown in Figure 3-27.

Corrosion is the conversion of the metallic ion into solution through an electrochemical process. For electrochemical corrosion to occur, there must be a current flow, an electrolyte, and oxygen. The current flow can be caused by external forces, or as the result of differences in potential between different metals or different portions of the

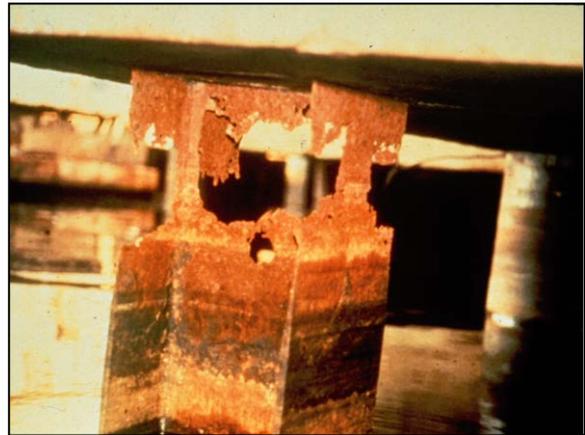


Figure 3-26 Severely Corroded H-Pile



Figure 3-27 H-pile Corrosion Below Concrete Encasement

same metal member. 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 by coatings, 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 uncontaminated 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 such as fine aggregates, these can also remove the initial film of corrosion and increase the rate of corrosion. The corrosion rate is also generally greater in warm waters than in cold waters.

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

b. Microbial-Induced Corrosion. Microbial-induced corrosion (MIC) is a form of localized and rapid corrosion that typically occurs at or below low water. A particularly severe form of MIC is known as Accelerated Low Water Corrosion (ALWC). MIC consists of microorganisms that through their biological processes cause elements to corrode at an accelerated rate. Cases have been documented where MIC has accelerated corrosion by as much as ten times the normal rate.

A bright orange sulfurous deposit on the steel, near the waterline, as shown in Figure 3-28, indicates the possible presence of MIC, but it must be removed to confirm the presence of MIC.



Figure 3-28 Orange Deposit on Sheet Pile



Figure 3-29 Steel Sheet Pile with MIC

The orange deposits can generally be easily removed by wiping with a gloved hand. When it is removed, if MIC is present, there will be a layer of gray, black, often flakey, corrosion products of iron sulfide. If the iron sulfide is removed, the underlying steel is generally pitted and shiny. Figure 3-29 shows the various layers of MIC.

Besides visual examination, the presence of MIC can be confirmed by chemical tests for MIC byproducts, by biological cultures of MIC, and by microscopic analysis.

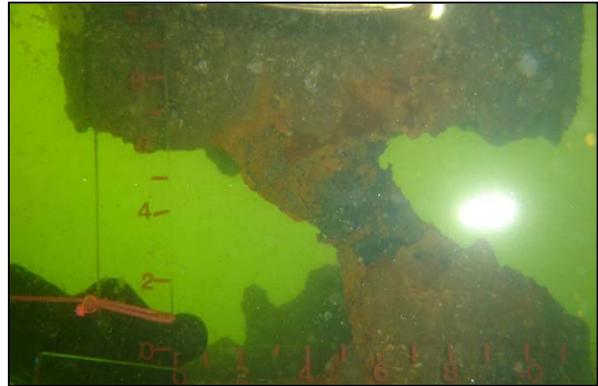


Figure 3-30 Steel Pipe Pile with ALWC

Figure 3-30 shows the remaining cross section of a 30-inch diameter steel pipe pile that has experienced severe losses due to MIC. The pile had been in service for less than 15 years in a saltwater port.

c. Coatings. Coatings are used to prevent corrosion. Coated steel structural members should be inspected 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.

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 tight fit. Even the bolts used to connect timber bracing can corrode. The differences in encapsulation between the portions of bolts in the timber and the portions directly exposed to water, and therefore differences in electrical potential, may be great enough to produce a corrosion cell. Dissimilarities between material properties of nuts and bolts can cause significant losses to either the nut or the bolt.

Connections such as H-pile splices should be examined at the welds. The dissimilarities between the 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 may be different from the base material of the pile. 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. Figure 3-31 shows a welded splice detail for a submerged H-Pile.



Figure 3-31 Welded Splice of H-Pile

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.

e. 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 for many years. They have not commonly been used on bridge substructures in the past, but cathodic protection systems may become more common on bridge substructures in the future.

Cathodic protection systems can stop further corrosion. When two dissimilar metals are connected to each other, there will be a flow of current between the two metals. The more active metal member, the anode, will sacrifice itself, i.e., corrode, to protect the less active member, the cathode. A cathodic protection system uses this principle to protect the entire structure, by adding anodes which are more active so that the entire structure becomes a cathode and is protected from further corrosion.

Cathodic protection systems can be galvanic or impressed current types. In an impressed current system, sometimes called an active system, a small direct current is generally provided by a rectifier to an anode constructed of an inert material. The current must be properly regulated to provide protection for the

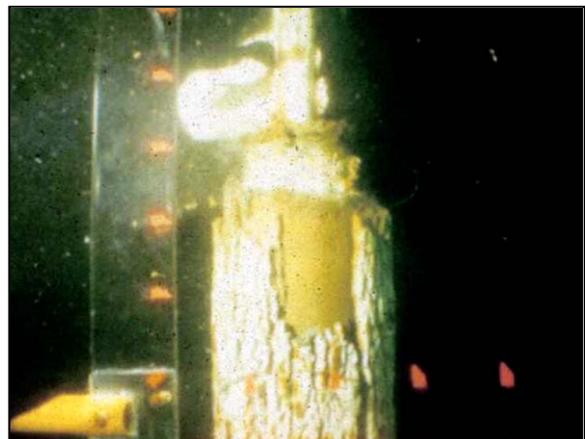


Figure 3-32 Impressed Current Anode

structure without excessive current. Figure 3-32 shows an underwater impressed current anode. The above water rectifier should be inspected to ensure it is operational. Electrical wiring and impressed current anodes should also be inspected for damage.

Galvanic, or passive, cathodic protection systems use sacrificial anodes. Sacrificial anodes are made from alloys of relatively inexpensive materials such as zinc, aluminum, and manganese, which are more electrically active than the steel of the structure. Sacrificial anodes may be bolted to the structure as shown in Figure 3-33, or may be suspended from steel cables. The anodes must have electrical continuity with the structure to be protected, and should not be painted. The anodes and electrical cables should be inspected for continuity. Some loss of anode material is to be expected if the system is working properly, but the anodes should exhibit some remaining life.



Figure 3-33 Sacrificial Anode on Steel Pipe Pile

An underwater inspection of a cathodic protection system should include determination and documentation of the condition of the anodes and all electrical components of the system.

### 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 in bridge substructures are granite, limestone, and sandstone. Typical problems 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, and the man-made mortar deteriorates like concrete. More rapid deterioration, such as cracking along bedding planes, may also occur in stone of lower quality. Figure 3-34 shows a typical masonry pier.



Figure 3-34 Masonry Bridge Pier of Two Types of Stone

Masonry mortar joints near the waterline are usually most susceptible to freeze-thaw damage. It is 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

Deterioration in timber members results from a variety of sources, including decay, marine infestation, bacterial degradation, abrasion, and collision. Other damage may result from careless construction practices, and faulty or missing connectors.

a. Decay. 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 present, at least intermittently. Microorganisms can easily penetrate untreated timber or older timber where the preservative has become ineffective. In early stages, decaying members appear slightly discolored.



Figure 3-35 Decayed Timber Pile near Waterline

In advanced stages of decay, the wood becomes spongy, stringy, crumbly, and splintered as shown in Figure 3-35.

Members with internal decay may appear slightly splintered and produce a hollow sound when struck with a hammer or metal bar. Vegetation growing from a pile is usually an indicator that decay is occurring on the interior of the pile.

b. 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 such as cracking invite the infestation of these creatures.

The teredo, or bankia, which is also known as a shipworm, 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 one-quarter to one-half inch in diameter as shown in Figure 3-36, with some species of bankia growing to three-quarters of an inch in diameter and four feet in length.

Since the damage caused by these shipworms is hidden within the timber, it is often difficult to detect. A close visual inspection of the entrance hole is one method of detection. Suspect areas may require coring or boring 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 one-half inch long, bores only a short way into the wood surface, and as water and wave 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 as shown in Figure 3-37.

Damage from marine borers can occur anywhere between the mudline and the waterline. 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, although environmental regulations may preclude their use in some areas.

c. Bacterial Degradation. Since the 1980s, there have been several instances reported in which continuously submerged timber pile structures have suffered significant loss of strength due to bacterial degradation. This degradation is the result of bacteria that live in the totally submerged piling. Bacterial attack is a slow process promoted by wet conditions. The bacteria exhibits distinct decay patterns which may be distinguished from fungal decay under microscopic examination.



Figure 3-36 Timber Pile with Teredo Damage

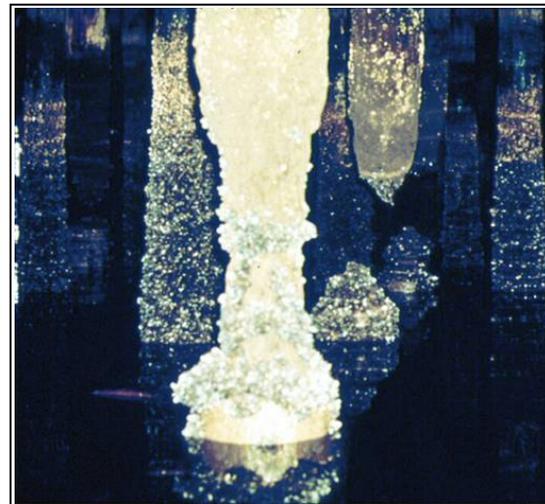


Figure 3-37 Timber Pile with Limnoria Damage

The bacterial attack may be classified as tunneling, in which bacteria mainly penetrate the wood cell walls and produce channels within the cell walls; erosion, in which bacteria erode the exposed faces of the cell walls producing troughs; or cavitation, in which bacteria form cavities within the cell walls. All three can significantly reduce the strength and other properties of the timber.

### 3-3.5 Composite Materials

a. Properties. Composites, or fiber reinforced polymers (FRP), are a mixture of fibers and resins. Typical fibers are glass, carbon, and aramid; typical resins are epoxy, polyester, and vinyl esters. The physical properties of composites, such as modulus of elasticity, strength, and toughness, are dependent on the type and amount of ingredients in the mixture. The materials are non-isotropic; i.e., they can have different properties in different directions. Those properties are dependent on the particular manufacturer, and data on the properties must be obtained from each manufacturer for particular products.

There are four main applications for composite materials:

- Structural shapes
- Non-metallic reinforcements
- Repair and strengthening elements
- Hybrid structural elements and systems

b. Mechanical Defects. Similar to traditional materials, most mechanical defects of composite materials are due to impact and abrasion, or construction related events.

In installation of composite piling, driving equipment must be matched to the product to prevent overdriving or chipping and cracking of materials. In driving composite sheet piling, joints and interlocks may become damaged or separated in rocky soils.

Non-metallic connectors are available for some installations, but traditional metallic connectors are commonly used. The metallic connectors may not have the same service life as the composite material. Some connectors may also be stronger than the composite material they connect and may result in yielding or splitting of the composite materials as shown in Figures 3-38 and 3-39.

Sometimes, in inspecting composite members underwater, it is difficult to identify that the member is composite. Many composites have shapes similar to dimensional lumber or small structural steel shapes. Figure 3-40 shows composite I-beams underwater. Use of a magnet, striking with a hammer, or scraping with a knife may be necessary to properly identify materials that have shapes common to other materials.

c. Environmental Defects. Composites are susceptible to fire and ultra-violet ray degradation. Admixtures can, however, reduce their effects on members. Composites are more resistant to marine borers than timber members.



Figure 3-38 Yielding Around Hole of Composite Member



Figure 3-39 Failure of Composite Member

### 3-3.6 Vessel Damage

All bridges located in water are susceptible to damage from external forces such as vessels. Bridges are often located at the narrowest portion of a waterway in order to reduce bridge construction costs; but even in wider waterways, piers may restrict the navigable channel, reducing the maneuverability of vessels. Damage from vessel collisions may be visible above water, as shown in Figure 3-41, but the extent of underwater damage cannot be properly assessed without a detailed underwater inspection.

Significant damage below water, caused by vessel prop wash, may not be visible above water. Ferry vessels leaving terminals and tugboats moving strings of barges from moorings often rotate their propellers at high speeds to overcome inertia. This movement can pick up bottom material and discharge it against foundations, in effect, sandblasting the material. Over time, this can cause erosion of concrete and steel surfaces.

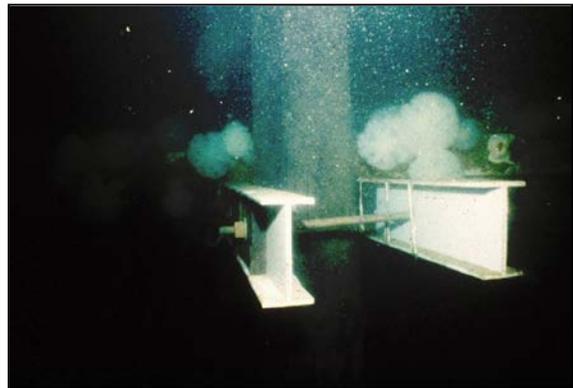


Figure 3-40 Composite I-Beams



Figure 3-41 Vessel Damage

## CHAPTER IV UNDERWATER INSPECTION EQUIPMENT

### SECTION 1. THE DIVER'S ENVIRONMENT

The diver's work environment is inherently hostile. Divers often work in dark, cold isolation and are exposed to a variety of pressure-decompression related illnesses and injuries. The dangers presented by waterways, such as high flow velocities, limited underwater visibility, potential for entanglement, and poor water quality also contribute to the hostile nature of the diver's work environment (Figure 4-1). Divers must rely completely on external life support systems while working under severe limitations such as diminished sensory and perceptual capabilities; interference with cognitive capabilities; and psychomotor skills. Reduced physical working capacity and physiological and psychological stress also limit diver effectiveness.



Figure 4-1 Diver After Working in a Polluted Environment

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

To work effectively, the diver must adapt to the environment, be familiar with the diving equipment, and select methods appropriate for the task. A bridge inspector cannot properly conduct an underwater inspection if the diver's sole concern is survival. A diver must feel safe and be comfortable while working in order to do an accurate and effective job.

Air is the most commonly used breathing medium for diving. When air is breathed under pressure, as in diving situations, inert nitrogen and other gases diffuse into the tissues of the body. The amount of nitrogen absorbed increases with the 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 tissue and blood. These bubbles tend to collect at the body's joints resulting in what is commonly known as the "bends" or, more correctly referred to as, decompression sickness. For this reason, a diver's time and depth in the water must be carefully monitored.

Combinations of deep dives and dives of long duration may require the diver to decompress in stages by slowly ascending and spending time at intermediate depths or in a recompression chamber, thereby allowing sufficient time for the nitrogen and other gases to safely come out of solution. The majority of bridge inspection dives are of short duration or at shallow depth; therefore, decompression stops or recompression are not normally needed. Such dives are referred to as no-decompression dives. Figure 4-2 indicates the no-decompression time limits for various depths of diving.

NO-DECOMPRESSION LIMITS <sup>1</sup>	
DEPTH (ft)	NO-DECOMPRESSION LIMIT (minutes)
30	405
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

<sup>1</sup>This table does not consider the effects of repetitive dives.

Figure 4-2 No-Decompression Dive Limits (Adapted from U.S. Navy Diving Manual)

Although decompression is not normally a concern within the limits shown in Figure 4-2, an amount of nitrogen remains in the diver's tissues after every dive. For repetitive dives, the diver must consider the effects of residual nitrogen in evaluating the adjusted no-compression times for subsequent dives and assessing the need for planned decompression.

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

The diver's greatest threat is loss of supply of the breathing gas, but another threat is inadequate ventilation of the diver's mask or helmet resulting in 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 the intake of a diving air source compressor.

Breathing air under high partial pressures can cause oxygen poisoning. Partial pressures of oxygen in excess of those 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 fsw. The greatest opportunity for exposure to oxygen poisoning is during recompression treatment or surface decompression using oxygen.

Because of the potential for nitrogen narcosis and to reduce the risk of decompression sickness, other breathing media, such as Heliox—a mixture of oxygen and helium, or Nitrox—a mixture of air with increased oxygen percentages may also be used. Mixed-gas dive stations are more costly to set up and operate, and they require specially trained dive personnel. Safety standards also require the presence of a recompression chamber for any type of mixed gas diving. Most bridge inspections are conducted at depths where air can be used as the breathing medium. 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 the air supply in a tank; and surface-supplied diving, in which the diver's air source is in a

boat or on shore and delivered to the diver through an umbilical hose. Both modes of diving are permitted by the Occupational Safety and Health Administration's (OSHA) Commercial Diving Operations standard (29 CFR 1910 Subpart T) and both can have a place in bridge inspections. In some situations, one mode may have significant economic benefits over the other, while allowing for the gathering of all the inspection information required without, in any way, compromising safety. The appropriateness of a particular mode for any specific diving situation depends on a number of factors including depth, bottom time, inspection tasks, waterway, environment, the presence of hazards, and the experience and capability of the diver. Each mode has unique operational advantages and disadvantages.

Because scuba diving is often associated with recreational diving, in the following sections related to bridge inspection, scuba will be referred to as commercial scuba to emphasize that all diving operations must, as a minimum, be conducted in accordance with the OSHA Commercial Diving Operations standard.

Commercial 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 with two-stage regulators to deliver air to the diver. High pressure compressors are used to fill the scuba tanks. The first stage of the regulator is attached directly to the valve of the high pressure tank. This first stage reduces the high pressure air (generally 3,000 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 (Figure 4-3). As the diver inhales, a valve is activated which allows the air to flow to the diver.



Figure 4-3 Diver with Scuba Equipment

Commercial scuba is well suited for inspection work because of its portability and ease of maneuverability in the water, in particular where many dives of short duration at different locations are required rather than one long sustained dive. Scuba equipment weighs about 75 pounds and requires no elaborate topside support operation. It has the advantage that the diver does not have to drag an air hose along. OSHA requires that a single commercial diver using scuba be line-tended when in the water. When a diver is

accompanied by and in continuous visual contact with another diver, there are situations when line-tending is not required. Divers using commercial scuba must be line-tended where visibility is poor, when the current exceeds one knot, or when diving is conducted within enclosed or physically confining spaces. OSHA prescribes other operational procedures, equipment, and minimum staffing requirements for the use of commercial scuba.

The use of commercial scuba is limited by OSHA to water depths of 130 feet and the bottom time is limited by the amount of air the diver can carry. The depth and bottom time requirements of most bridge inspections are well within the no-decompression limits of commercial scuba diving as shown in Figure 4-4.

Surface-to-diver communication is possible using scuba with either hard wire or wireless systems. The state of the technology for wireless systems has progressed to the point where direct line-of-sight conditions are not necessary for adequate transmission. Communication may be desirable for certain dive operations where commercial scuba has been determined appropriate in order to enhance safety or inspection efficiency.

Surface-Supplied Air. Commercial surface-supplied air diving equipment used for bridge inspection is commonly referred to as lightweight diving 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). There are free-flow air helmets in which a constant stream of air is supplied to the diver, but the more commonly employed commercial helmets and full

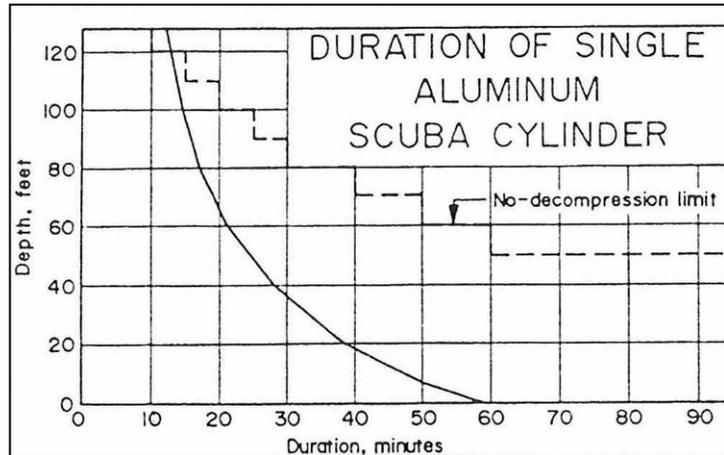


Figure 4-4 Typical Dive Duration for Scuba Diver with one 80 c.f. tank.

*Note: Dive duration varies significantly for different divers and different levels of exertion.*



Figure 4-5 Diver Using Surface-Supplied Air and Full Face Mask

face masks incorporate demand regulators similar to those used in the second stage of scuba equipment. Figure 4-5 shows a diver using a full face mask for surface-supplied diving.

In a surface-supplied system, air is supplied by a high volume, low pressure compressor or from a bank of high pressure cylinders (tanks) equipped with a regulator to reduce the high pressure. When a compressor is used, air is sent through a filtering system into a volume tank at about 150 to 200 psi. From the volume tank, the air goes to a manifold to which the diver's umbilical is connected. Figure 4-6 shows a diver using a lightweight helmet.



Figure 4-6 Diver Using Surface-Supplied Air with a Lightweight Helmet

The diver's umbilical is composed of a breathing air hose, a pneumofathometer air hose, a communication cable, and a strength cable. The strength and communication cable may be an integrated unit. The pneumofathometer hose is used by a tender at the surface to monitor the diver's depth. With a surface-supplied system, a tender must monitor the diver's air supply and depth, and maintain continuous communication with the diver. Umbilicals may also include hot water hoses for heated exposure suits and video cables.

Surface-supplied air diving provides a number of advantages, including "unlimited" breathing gas supply and communication, which greatly enhance operational safety. Helmets and dry suits also provide protection from polluted waters. Bottom times, beyond the no-decompression limits, can be achieved on surface-supplied dives if decompression schedules are used. Dives in accordance with OSHA standards, when surface-supplied air is used, can be conducted to depths of 190 feet or, if bottom times are less than 30 minutes, to depths of 220 feet.

Surface-supplied air diving operations require more topside support than scuba diving operations. The major disadvantage of surface-supplied diving is the limited mobility as a result of the connection to the surface. Inspection work generally requires the diver to constantly change depth or travel around structures or obstacles.



Figure 4-7 Recompression Chamber

Additional support equipment, for both scuba and surface supplied operations, could include a recompression chamber (Figure 4-7). A chamber is required by OSHA when dives exceed 100 fsw or when the no-decompression limits may be exceeded.

## SECTION 3. DIVER'S EQUIPMENT

### 4-3.1 Scuba

Exposure Suits. Water is a very effective cooling agent. A diver immersed in water at a temperature less than body temperature rapidly loses body heat. Even in relatively warm water, a 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 used for underwater inspections: the wet suit and the dry suit. Hot water suits, which are supplied with warm water from the surface, can also be used, but are not usually necessary for the typical duration of an underwater bridge inspection dive. In warm waters, generally above 50 degrees Fahrenheit, a wet suit will provide adequate thermal protection. The suit is intended to be 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. Wet suits are available in various thicknesses. The effectiveness of a wet suit depends on suit thickness, fit, water temperature, and the depth of the dive. A full wet suit consists of a jacket, pants, boots, gloves, and hood.

A variable volume dry suit is an extremely effective suit in cold water. Dry suits are also used extensively 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 integral to 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 or without thermal underwear, which provides additional protection against cold both in and out of water. The dry suit normally requires the diver to wear more weight than is worn with a standard wet suit, due to the volume of air in the suit.

Commercial Scuba Equipment. In addition to an exposure suit, the diver generally has a standard list of dive equipment, some of which items are mandated by OSHA. Essential equipment, other than the scuba regulator and tank, includes:

- Face mask
- Buoyancy compensator-personal flotation device
- Reserve breathing gas supply
- Weight belt
- Swim fins

- Knife
- Wristwatch
- Depth gauge
- Submersible pressure gauge

Each item is discussed below in general terms. Applicable safety standards may impose additional requirements for the use, maintenance, or testing of these items.

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. Most often a BC is in the form of a vest, although there are also "horse collar" style buoyancy compensators. BCs allow the diver to maintain neutral buoyancy at different depths or to maintain a face-up position at the water 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 a source independent of the breathing-gas supply; or 3) in an emergency with a CO<sub>2</sub> (carbon dioxide) cartridge attached to the BC.

Each scuba diver should have a diver-carried reserve breathing-gas supply that consists either of a manual reserve (J-valve) for the primary air cylinder, or an independent reserve cylinder that has a separate regulator. The independent reserve should be of sufficient size to meet the emergency air volume requirements of the planned dive.

A diver uses a weight belt to help control buoyancy. The most popular weights are molded lead which fit onto a nylon web belt equipped with a quick-release mechanism. The amount of weight worn by the diver depends on natural buoyancy and the buoyancy of the equipment that is worn. 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 a proper pair of fins.

The diver's knife is used primarily as a tool and is available for emergencies, such as entanglement. 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 a very important piece of equipment for scuba diving. A diver uses it to stay within the no-decompression limits, to control decompression dives or to monitor rates of ascent.

Depth gauges measure the pressure created by the column of water above the diver and are calibrated to indicate a direct reading of depth in feet of 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.

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

Dive lights are waterproof, pressure-proof, underwater flashlights. They can be very useful where natural light does not penetrate the water to the dive depths, but they are of limited usefulness in muddy or dirty water where there is significant turbidity.

A dive computer continuously monitors bottom time and water 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 time spent at different depths on the way to the surface. The advantage of this method of monitoring and calculation is that the diver can stay in the water for longer periods of time than if the 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. It should not be used, however, without a full understanding of its capabilities and limitations.

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 a cable to a surface transmitter-receiver. This is used regularly in surface-supplied diving and can be used when a scuba diver utilizing a full face mask is tended with a strength/communication line.

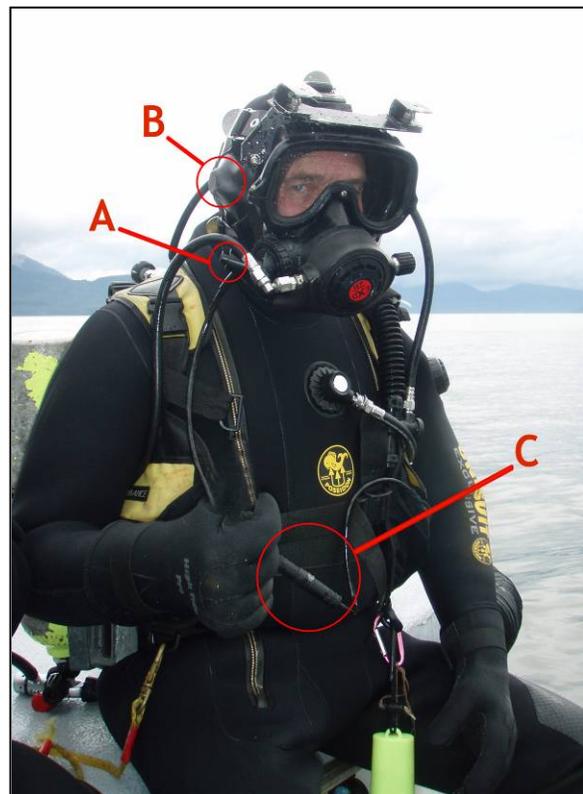


Figure 4-8 Diver with Wireless Communication System. Note Microphone (A) and Earphone (B) on Mask, and Transceiver (C) at Waist.

Wireless systems are available for use with scuba diving equipment. The advantage of a wireless system is that it allows the diver greater mobility. Figure 4-8 shows a commercial scuba diver using a wireless system.

### 4-3.2 Lightweight Surface-Supplied Diving

**Basic Equipment.** Lightweight surface-supplied divers share a few basic items with scuba divers, namely: an exposure suit, a weight belt, a knife, and a reserve breathing gas supply. Swim fins or boots are worn depending upon the work requirements. A wristwatch or timing device is generally not required to be worn by surface-supplied divers because the tender is responsible for accurate timekeeping during the dive. 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 or helmet, and to provide a lifting point to assist in recovering a diver in an emergency.

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

With a free-flow system, air is delivered to a helmet continuously and then 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 (Figure 4-9) is an example of a modern free-flow air helmet. 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 MK12 Free-Flow Helmet  
(Courtesy of Morse Diving, Inc.)

Demand masks combine a regulator, similar to the scuba regulator's second stage, with a "face mask" in one unit. The masks, referred to as "full-face masks" or "band masks," have a large face plate and a regulator, and a back strap, called a "spider," to secure the mask to the diver's head, and to promote a tight seal for the mask around the diver's face. Air is supplied to the regulator via a sideblock, a one-way valve attached to the mask or safety harness, which is in turn connected to a primary and backup air source (Figures 4-5 and 4-8).

Demand helmets (Figure 4-6) have 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 equalizing pressure in 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 helmets.

Backup Air Sources. When a surface-supplied 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 a reserve air source for shallower dives. This reserve is typically a high pressure tank of appropriate size, with appropriate fittings connected to the helmet for free-flow apparatuses, or connected to the sideblock of a demand mask or helmet.

OSHA also requires that when a surface-supplied dive is conducted deeper than 100 fsw or outside the no-decompression limits, there must be a reserve air supply system, independent of the primary supply system, at the surface location from which diving operations are conducted. Many organizations require a reserve air supply for all surface supplied air dives.

Tenders. Each diver must be continually tended while in the water. Tenders are responsible for ensuring that the planned dive profile is followed and for maintaining the dive station. All components of the surface-supplied dive systems, including communications, compressors, pressure gauges, backup systems, as well as the diver, are to be continuously monitored during each dive operation. 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. Often, a significant portion of the underwater work in bridge 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 commonly used underwater.

In deciding whether to use power tools or hand tools, the inspection team leader 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, however, where extensive cleaning is required, the use of power tools would normally be warranted.

#### 4-4.2 Tools

Hand Tools. Almost all standard hand tools can be used underwater, but they require better care and maintenance than tools used only above water. Typical tools used during a below water inspection include scrapers, ice picks or awls, hammers, axes, hand drills, wire brushes, pry bars, and hand saws. Divers routinely drop tools, so it is usually best to secure the tools to the diver with a lanyard to avoid lost time searching for lost tools in soft bottom material. Work with hand tools underwater can be slow and arduous, making their use impractical for larger jobs. Figure 4-10 shows a diver using a scraper with a lanyard to clean a submerged concrete surface.



Figure 4-10 Diver Cleaning Submerged Concrete Surface with Hand Scraper

Power Tools. Both pneumatic and hydraulic tools are used underwater. Although pneumatic tools are not usually designed specifically for underwater use, they can often 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. Pneumatic tools can be costly to maintain in the marine environment, requiring frequent disassembly and lubrication. Pneumatic tools also produce streams of bubbles that can obscure 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 the diver is heavily weighted or secured to something at the work site. An advantage of hydraulic tools is that they do not create the bubbles that pneumatic tools do. Power tools that use biodegradable vegetable oil rather than hydraulic fluid have also been developed. Additionally, power tools have been developed which use sea water or fresh water rather than air. A pump located on the surface pumps water to the tools, and the water is expelled underwater through the tools. A water blaster can be a useful piece of equipment for cleaning a structure below water. 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, in addition to biofouling.

## SECTION 5. UNDERWATER IMAGING

### 4-5.1 Photography and Video

Improvements in underwater documentation equipment and techniques have been significant in recent years, in part, because of improvements in underwater digital cameras and video equipment available 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.

a. Photography. Color digital photographs can be made of underwater conditions relatively easily. Most popular above water cameras 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 (Figure 4-11).

There are also waterproof digital 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 (Figure 4-12). There are also cameras in 35 mm format that can be used below water, either by virtue of being waterproof or when out-fitted with an underwater housing.

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 waterways, visibility is only a few inches; while in others, however, visibility is one or two feet. Given the limited visibility, the camera-subject distance must be minimized, and a wide angle lens must be used to photograph a reasonably-sized area in one picture. Because of the refractive property



Figure 4-11 Various Waterproof Camera Housings



Figure 4-12 Digital Camera in Waterproof Housing

of the water, underwater 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. For this reason, a graphic scale should be included in all underwater photographs.

It is also important to document the location of underwater photographs taken during an inspection. A photograph log should be maintained with information about the location, severity, and significance of conditions that are documented. See the end of this chapter for a sample Photograph Log.

b. Photographic 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 to the camera lens. To minimize this problem, the electronic flash unit must be placed to one side, or at an oblique angle, so that light does not reflect directly into the lens (Figure 4-13). 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 4-13 Underwater Camera and Strobe Unit

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 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. The process is facilitated by the digital technology of today's cameras, which allows for instant review of the photographs taken.

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 and editing 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 can also often be no frame of reference for identifying a particular picture because underwater photographs often look similar. Technicians editing underwater photographs may have difficulty in determining the correct tint. A graphic scale, with location information and a patch of known color—for example, the labeling tape—should be included in the photograph to provide a standard against which the photograph editor can adjust the color (Figure 4-14).



Figure 4-14 Graphic Scale with Location Shown

c. Video. Just as consumer video cameras and recorders have improved dramatically in recent years, underwater video equipment has likewise improved. Highly sophisticated, compact underwater video 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. Housings for the units are made by a number of manufacturers and can be modified so a monitor can be used at the unit or on the surface (Figure 4-15).



Figure 4-15 Video Camera in Housing with Monitor

These video systems can be configured to provide on-screen titles and clock, and also can include narration by the diver and the surface observer. In underwater video work, there is often a large portion of the recording 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 the recording which illustrate only good conditions. If the recording is to be reviewed by high level personnel, it is usually cost-effective to edit the recording to reduce viewing and review time.

Video cameras may also be attached to staffs or truck-mounted mechanical arms for deployment from bridge decks, with images relayed to monitors and recording devices. The same mechanical arms and staffs can be used to deploy sounding and imaging transducers, current meters, and similar equipment.



Figure 4-16 Clearwater Box

d. Clearwater Box. When the water is extremely turbid, visibility may be reduced to a few inches or less, 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 allowing the camera to focus through the space of clearwater. Various sizes and shapes of boxes can be constructed, depending on the objects to be photographed.

A typical clearwater box for general purpose underwater photography is fitted with handles to make control of the box easier, brackets for mounting the camera and flash units, and caps for filling the box with water (Figure 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. Ideally, the box should be slightly negatively buoyant when filled completely with water. An air gap may be left inside the box to make it positively buoyant, if necessary.

The face of the box shown in Figure 4-16 is about 16 inches high by 24 inches wide, and the distance from the front of the box to the back is about 10 inches. A wide angle lens is mounted on the back 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. Clearwater boxes can be custom-made for various camera-lens combinations and the resulting field of vision. The use of the clearwater box normally requires two divers: one to operate the camera and one to help control the box. In stronger currents, it may require more divers; and in extremely strong currents, it may not be possible to effectively use the device. Refer to Figure 4-17 for a photograph taken with a clearwater box.



Figure 4-17 Photo Taken Through Clearwater Box

e. Remotely Operated Vehicle (ROV). A remotely operated vehicle (ROV) is a tethered underwater video camera platform, sometimes equipped with manipulator systems or special testing equipment that incorporates an electric or electro-hydraulic propulsion system. 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 operations 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 4-18).



Figure 4-18 Remotely Operated Vehicle (ROV) with Control Console

Although the dependability of the ROV has steadily increased, some limitations still remain. The ROV can only supply two-dimensional views of conditions; 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 due to its umbilical being tangled.

#### 4-5.2 Underwater Imaging

Underwater acoustic imaging has been used for specialized offshore investigations for many years. Equipment now available provides greatly improved images of channel bottom conditions, undermining, and submerged foundations. The use of acoustic imaging can also aid in the planning of diving operations by detecting areas of apparent damage and allowing concentration of diver operations in those areas.

Acoustic imaging can also be used to enhance diver safety by identifying potential dive hazards, such as underwater obstructions, before divers enter the water.

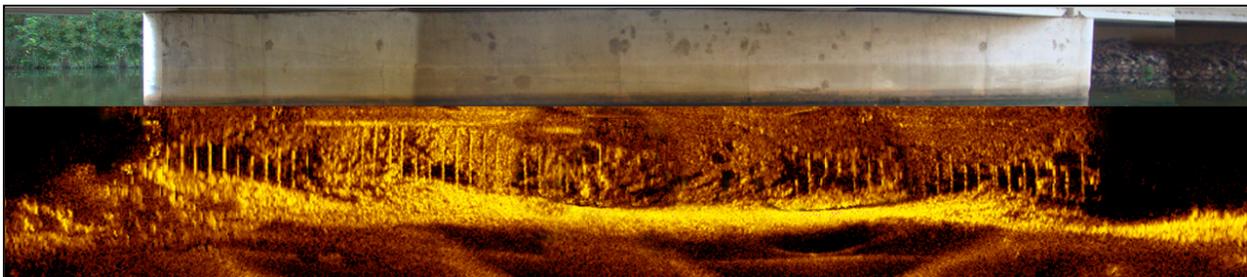


Figure 4-19 Acoustic Image of Pile-Supported Bridge Pier

Underwater acoustic imaging systems can provide images of underwater structures in situations where underwater cameras cannot be used because of turbidity in the water. Even in fairly clear water, the effective range of underwater cameras is limited to a few feet. Acoustic imaging equipment can operate at distances of over 200 feet.

Underwater acoustic imaging systems operate similarly to sonar depth sounders, but the acoustic imaging equipment operates at significantly higher frequencies. While depth sounders generally operate in the range of 200 kHz, acoustic imaging equipment operates in ranges from approximately 700 to 1400 kHz, resulting in much greater definition and clarity. Underwater acoustic imaging systems transmit sound waves which, upon striking an object, are reflected back to the equipment. Depending upon the equipment and software employed, two and three dimensional images can be generated.

Acoustic imaging is useful in making emergency evaluations of bridges damaged by vessel impacts, especially where water conditions, such as high currents, low visibility, sunken vessels, or accumulated debris, preclude deploying divers. Acoustic imaging may also be used prior to or as part of a Level I inspection to aid in planning an underwater inspection to more efficiently employ diver inspectors. Figures 4-19 and 4-20 illustrate images of bridge piers.



Figure 4-20 Acoustic Image of Concrete Pier with Steel Sheet Piling Cofferdam

## SECTION 6. DIVE PLATFORMS

### 4-6.1 General

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, as well as a suitable size for the waterway conditions. Working conditions must be safe for both the above water crew and the divers.

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 alpha 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, as shown in Figure 4-21, should generally be flown for safety.

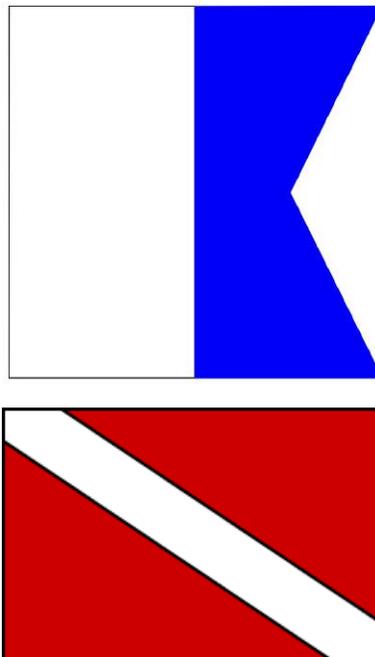


Figure 4-21 Code Alpha and Sport Diver Flags

## Sample Photograph Log

PHOTOGRAPH LOG

6/12/06 NOTES: DGS

CAMERA: Sea &amp; Sea 8 Mega pixel Digital Camera w/ underwater housing, 6x wide angle lens, and TS25 Auto strobe

NOTES: UW visibility at time of inspection was  $\pm 2'$ . Sufficient for camera setup w/ no clear water box required.

<u>PHOTO NO.</u>	<u>TAKEN BY</u>	<u>LOCATION/ORIENTATION</u>	<u>DESCRIPTION</u>
1	DGS	East bank 1kg SW	Overall of US Bridge Fascia
2	DGS	East bank 1kg NW	Overall of DS Bridge Fascia
3	DGS	Bridge deck 1kg N	Overall of US Waterway
4	DGS	Bridge deck 1kg S	Overall of DS Waterway
5	DGS	West bank 1kg SE	Overall of West side of Pier b
6	DGS	East bank 1kg NW	Overall of East side of Pier b
7	DGS	East bank 1kg W toward DS end of Pier b	View of section loss at top of pier under South Bearing (Insp. Note 1A)
8	DGS	East bank 1kg W near center of Pier b	View of - Vert. crack in shaft (Insp. Note 1) - Spall in shaft (Insp. Note 2) - Top band of sealing around shaft (Insp. Note 3)
9	DGS	East bank 1kg SW	View of impact damage on US nose of pier (Insp. Note 4)
10	DGS	West bank 1kg E near center of Pier b	View of crack in shaft (Insp. Note 1)
11	DGS	West bank 1kg SE	Overall of east bank at bridge
12 & 13 (U/W)	JC	NW corner of ftg 1kg E	View of bottom of exposed ftg and exposed pile at corner
14 & 15 (U/W)	JC	NE corner of ftg 1kg S	View of bottom of exposed ftg and exposed pile at corner
16 & 17 (U/W)	JC	$\pm 6'$ South of NE corner of ftg 1kg W	View of riprap at end of ftg undermining
18 thru 20 (U/W)	JC	$\pm 12'$ South of NW corner of ftg 1kg W	View of drift at end of ftg undermining

## CHAPTER V

# UNDERWATER INSPECTION TECHNIQUES

### SECTION 1. PREPARATION AND SAFETY

Underwater bridge inspections require careful planning to ensure that the work is performed effectively, economically and safely. Underwater inspections can be expensive, but prior planning, data collection, hazard analysis and development of a dive inspection operations plan can reduce the cost and risk by leading to selection of equipment and methods best suited to the work and staffing with appropriate personnel. Initially, the team leader should review the scope of work to determine the purpose of the underwater inspection. Initial inspections, for example, may require more data gathering than routine inspections, and damage inspections may require specialized testing equipment.

The team leader evaluates the safety regulations that will govern the underwater inspection. In all instances and as a minimum, the Occupational Safety and Health Administration's (OSHA) Commercial Diving Operations standard will govern commercially performed underwater bridge inspections. Local governmental regulations or owner specifications may impose additional, more restrictive safety regulations.

#### 5-1.1 Site Reconnaissance and Data Collection

Through data collection or an on-site reconnaissance, the dive inspection team leader should: 1) determine the number of substructure units in water, 2) estimate which units can be inspected by wading and which require diving, 3) determine the approximate water depth from the drawings or from field measurements, 4) determine the approximate velocity of the water, and 5) identify local hazards. Prior dive operation plans can provide valuable insight for the planning of the current dive and reduce preparation time.

The inspection team leader should obtain drawings of the structure, preferably as-built drawings, to prepare for an inspection. Repair drawings, if any, should also be obtained to aid in evaluating the effectiveness of previous repairs. By previewing the bridge drawings, the inspector can learn what may be encountered during the dive. The existing drawings can also be included in a field inspection book to aid in taking notes and in preparing checklists for the inspection.

Previous reports can also provide additional useful information. Review of prior reports can aid in determining the rate of deterioration of previously observed defects. Water depth sounding data contained in previous reports and scour Plans of Action (POA) should also be reviewed.

Waterway information may be obtained from topographical maps, on-line satellite photography, hydrological data from the Corps of Engineers or state agencies, and from discussions with local representatives.

### 5-1.2 Hazard Analysis

A hazard analysis, also referred to as a Job Hazard Analysis (JHA) or Job Safety Analysis (JSA), should be an on-going process during the planning and the conducting of the dive operations. Potential hazards must be identified; their effect on safety and diving operations evaluated; and actions must be taken to mitigate those hazards. Mitigation may involve avoidance, the use of specially trained personnel, employment of special equipment, or incorporation of specific operational techniques.

Among the primary hazards to be evaluated are:

- Swift Water (riverine or tidal)
- Deep Water
- High Altitude
- Extreme Water Temperatures
- Limited Visibility
- Poor Water Quality
- Ice Floes or Fixed Ice
- Floating or Accumulated Debris
- Marine Operations and Vessel Traffic
- Diver Entry and Exit Locations
- Adjacent Water Control Structures
- Marine/Aquatic Vegetation or Wildlife
- Construction Operations

The size and qualifications of the underwater inspection team should be selected in consideration of the factors listed above, as well as any regulatory or specific owner requirements. The technical inspection qualifications of the team members should be evaluated considering the type of structure, material type, and the inspection equipment and techniques to be employed.

The diving qualifications for the team members should be reviewed in light of governing safety regulations and project specifications; applicable training and certifications; physical condition; training in cardiopulmonary resuscitation (CPR), first aid, and oxygen administration; necessary inoculations; and the required diving techniques and equipment.

Diving equipment and techniques should be selected in consideration of the potential hazards identified at the site, governing safety regulations, waterway characteristics, currents and depths, means of access, water quality, drift accumulations, type and extent of data to be recorded, dive duration and site elevation, the need for penetration or confined access entry dives, and the preferences of the team members.

## SECTION 2. INSPECTION

### 5-2.1 General

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

For some bridge inspections, commercial scuba techniques, conducted in accordance with OSHA, are the most efficient. Scuba requires less set-up time and generally allows greater mobility than surface-supplied equipment. If communications are desired, a full face mask with a demand regulator and wired or wireless communication may suffice. This combination eliminates the need for hoses, mixing consoles, volume tanks, and other apparatus needed with surface-supplied equipment. Safety or other considerations such as the need for continuous topside-to-diver communication may, however, dictate the use of surface-supplied diving equipment in many inspection situations.

Access to many small bridges can be accomplished from the adjacent shore; for larger waterways, a boat will be necessary. Aluminum or inflatable boats in the 14- to 16-foot 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 20- to 25-foot range will be adequate for most inspections performed in larger rivers. Boats of this size are big enough to support a small surface-supplied operation. Boats used for underwater bridge inspection can easily be damaged by striking and scraping along bridge substructure units, so it is important that all sides of the boat be protected with resilient fenders. Boats should be securely anchored or tied to the structure before diving operations are initiated, and a means for getting a diver out of the water must be provided.

In certain instances, 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, if that is deemed feasible.

The type of equipment required to clean areas for a Level II inspection should be determined. Most cleaning for underwater bridge inspections 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.

Standard equipment for an inspector should include a hammer or scraper. These tools can be used for Level II inspection cleaning, and for probing and sounding apparent or suspect defective areas to confirm the presence and determine the extent of distress. For inspecting timber below water, an ice pick or awl should also be used to probe and assess material integrity. An underwater light is useful at times, depending on water clarity.

Water clarity often limits the diver's ability to visually inspect a submerged structure. In such cases, the diver must use tactile senses to supplement or replace the visual inspection. Usually, it is an effective technique for the diver to examine the underwater elements by moving both hands and arms in sweeping motions to cover all areas of each underwater element.

When a diver is working in low visibility water, the diver often must use the sense of touch to estimate the size, extent, and severity of conditions encountered. Physical and psychological forces may be acting on the diver, and usually, the diver will be wearing gloves, which hinder the inspector's ability to measure in situ defects and conditions. As an aid in estimating dimensions underwater, divers should know the dimensions of inspection tools, such as width, thickness, and length, and key measurements of the inspector's body, such as the width of the fist of the gloved hand, the width of the hand with fingers extended, the length from the elbow to the tip of the fingers, and the length of the extended arms from finger tip to finger tip. It should be recognized that the diver may only be able to provide measurements that are approximate.

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 Chapter IV 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 materials, typically referred to as riprap, are commonly placed around substructure units 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 and firmness 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 arm's 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, it may be difficult to circle the pier without tangling the lines. In this case, the diver should inspect one side of the pier at a time using a back and forth motion starting at the bottom (Figure 5-1). The diver can then repeat that inspection pattern on the other sides of the pier.

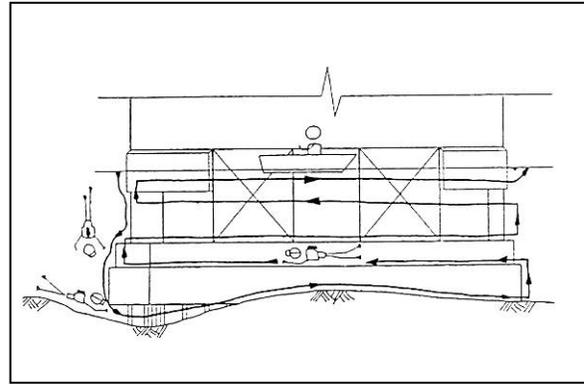


Figure 5-1 Schematic Representation of a Diver Inspecting a Pier

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

Of particular importance at the channel bottom, the diving inspector should report any exposure of the footing or foundation seal, defects within the material, the presence of foundation undermining, or evidence of scour.

### 5-2.3 Piles

Piles should be inspected in a spiral motion when possible. 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 (Figure 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 the diver should surface immediately, report the details of the defect, and then return to the point of the defect to continue the inspection.

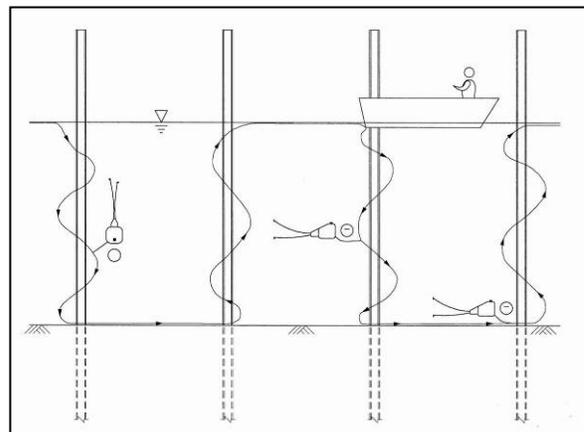


Figure 5-2 Schematic Representation of a Diver Inspecting a Pile Bent

When the inspector is line-tended or using surface-supplied equipment, the diver must move from side to side along individual or groups of piles to keep the lines free. Other aspects of the pile inspection procedure are the same as when using commercial scuba.

### 5-2.4 Cells, Cofferdams, and Bulkheads

The inspection procedure for cells, cofferdams, and bulkheads is similar to that for piers. The inspector should also note the presence, size, and condition of any riprap placed at the base of these units, and look for any indications of scour.

## SECTION 3. SPECIAL TESTING, LEVEL III INSPECTION

### 5-3.1 General

The types of testing described in this section are among those which may be used for Level III inspections. Level III inspections are employed when Level I and Level II inspections cannot conclusively determine the structural condition of the underwater elements. Findings of previous inspections or the age of the structure may also dictate the need for more detailed levels of inspection. Level III inspections are not needed for all inspections; however, they can be a useful part of many inspections, and some owners require them as part of the normal inspection process.

### 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, calipers or ultrasonic thickness measuring devices. There are underwater weld testing methods, such as magnetic particle testing and radiography, but these are not commonly used for underwater bridge inspection.

a. Graduated Scales. For measuring the exposed edges of flanges, a rule, or graduated scale is the most basic tool. It is not precise, however, and should be used only for approximate measurements. This method's accuracy is limited by the diver's vision, and its use is limited to exposed member surfaces with accessible edges.

b. Mechanical Gauges. Another simple method of thickness measuring is to use a set of calipers (Figure 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, although this method has the disadvantage of being partially-destructive to the element. The same drilled hole method could be used to measure the thickness of the web of H-piles, or a special large set of calipers could be fabricated that would provide clearance around the H-pile flanges.

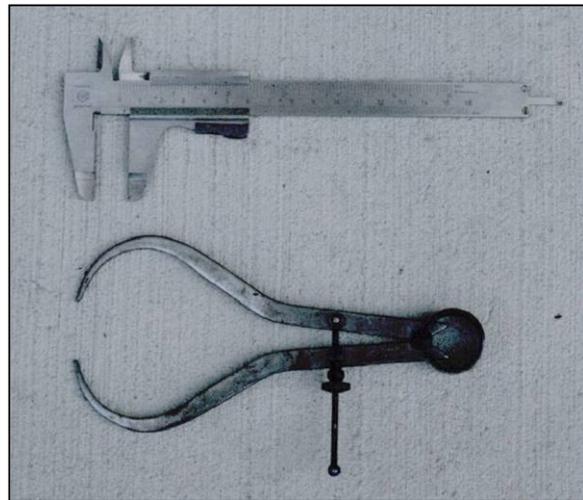


Figure 5-3 Calipers

A mechanical pit gauge can also be used to measure the depth of pitting in a corroded steel member. These gauges, as shown in Figure 5-4, are equipped with an exaggerated scale to improve accuracy.

c. Ultrasonic Measuring Devices. Ultrasonic devices are also available for measuring the remaining thickness of submerged steel members. The device sends a sound wave through the steel member to its back face, where the sound wave is reflected back through the steel to the device. The travel time of the sound wave is then measured and the device converts that travel time to the equivalent 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 then displayed on a digital display. To use the ultrasonic thickness measuring device underwater, the diver must clean a small area of the steel of marine growth, corrosion products, and any loose protective coatings or scale. If the steel is very rough or badly pitted, it may be difficult to obtain accurate measurement. There are, however, special transducers that can be used to overcome this problem.

If a member is composed of multiple layers of steel, the ultrasonic thickness measuring device will only measure the thickness of the member which the transducer contacts. Similarly, for concrete-filled steel pipe piles, the instrument will measure the remaining thickness of the steel pipe.

There are two types of ultrasonic thickness measuring devices available for use underwater. One type is totally submersible and the diver must record or relay the measurements to the surface (Figure 5-5). The second type has a waterproof transducer and cable which are carried below water while the electronics and display remain on the surface (Figure 5-6). These units can also be placed inside a waterproof housing and be completely submerged.

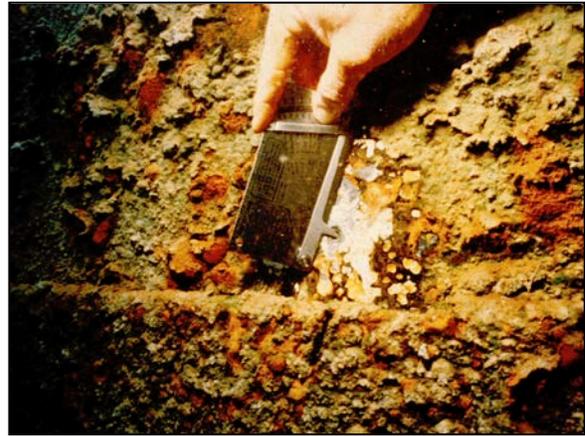


Figure 5-4 Pit Gauge



Figure 5-5 Waterproof Ultrasonic Thickness Measuring Device



Figure 5-6 Waterproof Transducer for an Ultrasonic Thickness Measuring Device

d. Magnetic Particle Testing. Magnetic particle testing (MPT) detects flaws in steel and welds. The process requires inducing a magnetic field into 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, and the inspector can photograph the particle pattern to document the results of the test. The area to be examined must also be carefully cleaned to obtain good results.

Underwater magnetic particle testing is commonly used during inspections of offshore structures. This test method is not commonly used for bridge inspections because few bridges have underwater welds, it is difficult to implement in high currents, and inland water clarity is generally not good.

d. 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 has been used underwater for testing pipelines and improved digital versions are under development; but to date, it has not been used in underwater bridge inspections.

### 5-3.3 Concrete

Several non-destructive tests for in-depth inspection can be performed on concrete; however, the non-destructive testing instruments must be modified for underwater use.

a. Ultrasonic Pulse Velocity Meter. The ultrasonic pulse velocity meter, or V-meter, is an ultrasonic testing device used to estimate the strength of in-situ concrete, and locate areas of discontinuity and relative low strength such as cracks and voids (Figure 5-7). When taking measurements, the transducers are generally arranged in one of two different positions. The direct transmission method, with the transducers on opposite sides of the member, as shown in Figures 5-8 and 5-9, provides the most accurate data. The indirect transmission method, with the transducers on the same



Figure 5-7 Ultrasonic Pulse Velocity Meter with Waterproof Cables and Transducers

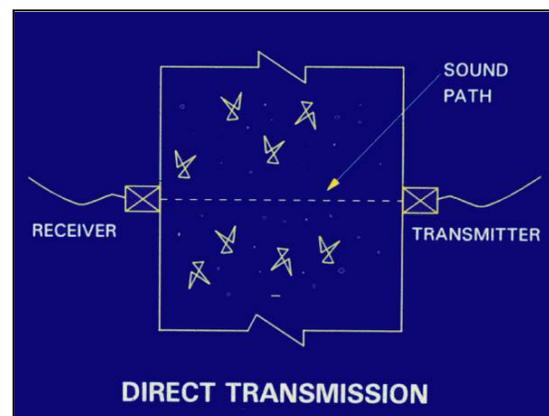


Figure 5-8 Direct Transmission Method

side of the member, as shown in Figure 5-10, requires correction factors to interpret the data. Standard methods for conducting the tests are found in ASTM Standard C-597. When using this method on concrete piles and columns, measurements should preferably be taken through the member at a minimum of two perpendicular directions at each elevation examined.



Figure 5-9 Diver Applying the Transducers to a Pile for the Direct Transmission Method

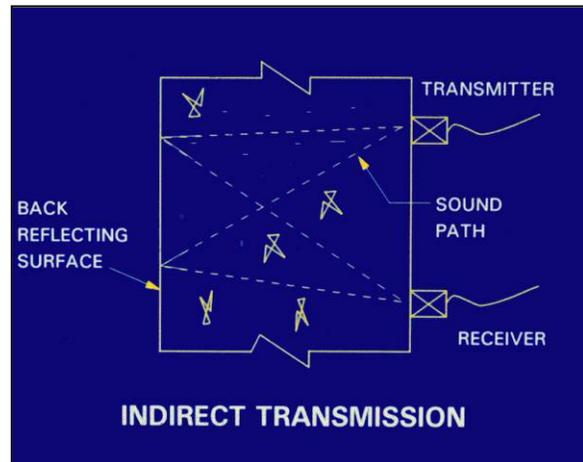


Figure 5-10 Indirect Transmission Method

b. Rebound Hammer. The rebound hammer (or Schmidt hammer) is a mechanical device used to estimate the compressive strength of in-place concrete based on its surface hardness. For underwater use, the hammer is placed within a waterproof housing and a special scale is used (Figure 5-11).

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.



Figure 5-11 Waterproof Rebound Hammer

c. Rebar Locator. The rebar locator, often referred to as the R-meter, can be used to determine the location and depth of cover of reinforcing steel in concrete structures. The device uses a low frequency magnetic field to locate the steel. Rebar locators must be modified for underwater use (Figure 5-12). This method of testing is of limited value in 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. Coring locations should be selected so as to not damage internal steel reinforcement, unless a reinforcing sample is desired, and core holes should be patched upon completion. Figure 5-13 shows concrete cores removed below water from a pier.



Figure 5-12 Rebar Locator in Waterproof Case

#### 5-3.4 Timber

Following the partial failure in 1976 of timber piles supporting a bridge that had previously been visually inspected, the University of Maryland developed a non-destructive ultrasonic wave propagation method to determine 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 the potential for internal marine borer attack is present.



Figure 5-13 Concrete Cores

More simply, ultrasonic testing apparatus, such as the V-meter described above for concrete testing, can be used for timber members to identify regions of no or significantly slowed sound transmission, which suggest internal voids or material breakdown like that caused by marine borers or decay.

Partially-destructive testing of timber by coring and boring can be accomplished with hand, pneumatic, and hydraulic tools. Samples of the pile material for laboratory testing can be obtained by coring (Figures 5-14 and 5-15). Boring a hole into the timber and probing the inside of the member with a thin, hooked rod to determine if there are voids due to decay or marine borers is also effective. After coring or drilling, the hole should be plugged with a preservative-treated hardwood dowel.



Figure 5-14 Diving Inspector Removing Timber Cores

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



Figure 5-15 Timber Cores

The inspection of piles with encapsulating flexible plastic wrap systems poses special problems. Timber pile wraps are intended to create an anaerobic state between the pile and wrap in which marine borers cannot survive. The accessible areas above and below the wraps may give an indication of pile condition within the encapsulation, and sounding of the timber through the wrap may indicate the condition of severely deteriorated piles; but, it is recommended that a sample of wrapped piles be unwrapped, if necessary, to determine the condition of the structure with certainty.

Because the cost of pile wrap removal and replacement can be significant, some owners have used a procedure that measures the level of dissolved oxygen (DO) within the wrap as an indicator of the presence or absence of active marine borers. The procedure consists of penetrating the wrap with the needle of a syringe, withdrawing a sample of the water from the space between the pile and the wrap, and sealing the needle hole with a stainless steel nail and a rubber washer. The water sample can then be tested for DO with a portable dissolved oxygen meter. A DO reading of 1.50 milligrams per liter is accepted by many as the level below which marine borers cannot exist.

Among factors which may affect the DO readings are the amount of water exchange between the inside and outside of the wrap during tidal cycles; seasonal water temperature variations; the elevation at which the water sample is taken from within the wrap; the location of the tested pile within the structure; and marine borer activity within the wrap. In employing this procedure, DO measurements should initially be taken from a sample of wrapped piles, containing some which are believed to be experiencing marine borer activity and others believed to not be experiencing marine borer activity. Some pile wraps should then be removed to correlate DO readings with site specific conditions.

## CHAPTER VI SCOUR INVESTIGATIONS

### SECTION 1. BACKGROUND

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. Statistics compiled by the Structures Division of the New York State Department of Transportation and Texas A&M University indicate that from 1996 to 2005, there were at least 1,502 documented bridge failures, 58 percent of which were the result of hydraulic conditions. In 1994, 500 bridges failed in Georgia during flood conditions; and in 1993, 23 bridges failed due to scour in the upper Mississippi River basin. 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. Bridges over coastal inlets can experience severe scour problems due to extreme tidal flows, violent storms, and constantly changing inlet configuration.



Figure 6-1 I-90 over Schoharie Creek



Figure 6-2 US 51 over the Hatchie River

Two of the most serious bridge failures due to scour—I-90 over Schoharie Creek, and US 51 over the Hatchie River, in 1985 and 1987, respectively (Figures 6-1 and 6-2)—led to formalization of the scour evaluation program requirements in the United States.

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

The evaluations should be conducted by a multidisciplinary team consisting of structural engineers, geotechnical engineers, and hydraulic engineers. All bridges which are scour critical, or for which the configuration of the foundation cannot be determined, must have a Plan of Action (POA) for monitoring or installing countermeasures.

## 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 and rivers. 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; limestone 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 when evaluating scour potential at bridges.

### 6-2.2 Total Scour

Total scour at a highway crossing is comprised of three components: aggradation and degradation; general or 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-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 (Figure 6-3).

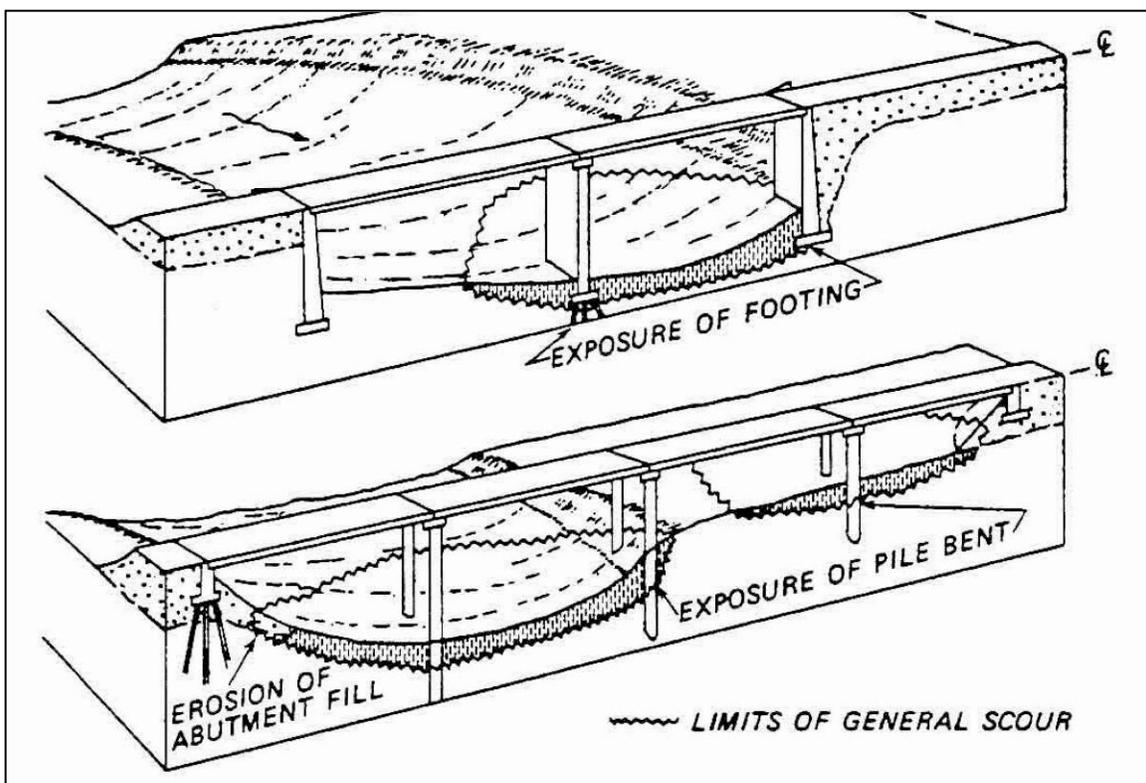


Figure 6-3 General Scour

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 and increased velocity on the outer part of the channel can erode the bed.

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 due to a contraction of the flow 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 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.

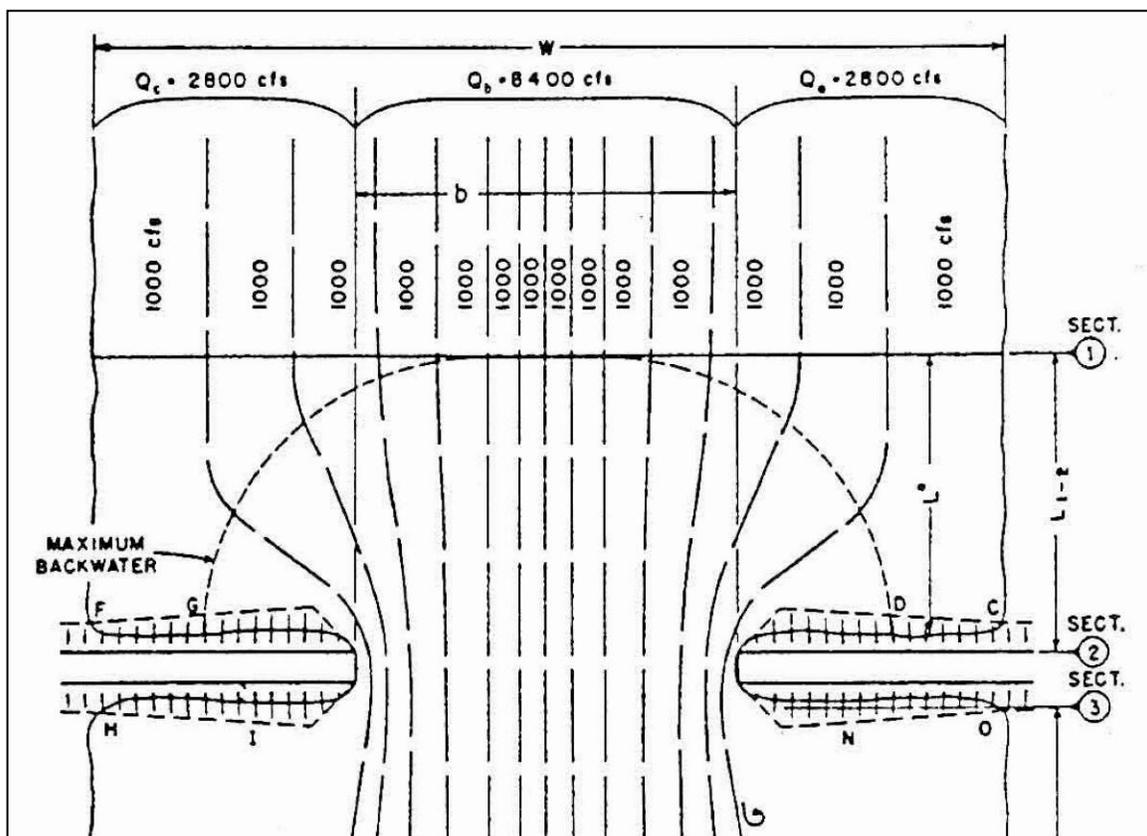


Figure 6-4 Contraction Scour

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. 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 (Figure 6-4). 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 (Figure 6-5). Also, at bends, the thalweg (the part of the stream where the flow is deepest and, typically, the velocity is the greatest) may shift toward the inside of the bend as the flow increases. This can increase scour and the nonuniform distribution of the scour in the bridge opening.

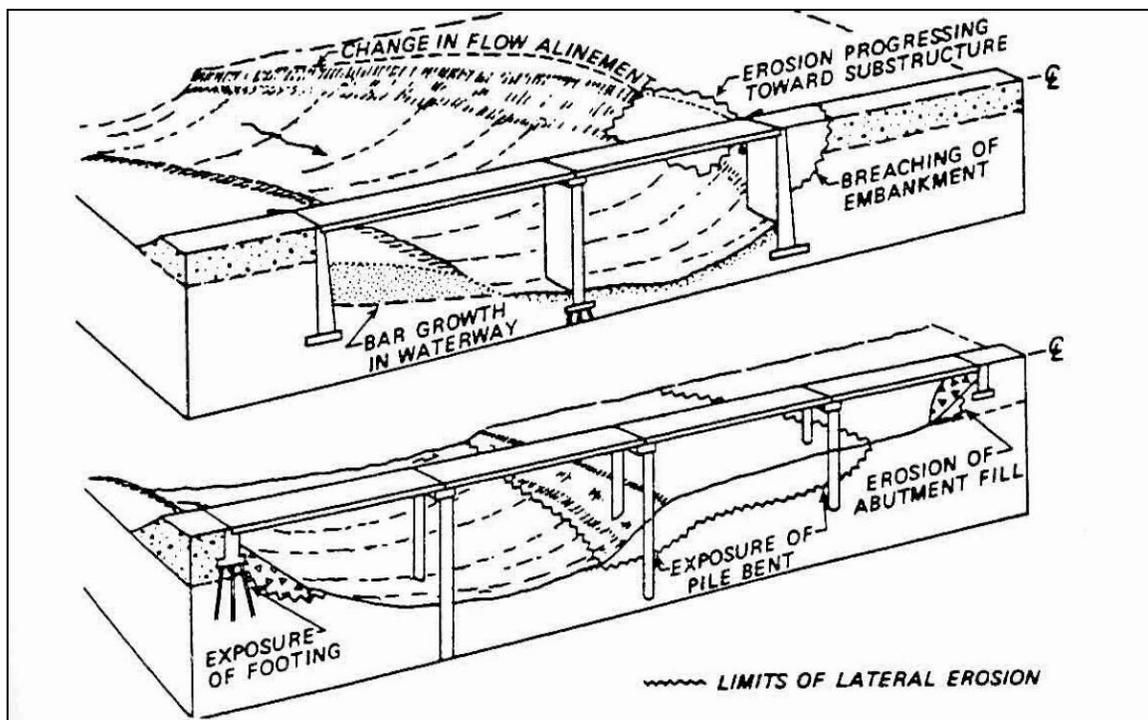


Figure 6-5 Lateral Erosion

**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 (Figure 6-6).

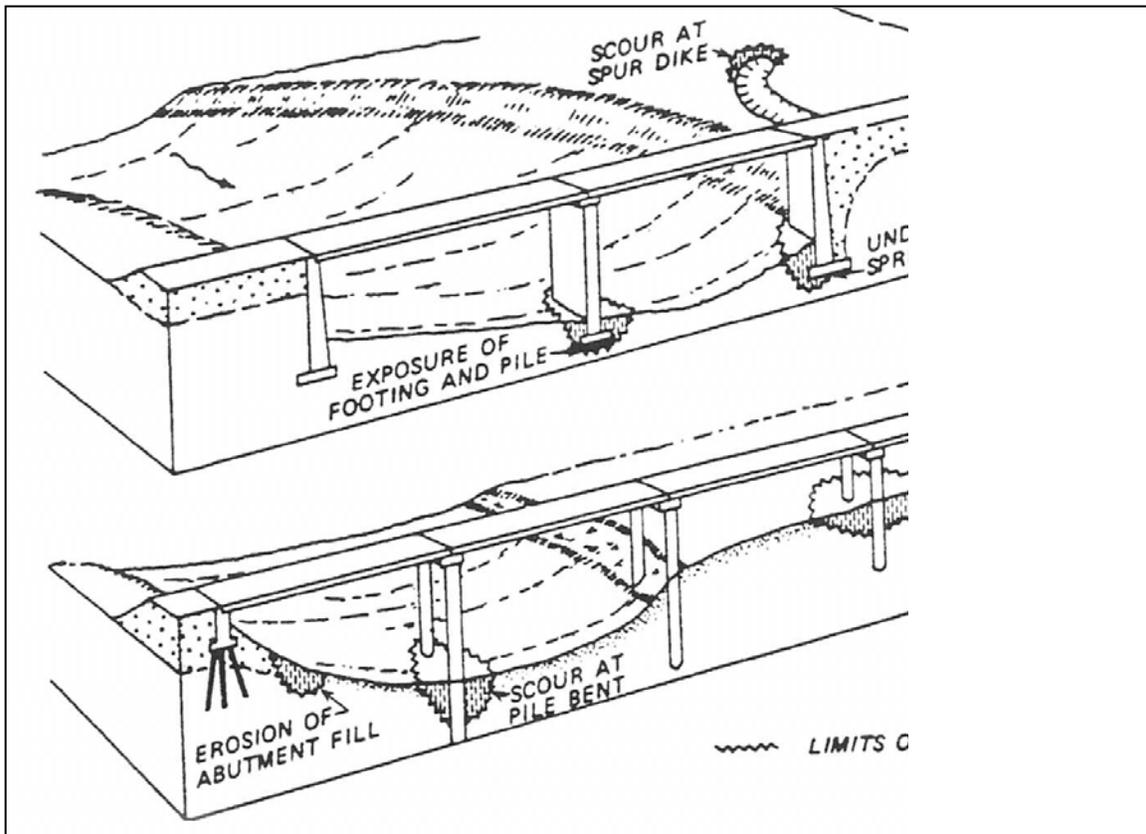


Figure 6-6 Local Scour

The basic mechanism causing local scour at piers or abutments 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 abutment. 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 equilibrium is reestablished and scouring ceases.

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 (Figure 6-7).

Both vortices remove material around the pier. Immediately downstream of a long pier, however, there is often deposition of material (Figure 6-8).

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 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 and the width of a scour hole. For example, an increase in pier width due to debris collection at the upstream nose can cause an increase in scour depth and a wider scour hole at the upstream end of a pier as shown in Figure 6-9.

Ice and debris, by increasing the effective 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.

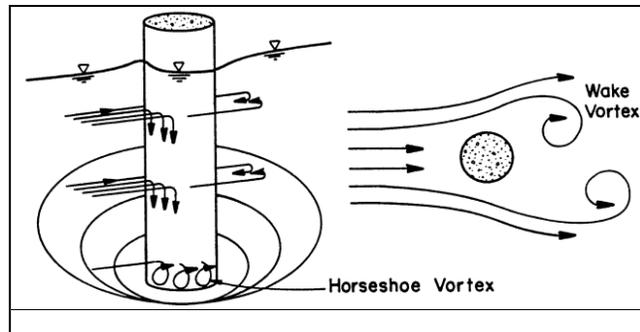


Figure 6-7 Schematic Representation of Scour at a Cylindrical Pier



Figure 6-8 Upstream Scour Hole and Debris with Downstream Deposition of Material Shown in Dry



Figure 6-9 Debris Increasing Width of Pier

Pier length has no appreciable effect on scour depth as long as the pier is aligned 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 by 30 to 60 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.

The velocity of the approach flow affects the local 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.

The size of the bed material in the sand size range has no effect on scour depth. Larger sized 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 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 as or deeper than sand bed streams. This is true even if bonded together by cohesion. The effect of cohesion is to increase 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 pointed out in the discussion of the effect of pier length above. With abutments, the depth of scour is reduced for abutments angled downstream and is increased if the abutments are angled upstream. The maximum depth of scour at an abutment inclined 45 degrees downstream is reduced by 20 percent, whereas the scour at an abutment inclined 45 degrees upstream is increased about 10 percent.

The pier or abutment shape also 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-

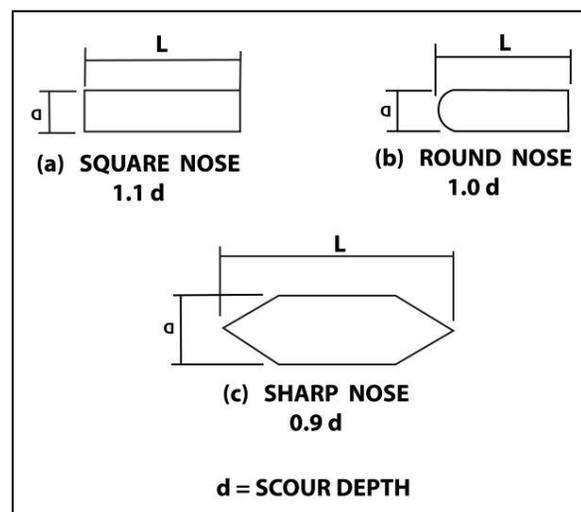


Figure 6-10 Effect of Pier Shape

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 as illustrated in Figure 6-10. Abutments with vertical walls on the stream side and upstream side will have scour depths about double that of spill slope abutments.

In addition to the types of scour described 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 waterway at the bridge crossing (Figure 6-11). 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.



Figure 6-11 Lateral Scour

Methods for calculating scour depths, considering the effects of each of the factors described above, as well as others, can be found in FHWA's Hydraulic Engineering Circular No. 18, *Evaluating Scour at Bridges* ([www.fhwa.gov](http://www.fhwa.gov)). In general, however, the faster the flow velocity, the greater the volume of flow, the wider the pier, the flatter the nose of the pier, the greater the angle of attack and the smaller the bed material, the greater the scour depth will be.

## SECTION 3. SCOUR INSPECTIONS

### 6-3.1 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 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. Furthermore, 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 a multidisciplinary team including structural, geotechnical, and hydraulic engineers.

### 6-3.2 Office Review

It is desirable to make an office review of bridge plans and previous inspection reports prior to conducting 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 (POA) been prepared 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?
- If the details of the foundations of the bridge are unknown, has a POA been made?
- Do special conditions exist requiring particular methods and equipment for scour and underwater inspections (divers, boats, depth sounders, sub-bottom profiling equipment, or underwater imaging equipment)?
- Are there special items that should be inspected? Examples might include damaged riprap, stream channel at adverse angle of flow, and problems with debris.

### 6-3.3 Site Observation

The *Recording and Coding Guide for the Structure Inventory and Appraisal of the Nation's Bridges (Coding Guide)* is used by Federal, State and other agencies in recording and coding the data elements that comprise the National Bridge Inventory database. Four coded items are related to scour: Item 60-Substructure,

Item 61-Channel and Channel Protection, Item 71-Waterway Adequacy, and Item 113-Scour Critical Bridges.

Item 60-Substructure describes the physical condition of piers, abutments, piles, fenders, footings or other components. All substructure elements should be inspected for visible signs of cracking, section loss, settlement, misalignment, scour, collision damage, and corrosion.

Item 61-Channel and Channel Protection describes the physical conditions associated with the flow of water through the bridge such as stream stability and the condition of the channel, riprap, slope protection, or stream control devices including spur dikes. The inspector should be particularly concerned with visible signs of excessive water velocity which may affect undermining of slope protection, erosion of banks, and realignment of the stream which may result in immediate or potential problems.

Item 71-Waterway Adequacy appraises the waterway opening with respect to passage of flow through the bridge.

Item 113-Scour Critical Bridges is used to identify the current status of the bridge regarding its vulnerability to scour. The underwater inspector may find current conditions that indicate that the bridge is scour critical, but the vulnerability of the structure to scour may not be discernible without a multidisciplinary analysis.

In coding these items during the bridge inspection, the inspector should refer to the detailed instructions and descriptions for each of these items. 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 upstream of the bridge, at the bridge, and downstream of the bridge.

### Conditions Upstream of Bridge

Upstream conditions to be observed include:

- Banks
- Stable—Natural vegetation, trees, bank stabilization measures such as riprap, paving, gabions, channel stabilization measures such as dikes and groins.
- Unstable—Bank sloughing, undermining, evidence of lateral movement, damage to stream stabilization installations, etc.
- Presence of dams or other flow control structures.

### Main Channel

- Clear and open with good approach flow conditions, or meandering or braided with main channel at the angle to the orientation of the bridge.
- Existence of islands, bars, debris, cattle guards, fences that may affect flow.
- Aggrading or degrading streambed.

- Evidence of movement of channel with respect to bridge (make sketches, take photographs).

### Floodplain

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

Debris: Extent of debris in upstream channel.

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.

- 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.
- Damage to scour countermeasures protecting the foundations (riprap, guidebanks (spur dikes), sheet piling, sills, etc.).
- Changes in streambed elevation at foundations (undermining of footings, exposure of piles).
- 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 a firm bottom.

### Superstructure

- Evidence of overtopping by floodwaters—Is superstructure anchored to substructure to prevent displacement during floods?

- Obstruction to flood flows—Does it collect debris or present a large surface to the flow?
- Design—Is superstructure vulnerable to collapse in the event of foundation movement as are simple spans and non-redundant designs?

#### Channel Protection and Scour Countermeasures

- 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?
- Guidebanks (spur dikes)—Are guidebanks in place? Have they been damaged by scour and erosion?
- 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 measurements? If so, in what way?

#### 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 increase the scour potential at bridge foundations?

#### Conditions Downstream of Bridge

Downstream conditions to be observed include:

- Banks Stable—Natural vegetation, trees, bank stabilization measures such as riprap, paving, gabions.
- Channel stabilization measures such as dikes and groins.
- Unstable Bank—sloughing, undermining, evidence of lateral movement, damage to stream stabilization installations, etc.
- Presence of dams or other flow control structures.

#### Main Channel

- Clear and open with good “getaway” conditions or meandering or braided with bends, islands, bars, cattle guards, and fences that retard and obstruct flow.
- Aggrading or degrading streambed.

- Evidence of downstream movement of channel with respect to the bridge (make sketches and take photographs).

### Floodplain

- 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.
- Evidence of scour and erosion due to downstream turbulence.

### Other Features

- Downstream dams or confluences with larger stream which may cause variable tailwater depths (which 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.

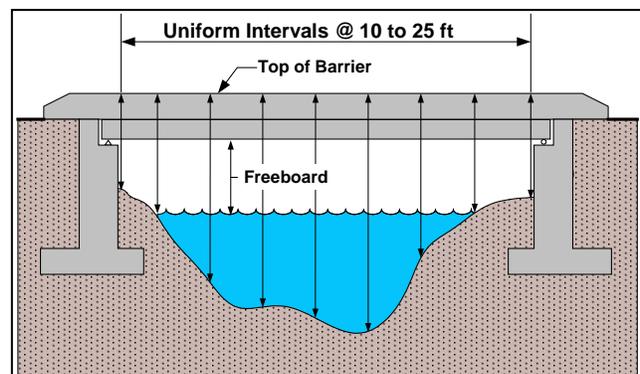
## SECTION 4. SOUNDINGS

It is general practice to take water depth soundings at every bridge over water at least every 24 months as part of the routine above water inspection. More extensive soundings are usually taken as part of a routine underwater inspection. Soundings should be made to determine the cross section of the waterway near the bridge and to determine the profile of the thalweg, i.e., the deepest part of the channel.

Soundings alone are not a substitute for an underwater diving inspection since soundings cannot evaluate structural conditions or integrity. Soundings cannot conclusively determine the extent of foundation exposure or undermining.

### 6-4.1 Equipment

In small, slow moving streams, sounding lines can be used to measure depths from the bridge deck at regular intervals as shown in Figure 6-12. Soundings are difficult to take, however, in fast moving streams with lines and poles, and may not reflect bottom conditions if not taken at very close intervals.



Soundings taken from the top of a bridge are necessarily limited, and

Figure 6-12 Cross Section along Bridge Fascia

provide no information as to channel configuration under the bridge or upstream and downstream of the bridge. Some of these disadvantages can be overcome in shallow water by wading and sounding with a pole, but generally, soundings are taken from a boat using a continuous reading fathometer (electronic depth sounder). Point soundings may also be taken using a handheld depth sounder.

Common practice is to take soundings, at a minimum, around each of the substructure units, along the upstream and downstream fascias of the bridge, and along lines parallel to the fascias at intervals of 50 feet, 100 feet and 200 feet upstream and downstream of the bridge. For long bridges, i.e., wide waterways, some inspectors recommend extending the soundings a distance upstream and downstream of the bridge equal to twice the channel width.

Fathometers consist of a transducer, which is suspended in the water, a sending/receiving device, and a data recording device which displays the depth on paper or on an electronic display. High frequency sound waves 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 in the form of a continuous plot of the channel bottom. Most fathometers are readily portable, weighing 5 to 10 pounds including the transducer and hardware. They are generally powered by a 12-volt battery. 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.

Operating at 200 kHz, most of the sound waves striking the channel bottom reflect to the transducer and do not penetrate significantly into the bottom material. This generally provides a good representation of the channel bottom profile, but does not provide information on sub-bottom materials. Some fathometers, designed for deep water use, also operate at lower frequencies that may provide limited information about channel bottom materials.

For many years, black and white paper chart depth sounders, or fathometers, were the most common way of recording depths. However, with advances in low cost boating electronics, the relatively inexpensive units are no longer manufactured for new purchase and as existing units wear out, it has become more difficult to find repair parts. Figure 6-13 illustrates a typical black and white paper chart fathometer.



Figure 6-13 Black and White Paper Chart Fathometer

Figure 6-14 illustrates a hydrographic survey grade black and white fathometer. These units can be coupled with a positioning system such as a global positioning system (GPS) or a range-azimuth survey system to record horizontal positioning data as well as depths. These units are significantly more expensive than the consumer grade fathometers.

Although continuously recording fathometers are generally most appropriate for making soundings, in some instances, the use of handheld depth sounders that provide point measurements may provide satisfactory data.

A number of modern consumer grade fathometers are now available in black and white or color units that can display and record sounding data that can also be plotted. These units can be integrated with GPS to provide horizontal positioning data as well as sounding data. This data, coupled with hydrographic survey plotting software can provide point elevation plots, and cross sections as well as contour lines. These units, with their many capabilities have generally replaced the older black and white paper chart fathometers. Figure 6-15 shows one of these units with a portable transducer for attachment to the gunnel of a boat, and a GPS antenna.

When using an electronic sounding device, it is necessary to verify and calibrate its operation with a sounding line or by suspending a calibration target beneath the transducer prior to sounding the entire bridge. The calibration should also be verified at the conclusion of the sounding work.

Although the best time to obtain the true depth of scour is during a flood when scour holes are deepest, this is rarely done because of the danger involved. Data obtained immediately after a flood is also very helpful, but some infilling of scour holes may have occurred. Water conditions, however, can make this difficult.

The continuously recording 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.



Figure 6-14 Hydrographic Survey Fathometer



Figure 6-15 Fathometer with Transducer and GPS Antenna



Figure 6-16 Transducer on Rod



Figure 6-17 Transducer on Float



Figure 6-18 Transducer on Articulated Head

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

Normally, fathometer soundings are taken with a boat, but where water or access conditions do not allow use of a boat, the transducer may be deployed from the bridge or shore, on a rod, on a float, or on a mechanical arm device as shown in Figures 6-16 through 6-18.

#### 6-4.2 Data Presentation

The most basic data obtained from a fathometer survey is a strip chart showing the continuous soundings record. Figure 6-19 is an example of the output from a strip chart fathometer showing the soundings along the side of a pier. A scour hole is visible at the upstream nose of the pier; channel bottom material has been deposited along and downstream of the pier; and the top of the pier footing is clearly seen. At a minimum, superimposing the existing foundation on the strip chart would show if the substructure unit is undermined at the time of the survey. The value of this chart is limited, however, because it provides no information about the channel bottom except in the area immediately adjacent to the substructure unit.

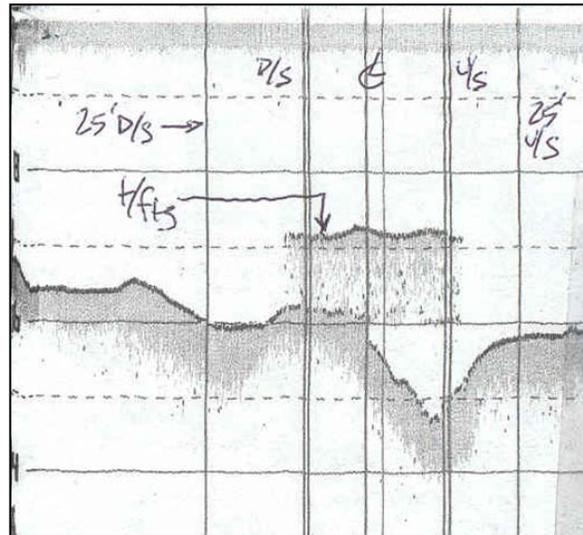


Figure 6-19 Fathometer Strip Chart Along Pier

A common way of performing and presenting soundings is in a grid format (Figure 6-20). Soundings are taken on lines parallel to the faces of the bridge and along both sides of the bridge piers using a continuous reading fathometer and point elevations

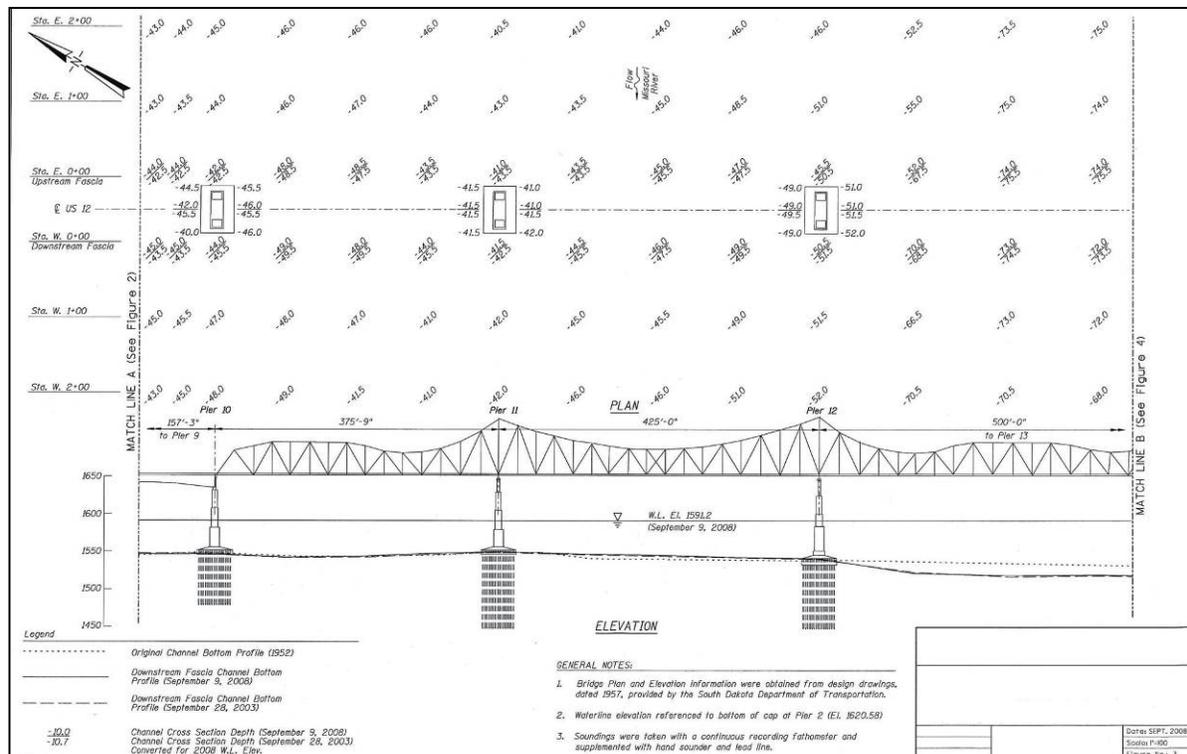


Figure 6-20 Sounding Plan Showing Typical Grid

can be plotted as shown. This pattern will provide information on the channel upstream and downstream of the bridge, and around each pier.

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 references with the bridge can be obtained by sighting on piers, floor beams, and truss panel points. This method of determining horizontal position is crude, but may be adequate for sites with relatively consistent channel bottoms. When working close to 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.

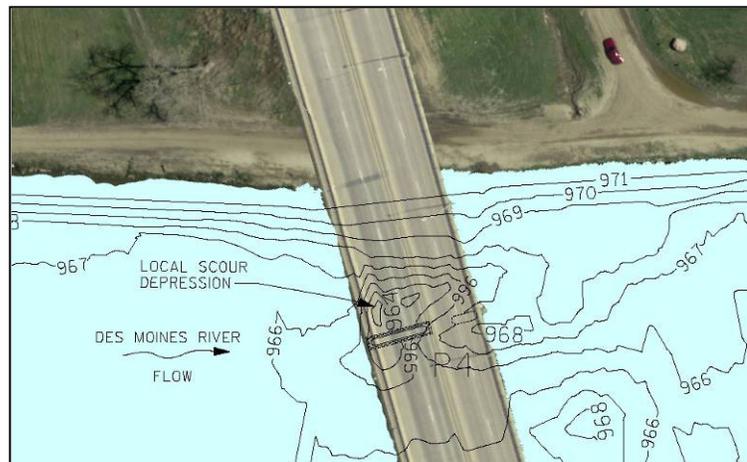


Figure 6-21 Channel Bottom Contour Plot

Currently available, relatively inexpensive, sophisticated fathometers, coupled with GPS and plotting software, can produce contours plots that provide a view of the channel bottom around each substructure units, across the entire waterway in the vicinity of the bridge, and upstream and downstream of the bridge. Figure 6-21 is a plot of the channel bottom contours at a major bridge crossing.

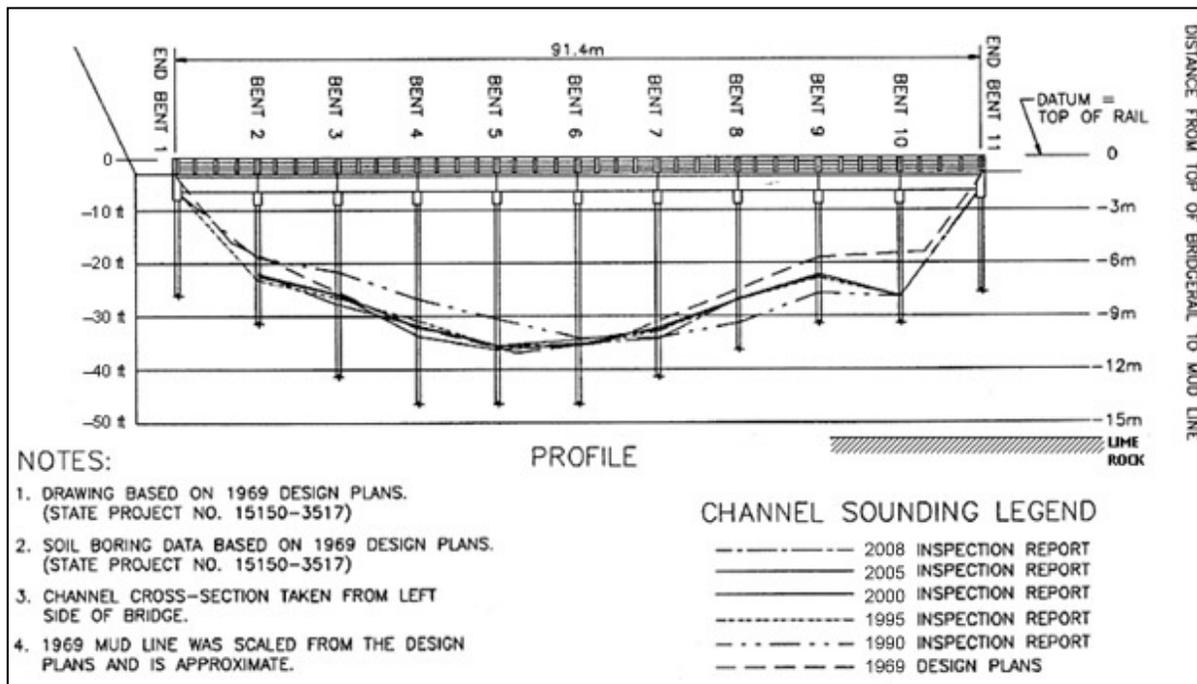


Figure 6-22 Channel Bottom Contour Plot

Review of current contour plots with the contours and cross sections from previous surveys can identify new scour holes, locate sunken objects that may affect the structure, and help evaluate the trend of channel bottom changes. Figure 6-22 shows the changes in the cross section of the waterway at a bridge over a number of years.

## SECTION 5. DIVER INSPECTION

### 6-5.1 Visual Inspection

The diver's role in identifying scour critical bridges is limited. A diver can identify conditions present at the time of the underwater inspection, but the greatest scour occurs during the periods of highest flows, a time when underwater inspections are generally not conducted. The diver's perception of scour is often also limited by poor visibility. The diver may not be able to detect scour holes a short distance from the structure which could be significant in the near future.

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. The diver 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. It is important that the extent and height of exposed footings or other foundation elements and the dimensions of any undermining be reported. If piles under a footing are exposed, the number and location should be noted and they should be examined.

### 6-5.2 Tools

The diver may be able to determine if riprap has been covered over by infill material by probing the bottom with a steel rod, such as a piece of reinforcing steel. The presence of buried riprap and subsoil conditions may also be verified 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 6. 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 redistribution 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 locating 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 can provide continuous subsurface profiles.

Geophysical tools which can be used to measure scour after infilling occurs are: ground penetrating radar and tuned transducer or low frequency sonar. Each of these methods has advantages and limitations that are described below.

### 6-6.1 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 include a transmitter and receiver (Figure 6-23), and an antenna (Figure 6-24).



Figure 6-23 Ground Penetrating Radar  
(Courtesy of Geophysical Survey Systems, Inc.)

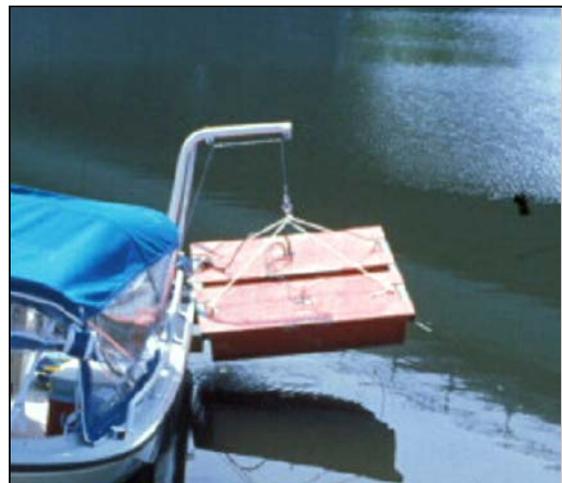


Figure 6-24 Ground Penetrating Radar  
Antenna

The transmitter and receiver can be mounted in a small boat and the antenna deployed over the side of the boat making contact with the water surface.

Figure 6-25 shows a cross section generated by a ground penetrating radar signal upstream of a bridge 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.

### 6-6.2 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 receiver, and 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 acoustical impedance between two layers. The major difference between this device and the fathometer is frequency. The tuned transducer uses lower frequency signals (2-20 kHz) which yield better penetration at the expense of resolution (Figure 6-19). High frequency fathometers (200 kHz) have good resolution with little or no penetration. In fine grained materials up to 100 feet of penetration can be obtained with a 3 to 7 kHz transducer, while in more coarse material subsurface penetration may be limited to a few feet. There are available a number of proprietary commercial variations of the basic low frequency sonar. Some of these operate over a range of frequencies and are commonly referred to as Chirp sub-bottom profilers (Figure 6-26).

The transducers, operating at low frequencies, are significantly larger and heavier than the transducers for conventional fathometers. Figure 6-27 shows a low frequency transducer, weighing approximately 60 pounds, supported by a flotation device along the side of a small boat.

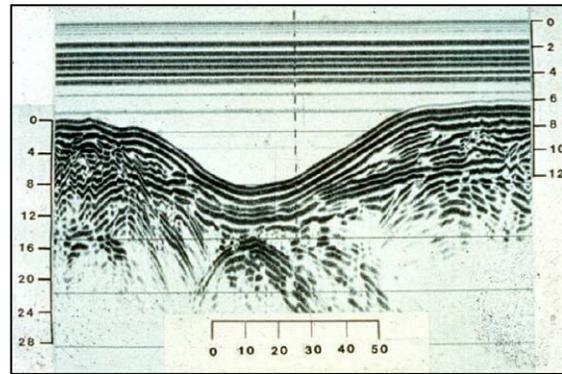


Figure 6-25 Ground Penetrating Radar Record

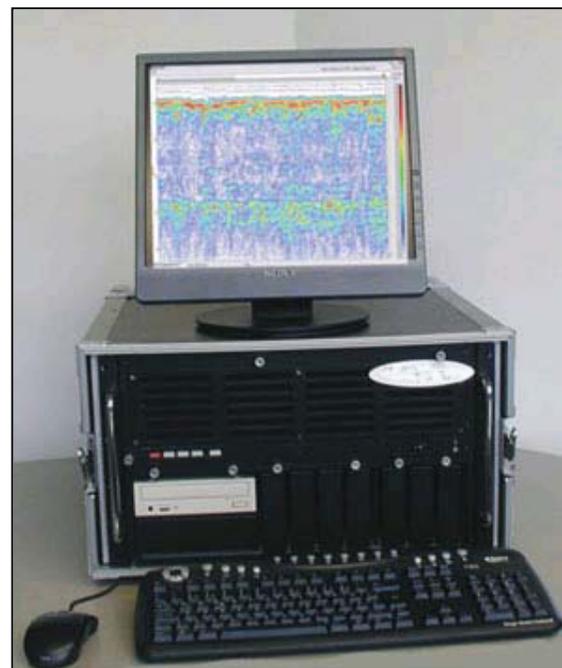


Figure 6-26 Typical Low Frequency Sonar

Figure 6-28 shows a cross section record provided by a 14 kHz tuned transducer. This is the same location as the GPR record in Figure 6-25. 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 6-29 shows a Chirp record of infill material and a scour hole at the upstream nose of a bridge pier.



Figure 6-27 Low Frequency Transducer

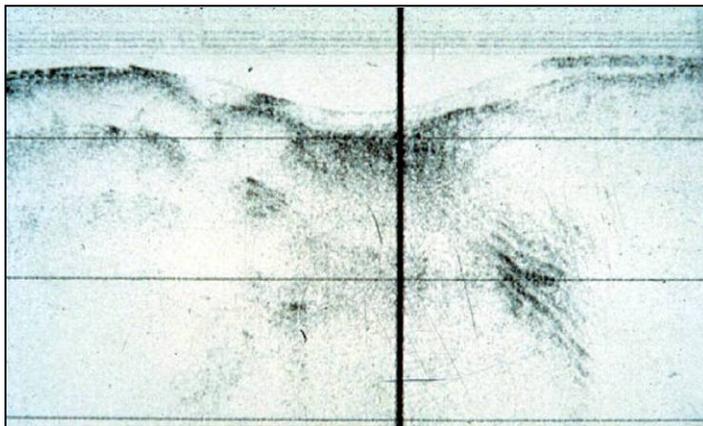


Figure 6-28 Typical Tuned Transducer Record

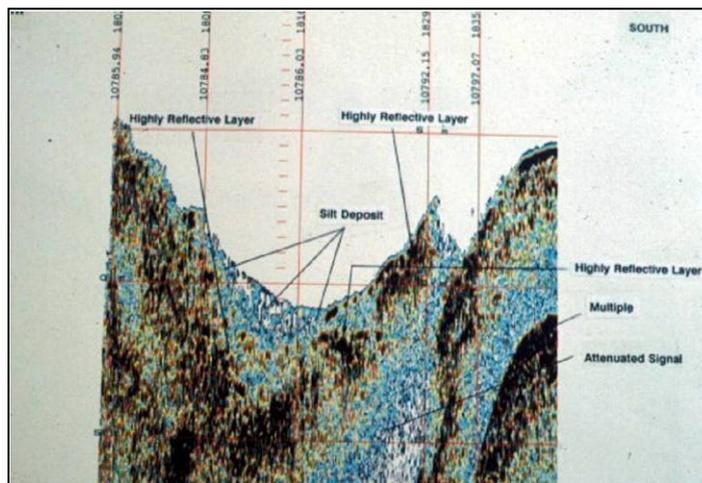


Figure 6-29 Chirp Sub-bottom Record



## CHAPTER VII INSPECTION REPORTS

### SECTION 1. INTRODUCTION

#### 7-1.1 General

Inspection reports provide information which is essential to ensure the safety of public bridges. The information provided by the bridge inspector is the foundation for actions at all levels of government as shown in Figure 7-1.

The underwater bridge inspector provides information for the overall inspection report that is used by the bridge owner to manage future structure maintenance, rehabilitation, and replacement planning and budgeting. The bridge owner then submits information on the condition of all bridges within its area of responsibility to its state. The individual states then collect information on the condition of all the bridges within that state and submit that information to the Federal Highway Administration (FHWA). FHWA collects all the states' information in the National Bridge Inventory (NBI) and reports to Congress on the condition of the bridges within the United States. Congress considers the information provided by FHWA in appropriating funds and apportioning those funds to the various states.



Figure 7-1 Bridge Inspection Reporting Hierarchy

#### 7-1.2 National Bridge Inventory Reporting

The basis for reporting the information in the NBI is the Structure Inventory and Appraisal (SI&A) sheet. The SI&A sheet is a tabulation of information that must be submitted for each individual structure. Many states use some form of the SI&A sheet as the basis for an expanded bridge inspection reporting system. The FHWA *Recording and Coding Guide for the Structure Inventory and Appraisal of the Nation's Bridges (Coding Guide)* is used in completing the SI&A sheet.

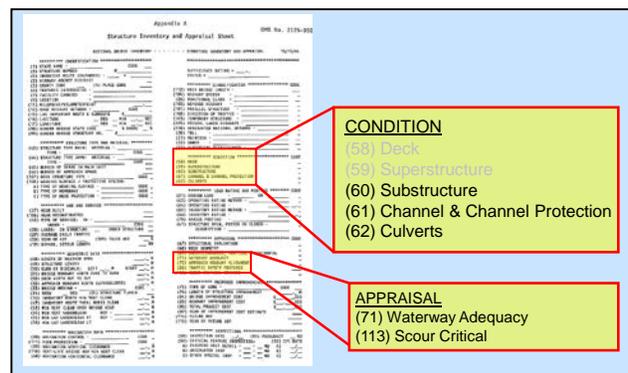


Figure 7-2 SI&A Sheet Underwater Components

Many states have developed their own bridge inspection coding guides or have developed supplements to the FHWA *Coding Guide*. The state coding guides may include additional information that is of use to the states in their bridge management systems, but is not reported to FHWA for the NBI. For example, some states inspect all bridges with spans greater than 10 feet, but only report NBI data for bridges with spans greater than 20 feet.

The underwater inspector will be primarily concerned with ratings of the five inventory and appraisal NBI items shown in Figure 7-2: Item 60-Substructure, Item 61-Channel and Channel Protection, Item 62-Culverts, Item 71-Waterway Adequacy, and Item 113-Scour Critical Bridges. A full size copy of the SI&A sheet may be found in the Appendix.

Items 60, 61, 71, and 113 are described in Chapter VI Scour Investigations.

Item 62-Culverts evaluates the alignment, settlement, joints, structural condition, and other items associated with culverts. This item may be of concern to the underwater inspector if all or part of the structure is inspected underwater. For more information on culvert inspection, refer to FHWA's Bridge Inspector's Reference Manual (BIRM).

In general, the SI&A items are rated on a scale from "9" to "0," with "9" being excellent condition. The *Coding Guide* describes the specific rating criteria for each item.

### 7-1.3 Element Level Inspections

Many states use element level bridge management systems that are based on element condition ratings. Where the NBI rating system assigns a numerical rating from "9" to "0" for substructure units, an element based rating system breaks the substructure units into Commonly Recognized (CoRe) Structural Elements, such as submerged piles, and determines the quantity of submerged piles that should be classified in various condition states. In general, the condition states range from "1" to "5," with "1" being good condition and "5" being critical condition.

The CoRe Structural Elements are a group of structural elements endorsed by the American Association of State Highway Transportation Officials (AASHTO) as a means of providing a uniform basis for data collection for any bridge management system, to enable the sharing of data between states, and to allow for uniform translation of element level data to NBI items. Many states also supplement the AASHTO CoRe elements with non-CoRe elements to track other features of highway structures.

Each element is also assigned an environment rating from "1" to "4" representing the aggressiveness of operating practices and the local environment in which the element is located. The element environment aids in predicting deterioration rates.

A feature of element level rating systems is the inclusion of Smart Flags which are used to identify local problems that are not reflected in CoRe element condition state language. Smart Flags allow agencies to track distress conditions in elements that do not follow the same deterioration pattern or do not have the same units of measurement as the distress described in the CoRe element. Two Smart Flags that might be indicated as a result of an underwater inspection are Settlement, which identifies substructure distress due to foundation settlement; and Scour, which identifies the presence of scour and its impact on the structure.

The element level reporting system can provide more detail than NBI reporting, quantifying the amount and severity of deterioration, and allowing engineers to use this data to plan future maintenance activities.

#### 7-1.4 Detailed Inspection Reports

NBI and element level reporting systems are designed to present summaries of inspection data. In the conduct of an underwater bridge inspection, much additional information about the structure is obtained that should be preserved in standard inspection forms or formal engineering reports. Reports supply information that allows evaluation of the current condition of the bridge, and provides the basis for determining future maintenance costs, scheduling and manpower requirements. Reports should consist of written descriptions, with sketches as necessary, to identify areas of damage and distress. In order to be of value, an inspection report must be clear and complete. A report should, as a minimum, 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, and the performance of those repairs.
- (c) Method of investigation (wading, diving, 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 observed defects and conditions have affected the substructure. This may include an analysis and load rating of the structure. The NBIS requires that the individual charged with overall responsibility for load rating bridges must be a registered professional engineer.
- (f) Recommendations for repair, future maintenance, or further inspection.
- (g) Signature of the 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

### 7-2.1 General

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

Inspectors should recognize that their notes may be subpoenaed and their reports may also be used in litigation when damage has been caused by an outside party, or when persons have been injured or property has been damaged as a consequence of bridge condition. The inspector's original notes should be organized and prepared with care. The quality of those notes and the inspector's competence may be judged by their appearance.

• W/L or WL = Waterline	• fps = Feet per second
• M/L or ML = Mudline	• kt = Knots
• S/L = Shoreline	• Vis. = Visibility (for U/W)
• CB = Channel bottom	• ftg = Footing
• WD = Water depth	• Pen. = Penetration (for CB, UM and defects)
• U/S or U.S. = Upstream	• UM = Undermining
• D/S or D.S. = Downstream	• Deg. = Degradation
• U/W = Underwater	• Agg. = Aggradation
• MLW = Mean low water	• Accm.= Accumulation (for drift/debris)
• HWM = High water mark	

Figure 7-3 Common Abbreviations for Underwater Bridge Inspections

In order to expedite the note-taking process, inspectors can use standard abbreviations, such as those described in the Bridge Inspector's Reference Manual (BIRM), or develop their own set of abbreviations. In using abbreviations, however, there must be no possibility of ambiguity or later misinterpretation. A list of all abbreviations used in note taking should be included in the field notebook. Some common abbreviations for underwater bridge inspections are shown in Figure 7-3.

Field notes should be complete, well-organized and of such detail that they would be able to serve as an interim report until the final formal report is completed. Typical problems that are common in note taking include:

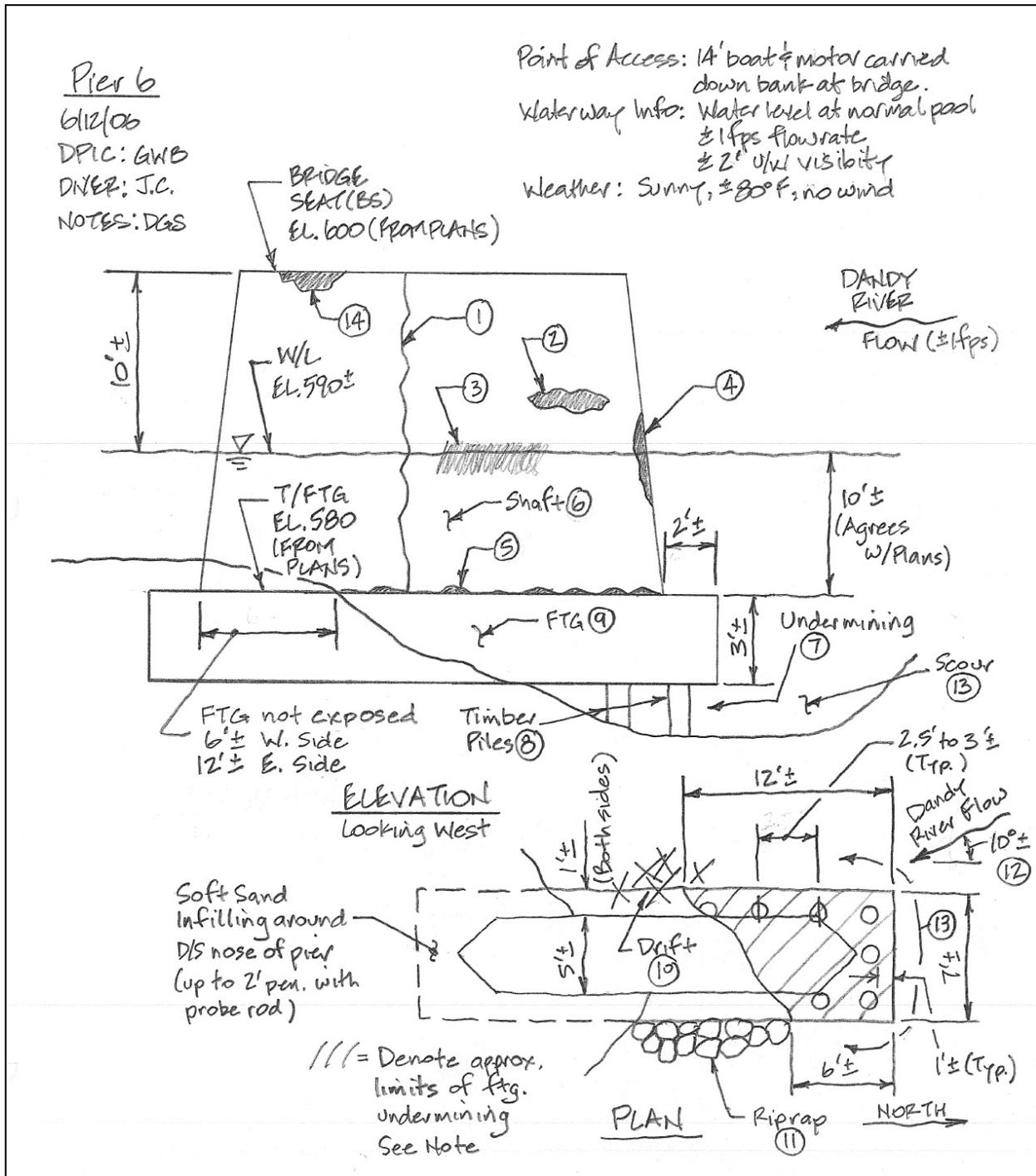
- Notes which are incomplete, too general, or too brief
- Poor nomenclature
- Too long a delay between inspection and report preparation
- Detailed reports prepared from sketchy notes

A sample set of inspection notes, indicating the level of detail that is required and the care that should be exercised is included at the end of this chapter.

## 7-2.2 Inspection Field Book

A pre-prepared inspection field book is often used to organize data collection and ensure a comprehensive approach to an underwater inspection. Information should be recorded systematically. The following summary describes a suggested content outline.

- a. Title Page. The title page should include the name of the structure, the structure identification number, the road section identification number, the name of the crossing, names of the members of the inspection party, the name of the team leader, the type of inspection, the weather conditions, and the dates on which the inspection was made.
- b. Table of Contents
- c. Background Data. This should include site reconnaissance information, design or as-built drawings, repair plans, previous inspection reports, and prior dive plans and hazard analyses. The extent of this documentation may preclude its total inclusion in the actual field book, but all background material should be maintained on site in some form during the inspection.
- d. Dive Operations Plan and Hazard Analysis (see Chapter II)
- e. Plan Reproductions or Pre-Drawn Sketches. This should include both the structure and the waterway. 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. These drawings should be supplemented with blank pages to be used for additional detailed notes as necessary.
- f. Water Depth Sounding Log Forms
- g. Photograph Log Forms
- h. Inspection and Dive Summary Forms. This should include the bridge owner's daily report forms, owner's underwater bridge inspection forms, and pre- and post-dive briefing forms.
- i. Coding Guide and Rating Information
- j. Summary of Findings Form and Checklists. This should include a certification by the team leader indicating an on-site review of the completed inspection and dive forms, a review of all substructure and waterway data, preliminary condition ratings with their rationale, preliminary evaluation and conclusions, preliminary recommendations for repair or maintenance actions, and a determination if any restrictions or emergency actions are necessary.



PIER 6 4/2/06 DPIC: GHB DNER: J.C. NOTES: DGS

INSPECTION NOTES

1. Vert. crack, both sides of shaft, from BS to t/ftg, approx. 10' to north of U/S nose. Mostly H/L to at times up to 1/16" wide. No rust staining or efflorescence/oxidation.
2. Spall, 4'± horiz. by up to 1' vert. w/ up to 4" pen. One horiz. rebar exposed for 2'± w/ up to 10% L.O.S. due to corrosion. Area approx. 8' below BS (EL. 592). Concrete in and around area sand w/ no loose material.
3. Horiz. band of scaling, around entire shaft, btwn 6"± above and 1.5'± below W/L (EL. 590.5 to 588.5). Moderate in extent w/ 1/4" max. pen. and exposed aggregate.
4. Loss of section on U/S nose, apparent impact (ice/debris) damage, btwn 2'± above and below W/L (EL. 592 to 588), no exposed rebar w/ up to 3" pen.
5. Random section loss along shaft and t/ftg interface (approx. 50% of pier perimeter affected), typ. 3" to 6" vert. w/ up to 3" pen. No rebar exposed.
6. Overall, shaft concrete in satisfactory condition w/ only defects 1-5.
7. Ftg undermined across U/S face, 6'± down east side, 12'± down west side. Cavity up to 2' high (vert.) and extends under full width of ftg w/ timber piles exposed.
8. Timber piles exposed along perimeter of ftg (interior piles unreachable). Piles 12" dia. and of good, sound integrity w/ no L.O.S. (See sketch for locations). Pile and ftg interfaces all good w/ pile well embedded.
9. Overall, ftg concrete in satisfactory condition w/ roughly formed surfaces and no significant defects.
10. Moderate accumulation of drift (one root ball and several 12" dia. logs) on C.B. near center of pier. Extends up approx. 5' w/ some of drift on top of ftg.
11. Riprap armoring on C.B. btwn ftg undermining and infilling at U/S end of pier. 1' to 2' dia. stones tightly packed.
12. Direction of river flow (approx. 1 fps) at 10°± skew to pier axis, such that current directed more to west side, which relates to the greater length of undermining.
13. Scour depression around U/S end of pier, 2' to 3' deeper than surrounding C.B. Extends along limits of ftg undermining w/ 6'± radius. Bottom material in scour is firm clay w/ some sand allowing up to 4" of probe rod pen.
14. Loss of section along east edge of BS under south bearing, 3'± horiz. by up to 1'± vert. w/ up to 1' pen. and exposed, corroded rebar. Although outside of U/S scope, area is beginning to affect bearing support and bridge owner should be notified.

Inspection	<input checked="" type="checkbox"/> North Arrow	<input checked="" type="checkbox"/> Waterway info noted	<input checked="" type="checkbox"/> All defects documented
Notes & Sketch	<input checked="" type="checkbox"/> Direction of flow	<input checked="" type="checkbox"/> C.B. material noted	<input checked="" type="checkbox"/> Photographs taken
Checklist	<input checked="" type="checkbox"/> Elevation reference	<input checked="" type="checkbox"/> Scour conditions noted	
	<input checked="" type="checkbox"/> Soundings taken	<input checked="" type="checkbox"/> Riprap and/or drift noted	



WATERWAY NOTES 6/12/06 SOUNDINGS: WDR NOTES: DGS

1. River at normal pool elevation (EL 538±) w/ estimated current of ± 2 fps. Waterway bends ± 45° (from NW to W flow) starting approx. 100' U/S of bridge. Direction of flow at bridge is at approx. 20° skew to longitudinal axis of
2. Due to bend in river, north bank is heavily eroded and steep (approx. 3 vert 1 horiz.). Bank material is primarily clayey w/ various tree roots exposed. trees completely uprooted. Top of bank is generally at 10'± above W/L.
3. South bank is primarily a fairly level flood plain w/ grassy vegetation. G/L is generally 2' to 3' above W/L.
4. G/L South and West of Pier 3 is primarily sand w/ tail of sand infilling at S
5. Two abandoned timber piles cut-off at approx. 1' above C.B.
6. Mound of riprap armoring around U/S nose and U/S half of south side of Pier 1 to 2' dia. stones that extend from 2' to 3' above W/L.
7. 1' to 2' deep drainage ditch, dry at time of inspection.
8. One 2'± dia. tree-trunk w/ root ball on G/L along pier shaft.
9. Moderate accumulation of timber drift (numerous tree trunks up to 2' dia.) on btwn pier and bank. Extends up from C.B. 6' to 7' to just above W/L.
10. C.B. along North side of Pier 3 consisted primarily of a sandy clay allowing up to 1' of probe rod pen.
11. Scour depression around U/S end and South side of Pier 4, generally 3' to 4' deeper than surrounding C.B. w/ 10'± radius. Bottom material w/ depression is firm clayey sand allowing only 2" to 3" of probe rod pen.
12. C.B. along North side of Pier 4 consisted primarily of a soft sandy clay; (infilling behind drift) allowing up to 1.5' of probe rod pen.

Waterway

 North Arrow Substructure designatic



## CHAPTER VIII MANAGEMENT OF UNDERWATER CONTRACTS

### SECTION 1. INTRODUCTION

#### 8-1.1 General

This chapter provides guidance for procuring and managing 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.

While the National Bridge Inspection Standards (NBIS) sets the national standard for the proper safety inspection and evaluation of all highway bridges, and the Federal Highway Administration (FHWA), through directives and technical advisories, establishes policies and provides guidance for implementation of bridge inspection programs, it is state departments of transportation and local agencies that must ensure that those minimum requirements are adopted and supplemented as necessary to ensure effective management of the structural safety of bridges located in water within their areas of responsibility.

Bridge owners must also maintain policies and procedures that ensure a high degree of accuracy and consistency in their bridge inspections through a systematic quality control (QC) and quality assurance (QA) program.

#### 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, unique 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 addressed in the procurement and contractual documents. In some instances, the technical staff may have to work closely with procurement personnel to ensure that the NBIS and FHWA requirements, as well as the administrative requirements that are special for this type of work, are included.

Generally, state departments of transportation procure bridge inspection services as a professional engineering service. In many states, because bridge inspections include evaluations of structural conditions, and recommendations for repair, they must be conducted under the responsible charge of a Professional Engineer (P.E.) licensed in that state. Many states require underwater inspection reports to be signed and sealed by a licensed professional engineer, although some portions of the work may be accomplished by engineers and divers who are not licensed.

The Safe, Accountable, Flexible, Efficient Transportation Equity Act, or SAFETEA-LU, (P.L. 109-59) 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.

The most common method of procuring underwater bridge inspection services is through the issuance of a Request for Proposals (RFP). The RFP will generally describe the scope of the work, the desired experience and qualifications of the firm and team members, the time frame for completing the work, the form of response desired, and the time by which responses are due.

The more information that can be provided in the RFP about the bridges to be inspected, the more appropriate the responses will be. Often the scope of work that will form the basis for the eventual contract is included in the RFP with a list of the bridges to be inspected, including their location and basic information about their configuration. In some cases, drawings or previous inspection reports will be made available.

## **SECTION 2. SCOPE OF WORK**

### **8-2.1 General**

The scope of work should define the extent of the required inspections; establish minimum standards for inspection personnel; mandate any specific equipment or specialized technology requested; describe the report format expected; and outline any known data or constraints which may affect the inspection. A scope of work or standard specification 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 scope of work can be developed using the aspects discussed herein and outlined in the checklist provided at the end of this chapter.

### **8-2.2 Structure Description**

A complete description of each 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, water depth at each substructure unit, and water quality. If the water extends to the underside of the superstructure such that the superstructure inspection must be conducted as a penetration dive, that should also be noted. Waterway current velocity should be included, if known. If there are any special requirements such as coordination for access to the site, control of nearby dam gates, or special safety training that should also be specified.

### 8-2.3 Level of Inspection

The level of inspection to be performed should be clearly defined, as well as any expectations for augmenting an underwater inspection by divers with other useful technology such as ultrasonic testing and acoustic imaging. FHWA has established minimum guidelines for level of inspection effort for a 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.
- Scour Inspection - 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 Level III inspections must be made as necessary to evaluate the condition of the structure. If it is found during a routine inspection that there is a need for a significant increase in the number of Level II inspection locations or a need for Level III inspections that was not included in the original scope of work, a change in scope may be necessary.

For damage inspections, in-depth inspections or special inspections, a specific scope of work should be developed to accomplish the goal of the inspection. This may require more extensive cleaning and measuring. In determining the number of additional tests and measurements to require, it is important to gather sufficient data to achieve certainty with the results. Reference to statistical survey methods may be useful, but selection of the appropriate sample size in an underwater structure is difficult because of the varying environmental conditions that may be present.

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; to make major economic decisions regarding the future of the structure; or to prepare detailed repair plans. In such cases, it is generally more cost-effective to initially include more Level II examinations, as well as 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 effort, for example, the height of Level II inspection cleaning. The definitions of the levels of inspection presented in Chapter II of this manual are generic definitions and as such include items which are not applicable to each bridge. Inclusion of inappropriate requirements can increase the cost of the work unnecessarily.

It should be noted that the minimum requisites for routine inspections as listed above are not necessarily intended to identify every defect, but should result in an overall assessment of existing conditions. In some instances, the minimum required effort and its limited Level II inspections may not be sufficient to accurately determine overall defect quantities.

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 and could be specified.

For the upper limit of the inspection, the waterline; some distance above the waterline such as 3 feet; or the top of the entire substructure element such as the pier or the pile may be specified. Using the waterline as the demarcation between the above water and underwater inspection can be confusing because the waterline elevation may change between the time of the above water and underwater inspections, and leave a portion of the substructure unit uninspected. Including the entire element, both above and below water, as part of the underwater inspection has many advantages. It eliminates coordination problems between above and below water inspectors in recording data and evaluating the substructure unit. It also 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. Additionally, there is the benefit that the inspector's report will present all substructure inspection data in one location.

#### **8-2.4 Channel Bottom Survey Soundings**

Soundings should be made to provide a record of the channel bottom profile at the bridge. Unless the water is too shallow for a boat, soundings are typically taken using sonar, and may be supplemented by physical measurements around the substructure units. During a sonar survey, the output should be adjusted to account for the depth of the transducer below the water surface. Soundings, at least those recorded 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. The scope of work should designate the datum and type of equipment to be used.

Soundings should be taken around all elements in water and along lines parallel to the bridge at both fascias. 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, soundings should also be taken along lines parallel to the fascia of the bridge, at 50 feet, 100 feet, and 200 feet upstream and downstream of the bridge. Using a consistent sounding pattern over a number of years will allow for the plotting of historical data so that changes in the channel bottom can be noted, as shown in Figure 8-1.

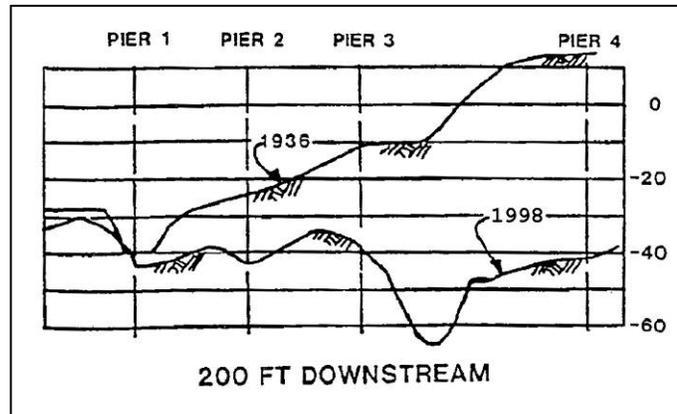


Figure 8-1 Plot of Channel Cross Section

Additional soundings should be made as necessary to determine significant bottom features in and around the bridge such as a scour depression at a substructure unit. In some cases, additional lines of soundings should be taken and channel bottom contour lines plotted (as shown in Figures 6-20 through 6-22).

Additional soundings should be made as necessary to determine significant bottom features in and around the bridge such as a scour depression at a substructure unit. In some cases, additional lines of soundings should be taken and channel bottom contour lines plotted (as shown in Figures 6-20 through 6-22).

### 8-2.5 Documentation

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

Detailed field notes should always be required. Documentation should include detailed notes for defects with all pertinent identifying and dimensional information such as location, height, width, and penetration. Similarly, detailed dimensional information should be included in the notes for any substructure foundation exposure or undermining. These notes should be sufficiently detailed to permit evaluation of the structure and preparation of repair documents and cost estimates. Chapter VII describes field note documentation in greater detail. It should be noted that some bridge owners require submission of the original field notes with the final report.

In addition to the underwater inspector's notes, supplemental documentation visually depicting conditions is commonly required. Underwater color digital photographs or acoustic imaging generally should be required for significant defects. Photography in clear, calm water is relatively inexpensive. In more turbid water with diminished visibility, where a clear water box must be used, or in situations of high current, the cost increases. High-definition acoustic images can be more cost-effective in turbid conditions. Photographs and other images can be extremely valuable to illustrate conditions in order to obtain funding, and to assist in the preparation of repair documents. The additional cost of underwater photographs or acoustic images, for most inspections, is relatively small. At a minimum, significant defects should be

captured using underwater photographic or acoustic imaging methods. In some instances, it may also be appropriate to provide images of typical conditions, but not every minor defect. A minimum number of photographs should be required at each bridge—for example, views of both bridge fascias, and two views of each pier. There should be flexibility, however, in the scope of work to permit reducing the number of images of good conditions, if there is a corresponding increase in the number of defect photographs or panoramic acoustic images provided.

Underwater digital video recording may be specified as a required form of documentation either alone or in combination with other underwater still images. It is also possible to capture still photographic images from digital video recordings. Video recording documentation requires more diving time than still photography, as well as time to edit the output. This makes it particularly important to use video recording time selectively. A competent, trained diver-inspector, in consultation with the on-site team leader, should be able to judge those areas requiring video recording during the investigation. The value of the video is limited by the ability of the diver to recognize significant conditions and to properly use the camera to capture the conditions at such areas.

A video of an entire underwater inspection is often not necessary and seldom reviewed in its entirety by others. Although state-of-the-art digital video can sometimes “see” better than the human eye, there still can be problems in viewing video since many variations of color and depth cannot be perceived when viewing a video recording. The video system should record the diver’s audio comments during the inspection, as well as the questions and comments of on-site observers. Later editing of the inspection video may also be used to add to or clarify these comments.

In digital video recording, there is much meaningless material recorded: starting; stopping; moving from substructure unit to substructure unit; adjusting lighting; and malfunctions. If a member of the bridge owner’s agency is to review hours of inspection video footage, the reviewer will quickly become bored and inattentive. Therefore, recordings should be edited to remove as much meaningless content as possible. Edited recordings should be provided with an on-screen clock or counter and titles to aid in reviewing the tape and finding the documentation for specific units. Submission of the complete, unedited raw video recording may also be required.

### **8-2.6 Report Requirements**

The scope of work should state the content and format of the inspection report, and number of copies of the report required. Since the report can range from a two or three-page letter to a bound multi-page volume, costs of report preparation can vary widely. Factors which may influence the choice of report format and the amount of detail include: agency standards, the size and importance of the bridge, 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
- (5) Drawings/acoustic images
- (6) Sounding plans and waterway cross sections
- (7) Additional inspection forms
- (8) Load rating calculations

Drafts of inspection reports should generally be submitted to the owner for review and comment. The completed underwater inspection report should bear the signature and seal of the Registered Professional Engineer who was responsible for the underwater bridge inspection.

### 8-2.7 Scheduling

The scope of work should include a time period for completing an underwater bridge inspection project, and require that individual underwater bridge inspections be completed within routine inspection frequency recommended during the previous inspection cycle. Within that framework, economies may be realized by allowing the inspectors latitude for scheduling their field work.

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 might it be difficult for the diver to concentrate on the inspection, but topside support personnel are also hampered by severe weather. 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.

When 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.

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.

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

### **8-2.8 Methods of Payment**

State departments of transportation generally award contracts for engineering and bridge inspection services using Qualification Based Selection (QBS) procedures and compensation is determined in compliance with cost principles in the Federal Acquisition Regulations (FAR). Typical methods of payment are: cost plus fixed fee; lump sum (unit price) per bridge; and lump sum (unit price) per substructure unit. Whichever method is selected, provisions should be incorporated for progress or partial payments as the work proceeds, especially if review and approval of the report by the bridge owner may be delayed. A typical payment schedule for a unit price contract might allow payment of 60 percent of the unit price upon completion of the inspection, 30 percent payment upon submission of the report and a final 10 percent payment upon approval of the final report.

### **8-2.9 Safety**

The scope of work should contain a statement that all work shall be in accordance with the requirements of the Occupational Safety and Health Administration (OSHA) and local safety regulations.

The bridge owner may also require compliance with additional safety regulations and the submission of safety records and indices, such as the total incidence rate, which is a measure of the company's reportable accidents. Each diving employer is required to develop and maintain a diving safe practices manual. The bridge owner can require submission of the manual, and a project specific diving operations plan with hazard analysis for review prior to the start of the work.

The diving company should have a well established in-house program for the inspection and maintenance of all diving, marine, and testing equipment so that equipment is operational and reliable at all times.

## SECTION 3. QUALIFICATIONS OF INSPECTION PERSONNEL

### 8-3.1 General

It is the prerogative of the agency in charge of conducting underwater bridge inspections to establish the minimum qualifications for the underwater bridge inspector provided that they meet or exceed the requirement of the NBIS. The underwater inspection team should consist of a team leader and additional inspectors as required by the project scope and time frame, and based on all applicable safety considerations. Divers performing underwater inspections and evaluations should be fully qualified by training and experience in evaluating the types of 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, however, the diver will usually be the only one to inspect a suspect or critical area. The inspector-diver must also be able to judge his own limitations, in evaluating structural conditions. If the diver encounters a situation which exceeds his expertise, the diver 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, but meets the NBIS requirements can be used, but the diver should be fully trained and experienced in the structure type and channel conditions at the given bridge locations.

### 8-3.2 Team Leader

The underwater bridge inspection team leader should meet the NBIS requirements for a bridge inspection team leader. Individual agencies may require additional training, experience, and licensure. Although not required by the NBIS, it is recommended that the team leader be certified as a diver by one of the accepted commercial diver certification organizations or have the training and experience to comply with the requirements of the Occupational Safety and Health Administration (OSHA). This will allow the team leader to perform the underwater inspection or, if deemed necessary, the team leader can verify or evaluate conditions reported by other underwater inspectors. The team leader must be onsite at all times during the underwater inspection and it is recommended that the team leader perform a representative portion of the inspection in order to evaluate the structure. This individual will have overall responsibility for the inspection and should be experienced in planning and conducting diving operations. The team leader is responsible for the preparation of all written reports. It is recommended that the team leader for underwater inspections have successfully completed an FHWA approved underwater bridge inspection training course.\*

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\*National Highway Institute Course No. 130091 Underwater Inspection of Bridges

### 8-3.3 Underwater Bridge Inspectors

Additional underwater bridge inspectors used for the project should be fully trained and experienced to satisfy the minimum requirements of the NBIS for underwater bridge inspectors. They should be certified as a diver by one of the commercial diver certification organizations or have the training and experience to comply with the requirements of the Occupational Safety and Health Administration (OSHA). In addition, they should be able to document their training and experience in similar type inspections and diving situations.

### 8-3.4 Additional Considerations

The solicitation for underwater inspection services should clearly state the required qualifications of all members of the inspection team. In order to ensure that team members meet the requirements of both the NBIS and OSHA, owners should require that copies of certifications, proof of training and records of experience be submitted to the agency. If non-destructive testing, hydrographic surveying, or acoustic imaging is specified, personnel should be required to demonstrate their certifications and qualifications in those areas.

## SECTION 4. INSURANCE REQUIREMENTS

### 8-4.1 General

All types of field inspection work have risks associated with them. Work in and over water has special risks. Careful planning and hazard analysis can reduce those risks, but insurance is necessary to protect employees, employers, bridge owners, and the general public. The types of insurance provided for underwater inspection contracts must meet the requirements of the agency's standard contracting procedures. In addition to the normal requirements of an agency, there are several coverages which are unique to underwater or marine work. 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.

The types of insurance coverage that are required for a particular project vary, but may include comprehensive general liability and property damage insurance, workers' compensation insurance, United States Longshoremen's and Harbor Workers' Insurance, Jones Act Maritime Insurance, and professional liability insurance. The insurance coverage, with appropriate monetary limits, may be provided by individual policies in each of these categories or may be provided by basic policies in conjunction with an umbrella policy to raise the limits of the underlying policies.

### 8-4.2 Comprehensive General Liability and Property Damage Insurance

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

### 8-4.3 Workers' Compensation

Workers' Compensation (WC) insurance is a no-fault type of insurance that protects workers who suffer occupational injury, disability, or disease. If a worker is injured on a job, the worker does not have to prove that the employer, or another employee, was negligent in order to be compensated for medical expenses, rehabilitation, and lost time, or for a partial or complete disability. It also pays death benefits to dependents for job-related injuries. The WC insurance requirement is mandated by the individual states, and its benefits are monitored by individual state boards. In most states, WC insurance can be purchased from private insurance companies, but in a few states, known as monopolistic states, the coverage must be purchased from a state agency.

There is a second component of WC, Employers Liability Insurance, which protects employers from suits by injured employees in the event that an injury is not compensable under the state's WC law.

Commercial diving activities are considered high risks by insurance firms. Rates for Workers' Compensation insurance for diving activities are very high, varying from year to year, affected by the experience of the diving industry as a whole and individual company experience. They are often in the range of 50 percent of direct wages or higher.

### 8-4.4 Longshoremen's and Harbor Workers' Compensation Insurance

U.S. Longshoremen's and Harbor Workers' (USL&H) Insurance is similar to WC insurance, but it provides coverage for employees working on, over, or adjacent to navigable waters of the United States. It is a federally mandated insurance and generally provides greater benefits to the employee than state WC insurance. Benefits are monitored by a federal board, but the insurance must be purchased from a private insurance company. WC insurance coverage does not include USL&H coverage unless it is specifically added as endorsement. A separate policy may also be used to secure Longshoremen's coverage. The determination of when state WC insurance applies and when USL&H insurance applies is not always apparent, especially when the location where the injury or disability occurred is not clear or when the limits of the navigable waterway are not well defined. For this reason, USL&H insurance should be a requirement for all underwater inspection contracts.

#### **8-4.5 Jones Act Maritime Insurance and Maritime Employers Liability Insurance**

Jones Act Maritime Insurance and Maritime Employers Liability (MEL) Insurance are similar to WC and USL&H, except it covers employees who are members of crews of vessels. Because divers and their support personnel may at times work from a boat, this maritime coverage may apply to some underwater inspection operations. In the past, it was often not considered applicable to diving work unless the diver was regularly assigned to a vessel. Court decisions on this coverage, however, have not been consistent, and prudence would dictate that the coverage be provided to prevent a possible gap in coverage. Specific policies may limit coverage to only boats owned by the employer or may exclude boats owned by the employer. Professional legal and insurance advice is recommended to ensure adequate coverage.

#### **8-4.6 Professional Liability**

Professional liability insurance, sometimes called “errors and omissions” insurance, protects the engineer and the owner from claims alleging malpractice and similar professional errors. If, for example, an engineer made an error in the inspection and evaluation of a structure that led to injuries, property damage, contractor claims for additional compensation, owner’s claims, or similar claims, the professional liability insurance could be available to protect the owner. In today’s litigious society, professional liability limits of at least \$1 million, and preferably more, are appropriate. Professional liability coverage is required by most agencies in above-water and underwater bridge inspection contracts.

#### **8-4.7 Certificates of Insurance**

Certificates of insurance are issued by insurance companies or their broker representatives as evidence that the various types of insurance coverage are in place. The certificates indicate the types of insurance, the name of the insurance company providing each insurance policy, insurance policy numbers, the limits for each type of insurance, and the expiration date for each policy. A sample insurance certificate is shown in Figure 8-2.

The certificate should be issued in the bridge owner’s name as the certificate holder and it should list the project for which the certificate is issued. The certificate will also indicate a minimum number of days’ notice that will be given to the certificate holder before the insurance policies can be cancelled. It may also indicate endorsements to the policies such as additional coverage provided or the names of additional insured parties.

Obtaining insurance certificates is a routine procedure that is without cost to the insured. Bridge owners should not accept certificates of insurance that are not addressed specifically to the owner; otherwise, the insurance could be cancelled without the owner’s knowledge.

The underwater bridge inspector should, as a minimum, provide evidence of insurance that includes professional liability insurance, comprehensive general liability (personal injury and property damage) insurance, automobile insurance for vehicles at the work site, WC insurance, USL&H insurance when working in, or adjacent to navigable waters, and maritime insurance when working from a vessel.

<b>ACORD™ CERTIFICATE OF LIABILITY INSURANCE</b>						DATE (MM/DD/YYYY) 08/21/09
<b>PRODUCER</b> ACME Insurance Services, Inc. 999 Main Street Anywhere, USA			THIS CERTIFICATE IS ISSUED AS A MATTER OF INFORMATION ONLY AND CONFERS NO RIGHTS UPON THE CERTIFICATE HOLDER. THIS CERTIFICATE DOES NOT AMEND, EXTEND OR ALTER THE COVERAGE AFFORDED BY THE POLICIES BELOW.			
<b>INSURED</b> Consulting Engineers, Inc. 123 Main Street Anywhere, USA			<b>INSURERS AFFORDING COVERAGE</b>		<b>NAIC #</b>	
			INSURER A: <b>General Liability and Fire</b>	20052		
			INSURER B: <b>Workers Insurance</b>	1904		
			INSURER C: <b>Boat Insurance Company</b>	18891		
			INSURER D: <b>Auto Casualty Ins Co</b>	29424		
			INSURER E: <b>Maritime Insurance Co.</b>	29424		
<b>COVERAGES</b>						
THE POLICIES OF INSURANCE LISTED BELOW HAVE BEEN ISSUED TO THE INSURED NAMED ABOVE FOR THE POLICY PERIOD INDICATED, NOTWITHSTANDING ANY REQUIREMENT, TERM OR CONDITION OF ANY CONTRACT OR OTHER DOCUMENT WITH RESPECT TO WHICH THIS CERTIFICATE MAY BE ISSUED OR MAY PERTAIN. THE INSURANCE AFFORDED BY THE POLICIES DESCRIBED HEREIN IS SUBJECT TO ALL THE TERMS, EXCLUSIONS AND CONDITIONS OF SUCH POLICIES. AGGREGATE LIMITS SHOWN MAY HAVE BEEN REDUCED BY PAID CLAIMS.						
INSR LTR	ADDL NSRD	TYPE OF INSURANCE	POLICY NUMBER	POLICY EFFECTIVE DATE (MM/DD/YY)	POLICY EXPIRATION DATE (MM/DD/YY)	LIMITS
A		<b>GENERAL LIABILITY</b> <input checked="" type="checkbox"/> COMMERCIAL GENERAL LIABILITY <input type="checkbox"/> CLAIMS MADE <input checked="" type="checkbox"/> OCCUR  GN'L AGGREGATE LIMIT APPLIES PRR <input type="checkbox"/> POLICY <input type="checkbox"/> PREM <input type="checkbox"/> LOC	GL12345	11/01/08	11/01/09	EACH OCCURRENCE \$ 1,000,000 DAMAGE TO RENTED PRFM/SFS (EA occurrence) \$ 50,000 MED EXP (Any one person) \$ PERSONAL & ADV INJURY \$ 1,000,000 GENERAL AGGREGATE \$ 2,000,000 PRODUCTS - COMP/OP AGG \$ 1,000,000
D		<b>AUTOMOBILE LIABILITY</b> <input checked="" type="checkbox"/> ANY AUTO <input type="checkbox"/> ALL OWNED AUTOS <input type="checkbox"/> SCHEDULED AUTOS <input checked="" type="checkbox"/> HIRED AUTOS <input checked="" type="checkbox"/> NON-OWNED AUTOS <input checked="" type="checkbox"/> <b>Hired Auto</b> <input checked="" type="checkbox"/> <b>PD \$100K</b>  <b>GARAGE LIABILITY</b> <input type="checkbox"/> ANY AUTO	D6789107	11/01/08	11/01/09	COMBINED SINGLE LIMIT (EA accident) \$ 1,000,000 BODILY INJURY (Per person) \$ BODILY INJURY (Per accident) \$ PROPERTY DAMAGE (Per accident) \$ AUTO ONLY - EA ACCIDENT \$ OTHER THAN EA ACC AGG \$
A		<b>EXCESS/UMBRELLA LIABILITY</b> <input type="checkbox"/> OCCUR <input checked="" type="checkbox"/> CLAIMS MADE  DEDUCTIBLE <input checked="" type="checkbox"/> RETENTION \$ 25000	EXL567890	11/01/08	11/01/09	EACH OCCURRENCE \$ 5,000,000 AGGREGATE \$ 5,000,000 \$ \$
B		<b>WORKERS COMPENSATION AND EMPLOYERS' LIABILITY</b> ANY PROPRIETOR/PARTNER/EXECUTIVE OFFICER/MEMBER EXCLUDED? If yes, describe under SPECIAL PROVISIONS below	WC999899 WC892789(CA) Incl USL&H	11/01/08 11/01/08	11/01/09 11/01/09	<input checked="" type="checkbox"/> STATUTORY LIMITS <input type="checkbox"/> OTHER E.L. EACH ACCIDENT \$ 1,000,000 E.L. DISEASE - EA EMPLOYEE \$ 1,000,000 E.L. DISEASE - POLICY LIMIT \$ 1,000,000
C		OTHER <b>P&amp;I, Hull</b>	OMH6238745	08/01/08	08/01/09	\$1,000,000 CSL
E		<b>Maritime Empl Liability</b> <b>Professional Liability</b>	MEL29108745 PL1236809	11/01/08 11/01/08	11/01/09 11/01/09	\$1,000,000 AO Person/\$2,000,000 Acc. \$2,000,000 Claim/\$2,000,000 Agg
DESCRIPTION OF OPERATIONS / LOCATIONS / VEHICLES / EXCLUSIONS ADDED BY ENDORSEMENT / SPECIAL PROVISIONS  Underwater Inspection of Bridges, Anywhere, USA						
<b>CERTIFICATE HOLDER</b>				<b>CANCELLATION</b>		
State Department of Transportation Attn John Smith 100 Capital Drive Anywhere, USA				SHOULD ANY OF THE ABOVE DESCRIBED POLICIES BE CANCELLED BEFORE THE EXPIRATION DATE THEREOF, THE ISSUING INSURER WILL ENDEAVOR TO MAIL <del>30</del> DAYS WRITTEN NOTICE TO THE CERTIFICATE HOLDER NAMED TO THE LEFT, BUT FAILURE TO DO SO SHALL IMPOSE NO OBLIGATION OR LIABILITY OF ANY KIND UPON THE INSURER, ITS AGENTS OR REPRESENTATIVES.		
				REPRESENTATIVE AUTHORIZED REPRESENTATIVE		

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Figure 8-2 Sample Insurance Certificate

## SECTION 5. QUALITY CONTROL AND QUALITY ASSURANCE

### 8-5.1 General

Quality control (QC) constitutes those procedures that are intended to maintain the quality of underwater bridge inspections at or above a specified level. Quality assurance (QA) is the use of sampling and other measures to assure the adequacy of quality control procedures in order to verify or measure the quality level of an entire underwater bridge inspection program. The NBIS requires bridge owners assure that systematic QC and QA procedures are used to maintain a high degree of accuracy and consistency in the bridge inspection program.

Because the areas inspected during an underwater investigation are only accessible by persons with specialized training and equipment, the quality of the inspection is not easily evaluated 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 procedures and a critical review of the product of the inspection coupled with a comparison of the underwater report findings with those of previous inspections.

It is the responsibility of the diving inspection team leader to assure the quality of the inspection effort. The procedures followed by the team leader to assure quality should be part of the quality control program. The quality control program should include the following:

- (a) Verification of assignment of qualified inspection team members.
- (b) Periodic bridge inspection and diving refresher training.
- (c) Establishment of and adherence to standard inspection procedures.
- (d) Development and use of standard inspection forms and checklists for recording inspection data.
- (e) Preparation of reports using an established, comprehensive format.
- (f) Unannounced site visits by senior staff to review team qualifications, inspection methods, safety procedures, and equipment.
- (g) In-house, independent review of inspection reports.

The technical staff of the bridge agency should critically review the in-house or the outside diving firm'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 insufficient or inaccurate inspection requiring further action to confirm conditions.

## Bridge Owner's Underwater Inspection Plan Checklist

### Bridge Identification

- Bridge Name
- Structure ID
- Owner
- Route
- Milepoint
- Latitude
- Longitude
- Underwater inspection interval
- Points of Contact (name and phone number) for immediate action such as closing the bridge based on findings: \_\_\_\_\_  
\_\_\_\_\_

### Marine Information

- Waterway Name
- Navigable? (Y/N) \_\_\_\_\_  
If so:
  - Waterway river point
  - Inspection coordination contacts (names, agencies, phone #s, required lead time for notification)
- Type of water - salt/fresh/brackish
- Anticipated dive depths: \_\_\_\_\_
- Anticipated current: \_\_\_\_\_
- Anticipated water visibility: \_\_\_\_\_
- Other waterway concerns or items to note, i.e., presence near military facility, tribal fishing, water quality concerns, historic presence of logjams, etc.

### Scour Information

- Is bridge Scour Critical? \_\_\_\_\_
- Current Bridge Scour Code (Item 113): \_\_\_\_\_
- Is Plan of Action (POA) in place?
- Are scour mitigation/countermeasures present? (Locations, types and significance)
- Are scour monitoring devices present? (Locations and types)

**Structure Information**

- Type of Superstructure
  - Main Spans
  - Approach Spans
- Type of Substructure
  - Abutments
  - Piers
  - Foundations

**Inspection Information**

- Date of last inspection
- Findings and necessary follow-up from previous inspection
- Routine Inspection codes for:
  - Substructure Condition \_\_\_\_\_
  - Superstructure Condition \_\_\_\_\_
  - Channel and Channel Protection \_\_\_\_\_
  - Waterway Adequacy \_\_\_\_\_
- Special equipment necessary

**Dive Team Certification Requirements**

- Team Leader
  - NBIS requirements
  - Professional Engineer
  - Successful completion of underwater bridge inspection course
  - OSHA qualified diver
- Team Members
  - Engineer-diver
  - Successful completion of comprehensive bridge inspection course
  - Successful completion of underwater bridge inspection course
  - OSHA qualified diver

**Inspection Requirements (Directions to dive team)**

- Specify level of inspection (I, II or III) and amount of coverage of in-water elements
  - Ex: Level I, 100%
  - Level II, at three elevations on 10% of piles, and four locations at three elevations per substructure unit
  - Level III, \_\_\_\_\_

- Specify Scour Inspection
  - Soundings around substructure units
  - Cross sections at upstream and downstream fascias
  - Cross sections at \_\_\_ ft and \_\_\_ft upstream and downstream of fascias
  - Profile along thalweg of waterway for \_\_\_ ft upstream and downstream of fascias
  - Fathometric survey with plotted contour lines extending \_\_\_ft upstream and downstream of fascias
  
- Substructure elements to be inspected by divers\_\_\_\_\_
  
- If an element is identified to be inspected underwater is not in water, \_\_\_\_\_
  
- Required Dive Mode
  - Scuba
  - Scuba with communication
  - Surface supplied air with communication
  
- Reference Datum \_\_\_\_\_
  
- Criteria for Underwater Photographs
  - Minimum number per substructure unit
    - Typical conditions
    - Conditions rated less than \_\_\_\_\_
  
- Check and document condition of structural members looking for cracks, spalling, abrasion, corrosion, exposed reinforcing steel, and undermining
  
- Document depth, length, height, and location of exposed or undermined portions of the foundations. Record number of exposed piles for footings supported by piles.
  
- Photography requirement
- Video requirement
- Check for and document presence and effectiveness of scour mitigation/countermeasures
  
- Sounding requirement
- Acoustic imaging
- Check for and document presence, condition, and operability of scour monitoring devices

- Examine streambed and channel for stability, especially around substructure units
- Note presence of debris build-up

**Criteria for Communications from Dive Team**

- In event of critical/emergency condition
  - Frequency otherwise: start, finish, daily?
- 
- 

**Report Requirements**

- Document findings from inspection in report
- Record pertinent inspection environment—current, depths, visibility, equipment used, etc.
- Comment on any recommendations and justification for changes that need to be made to Superstructure, Substructure, Channel & Channel Protection, Scour and/or Waterway Adequacy codes based on this inspection.
- Document recommendations for needed repairs and their urgency
- Include plan and elevation of the structure with important features highlighted
- Include definitions referred to in this document for Levels of Inspection, degree of corrosion, urgency of repairs, etc.
- Other \_\_\_\_\_

## APPENDIX



## Structure Inventory & Appraisal (SI&A) Sheet



OMB No. 2125-0501

Structure Inventory and Appraisal Sheet

NATIONAL BRIDGE INVENTORY - - - - - STRUCTURE INVENTORY AND APPRAISAL 10/15/94

\*\*\*\*\* IDENTIFICATION \*\*\*\*\*

(1) STATE NAME - \_\_\_\_\_ CODE \_\_\_\_

(8) STRUCTURE NUMBER # \_\_\_\_\_

(5) INVENTORY ROUTE (ON/UNDER) - \_\_\_\_\_ = \_\_\_\_\_

(2) HIGHWAY AGENCY DISTRICT \_\_\_\_\_

(3) COUNTY CODE \_\_\_\_\_ (4) PLACE CODE \_\_\_\_\_

(6) FEATURES INTERSECTED - \_\_\_\_\_

(7) FACILITY CARRIED - \_\_\_\_\_

(9) LOCATION - \_\_\_\_\_

(11) MILEPOINT/KILOMETERPOINT \_\_\_\_\_

(12) BASE HIGHWAY NETWORK - \_\_\_\_\_ CODE \_\_\_\_

(13) LRS INVENTORY ROUTE & SUBROUTE # \_\_\_\_\_

(16) LATITUDE \_\_\_\_ DEG \_\_\_\_ MIN \_\_\_\_ SEC

(17) LONGITUDE \_\_\_\_ DEG \_\_\_\_ MIN \_\_\_\_ SEC

(98) BORDER BRIDGE STATE CODE \_\_\_\_ % SHARE \_\_\_\_ %

(99) BORDER BRIDGE STRUCTURE NO. # \_\_\_\_\_

\*\*\*\*\* STRUCTURE TYPE AND MATERIAL \*\*\*\*\*

(43) STRUCTURE TYPE MAIN: MATERIAL - \_\_\_\_\_

TYPE - \_\_\_\_\_ CODE \_\_\_\_

(44) STRUCTURE TYPE APPR: MATERIAL - \_\_\_\_\_

TYPE - \_\_\_\_\_ CODE \_\_\_\_

(45) NUMBER OF SPANS IN MAIN UNIT \_\_\_\_\_

(46) NUMBER OF APPROACH SPANS \_\_\_\_\_

(107) DECK STRUCTURE TYPE - \_\_\_\_\_ CODE \_\_\_\_

(108) WEARING SURFACE / PROTECTIVE SYSTEM:

A) TYPE OF WEARING SURFACE - \_\_\_\_\_ CODE \_\_\_\_

B) TYPE OF MEMBRANE - \_\_\_\_\_ CODE \_\_\_\_

C) TYPE OF DECK PROTECTION - \_\_\_\_\_ CODE \_\_\_\_

\*\*\*\*\* AGE AND SERVICE \*\*\*\*\*

(27) YEAR BUILT \_\_\_\_\_

(106) YEAR RECONSTRUCTED \_\_\_\_\_

(42) TYPE OF SERVICE: ON - \_\_\_\_\_

UNDER - \_\_\_\_\_ CODE \_\_\_\_

(28) LANES: ON STRUCTURE \_\_\_\_ UNDER STRUCTURE \_\_\_\_

(29) AVERAGE DAILY TRAFFIC \_\_\_\_\_

(30) YEAR OF ADT \_\_\_\_\_ (109) TRUCK ADT \_\_\_\_ %

(19) BYPASS, DETOUR LENGTH \_\_\_\_\_ KM

\*\*\*\*\* GEOMETRIC DATA \*\*\*\*\*

(48) LENGTH OF MAXIMUM SPAN \_\_\_\_\_ M

(49) STRUCTURE LENGTH \_\_\_\_\_ M

(50) CURB OR SIDEWALK: LEFT \_\_\_\_ M RIGHT \_\_\_\_ M

(51) BRIDGE ROADWAY WIDTH CURB TO CURB \_\_\_\_\_ M

(52) DECK WIDTH OUT TO OUT \_\_\_\_\_ M

(32) APPROACH ROADWAY WIDTH (W/SHOULDERS) \_\_\_\_\_ M

(33) BRIDGE MEDIAN - \_\_\_\_\_ CODE \_\_\_\_

(34) SKEW \_\_\_\_ DEG (35) STRUCTURE FLARED \_\_\_\_\_

(10) INVENTORY ROUTE MIN VERT CLEAR \_\_\_\_\_ M

(47) INVENTORY ROUTE TOTAL HORIZ CLEAR \_\_\_\_\_ M

(53) MIN VERT CLEAR OVER BRIDGE RDWY \_\_\_\_\_ M

(54) MIN VERT UNDERCLEAR REF - \_\_\_\_\_ M

(55) MIN LAT UNDERCLEAR RT REF - \_\_\_\_\_ M

(56) MIN LAT UNDERCLEAR LT \_\_\_\_\_ M

\*\*\*\*\* NAVIGATION DATA \*\*\*\*\*

(38) NAVIGATION CONTROL - \_\_\_\_\_ CODE \_\_\_\_

(111) PIER PROTECTION - \_\_\_\_\_ CODE \_\_\_\_

(39) NAVIGATION VERTICAL CLEARANCE \_\_\_\_\_ M

(116) VERT-LIFT BRIDGE NAV MIN VERT CLEAR \_\_\_\_\_ M

(40) NAVIGATION HORIZONTAL CLEARANCE \_\_\_\_\_ M

\*\*\*\*\* CLASSIFICATION \*\*\*\*\*

(112) NBIS BRIDGE LENGTH - \_\_\_\_\_

(104) HIGHWAY SYSTEM - \_\_\_\_\_

(26) FUNCTIONAL CLASS - \_\_\_\_\_

(100) DEFENSE HIGHWAY - \_\_\_\_\_

(101) PARALLEL STRUCTURE - \_\_\_\_\_

(102) DIRECTION OF TRAFFIC - \_\_\_\_\_

(103) TEMPORARY STRUCTURE - \_\_\_\_\_

(105) FEDERAL LANDS HIGHWAYS - \_\_\_\_\_

(110) DESIGNATED NATIONAL NETWORK - \_\_\_\_\_

(20) TOLL - \_\_\_\_\_

(21) MAINTAIN - \_\_\_\_\_

(22) OWNER - \_\_\_\_\_

(37) HISTORICAL SIGNIFICANCE - \_\_\_\_\_

\*\*\*\*\* CONDITION \*\*\*\*\*

(58) DECK \_\_\_\_\_

(59) SUPERSTRUCTURE \_\_\_\_\_

(60) SUBSTRUCTURE \_\_\_\_\_

(61) CHANNEL & CHANNEL PROTECTION \_\_\_\_\_

(62) CULVERTS \_\_\_\_\_

\*\*\*\*\* LOAD RATING AND POSTING \*\*\*\*\*

(31) DESIGN LOAD - \_\_\_\_\_ OR \_\_\_\_\_

(63) OPERATING RATING METHOD - \_\_\_\_\_

(64) OPERATING RATING - \_\_\_\_\_

(65) INVENTORY RATING METHOD - \_\_\_\_\_

(66) INVENTORY RATING - \_\_\_\_\_

(70) BRIDGE POSTING - \_\_\_\_\_

(41) STRUCTURE OPEN, POSTED OR CLOSED - \_\_\_\_\_

DESCRIPTION - \_\_\_\_\_

\*\*\*\*\* APPRAISAL \*\*\*\*\*

(67) STRUCTURAL EVALUATION \_\_\_\_\_

(68) DECK GEOMETRY \_\_\_\_\_

(69) UNDERCLEARANCES, VERTICAL & HORIZONTAL \_\_\_\_\_

(71) WATERWAY ADEQUACY \_\_\_\_\_

(72) APPROACH ROADWAY ALIGNMENT \_\_\_\_\_

(36) TRAFFIC SAFETY FEATURES \_\_\_\_\_

(113) SCOUR CRITICAL BRIDGES \_\_\_\_\_

\*\*\*\*\* PROPOSED IMPROVEMENTS \*\*\*\*\*

(75) TYPE OF WORK - \_\_\_\_\_ CODE \_\_\_\_

(76) LENGTH OF STRUCTURE IMPROVEMENT \_\_\_\_\_ M

(94) BRIDGE IMPROVEMENT COST \$\_\_\_\_,\_\_\_\_,000

(95) ROADWAY IMPROVEMENT COST \$\_\_\_\_,\_\_\_\_,000

(96) TOTAL PROJECT COST \$\_\_\_\_,\_\_\_\_,000

(97) YEAR OF IMPROVEMENT COST ESTIMATE \_\_\_\_\_

(114) FUTURE ADT \_\_\_\_\_

(115) YEAR OF FUTURE ADT \_\_\_\_\_

\*\*\*\*\* INSPECTIONS \*\*\*\*\*

(90) INSPECTION DATE \_\_\_\_/\_\_\_\_/\_\_\_\_ (91) FREQUENCY \_\_\_\_ MO

(92) CRITICAL FEATURE INSPECTION: (93) CFI DATE

A) FRACTURE CRIT DETAIL - \_\_\_\_ - \_\_\_\_ MO A) \_\_\_\_/\_\_\_\_

B) UNDERWATER INSP - \_\_\_\_ - \_\_\_\_ MO B) \_\_\_\_/\_\_\_\_

C) OTHER SPECIAL INSP - \_\_\_\_ - \_\_\_\_ MO C) \_\_\_\_/\_\_\_\_



**OSHA**  
**29 CFR Part 1910, Subpart T - Commercial Diving Operations**

*Please visit [OSHA.gov](https://www.osha.gov) to obtain the most current version of this document.*



**Title 29: Labor****PART 1910—OCCUPATIONAL SAFETY AND HEALTH****Subpart T—Commercial Diving Operations**

**Authority:** Sections 4, 6, and 8 of the Occupational Safety and Health Act of 1970 (29 U.S.C. 653, 655, and 657); Sec. 107, Contract Work Hours and Safety Standards Act (the Construction Safety Act) (40 U.S.C. 333); Sec. 41, Longshore and Harbor Workers' Compensation Act (33 U.S.C. 941); Secretary of Labor's Order No. 8-76 (41 FR 25059), 9-83 (48 FR 35736), 1-90 (55 FR 9033), 3-2000 (65 FR 50017), or 5-2002 (67 FR 65008) as applicable; 29 CFR part 1911.

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

**General****§ 1910.401 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 and Human Services) 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.

(3) *Alternative requirements for recreational diving instructors and diving guides.* Employers of recreational diving instructors and diving guides are not required to comply with the decompression-chamber requirements specified by paragraphs (b)(2) and (c)(3)(iii) of §1910.423 and paragraph (b)(1) of §1910.426 when they meet all of the following conditions:

(i) The instructor or guide is engaging solely in recreational diving instruction or dive-guiding operations;

(ii) The instructor or guide is diving within the no-decompression limits in these operations;

(iii) The instructor or guide is using a nitrox breathing-gas mixture consisting of a high percentage of oxygen (more than 22% by volume) mixed with nitrogen;

(iv) The instructor or guide is using an open-circuit, semi-closed-circuit, or closed-circuit self-contained underwater breathing apparatus (SCUBA); and

(v) The employer of the instructor or guide is complying with all requirements of Appendix C of this subpart.

(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; 58 FR 35310, June 30, 1993; 69 FR 7363, Feb. 17, 2004]

**§ 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 elapsed 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-guiding operations* means leading groups of sports divers, who use an open-circuit, semi-closed-circuit, or closed-circuit self-contained underwater breathing apparatus, to local undersea diving locations for recreational purposes.

*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).

*F<sub>sw</sub>:* 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):* Pounds per square inch (gauge).

*Recreational diving instruction* means training diving students in the use of recreational diving procedures and the safe operation of diving equipment, including an open-circuit, semi-closed-circuit, or closed-circuit self-contained underwater breathing apparatus, during dives.

*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; 69 FR 7363, Feb. 17, 2004]

## **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.

[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.

[42 FR 37668, July 22, 1977, as amended at 47 FR 14706, Apr. 6, 1982; 54 FR 24334, June 7, 1989]

**§ 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 liveboating 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.

[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<sub>2</sub>) 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.

[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)(1) [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 and Human Services 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 1910.1020 (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 and Human Services.

[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; 61 FR 9242, Mar. 7, 1996; 71 FR 16672, Apr. 3, 2006]

**Appendix A to Subpart T to Part 1910—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 cavitory disease of the lungs.

Impaired organ function caused by alcohol or drug use.

Conditions requiring continuous medication for control (e.g., antihistamines, steroids, barbiturates, mood altering 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 to Subpart T to Part 1910—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]

#### **Appendix C to Subpart T to Part 1910—Alternative Conditions Under §1910.401(a)(3) for Recreational Diving Instructors and Diving Guides (Mandatory)**

Paragraph (a)(3) of §1910.401 specifies that an employer of recreational diving instructors and diving guides (hereafter, “divers” or “employees”) who complies with all of the conditions of this appendix need not provide a decompression chamber for these divers as required under §§1910.423(b)(2) or (c)(3) or 1910.426(b)(1).

1. Equipment Requirements for Rebreathers

- (a) The employer must ensure that each employee operates the rebreather ( *i.e.*, semi-closed-circuit and closed-circuit self-contained underwater breathing apparatuses (hereafter, “SCUBAs”)) according to the rebreather manufacturer's instructions.
- (b) The employer must ensure that each rebreather has a counterlung that supplies a sufficient volume of breathing gas to their divers to sustain the divers' respiration rates, and contains a baffle system and/or other moisture separating system that keeps moisture from entering the scrubber.
- (c) The employer must place a moisture trap in the breathing loop of the rebreather, and ensure that:
- (i) The rebreather manufacturer approves both the moisture trap and its location in the breathing loop; and
  - (ii) Each employee uses the moisture trap according to the rebreather manufacturer's instructions.
- (d) The employer must ensure that each rebreather has a continuously functioning moisture sensor, and that:
- (i) The moisture sensor connects to a visual ( *e.g.*, digital, graphic, analog) or auditory ( *e.g.*, voice, pure tone) alarm that is readily detectable by the diver under the diving conditions in which the diver operates, and warns the diver of moisture in the breathing loop in sufficient time to terminate the dive and return safely to the surface; and
  - (ii) Each diver uses the moisture sensor according to the rebreather manufacturer's instructions.
- (e) The employer must ensure that each rebreather contains a continuously functioning CO<sub>2</sub>sensor in the breathing loop, and that:
- (i) The rebreather manufacturer approves the location of the CO<sub>2</sub>sensor in the breathing loop;
  - (ii) The CO<sub>2</sub>sensor is integrated with an alarm that operates in a visual ( *e.g.*, digital, graphic, analog) or auditory ( *e.g.*, voice, pure tone) mode that is readily detectable by each diver under the diving conditions in which the diver operates; and
  - (iii) The CO<sub>2</sub>alarm remains continuously activated when the inhaled CO<sub>2</sub>level reaches and exceeds 0.005 atmospheres absolute (ATA).
- (f) Before each day's diving operations, and more often when necessary, the employer must calibrate the CO<sub>2</sub>sensor according to the sensor manufacturer's instructions, and ensure that:
- (i) The equipment and procedures used to perform this calibration are accurate to within 10% of a CO<sub>2</sub>concentration of 0.005 ATA or less;

- (ii) The equipment and procedures maintain this accuracy as required by the sensor manufacturer's instructions; and
- (iii) The calibration of the CO<sub>2</sub> sensor is accurate to within 10% of a CO<sub>2</sub> concentration of 0.005 ATA or less.
- (g) The employer must replace the CO<sub>2</sub> sensor when it fails to meet the accuracy requirements specified in paragraph 1(f)(iii) of this appendix, and ensure that the replacement CO<sub>2</sub> sensor meets the accuracy requirements specified in paragraph 1(f)(iii) of this appendix before placing the rebreather in operation.
- (h) As an alternative to using a continuously functioning CO<sub>2</sub> sensor, the employer may use a schedule for replacing CO<sub>2</sub>-sorbent material provided by the rebreather manufacturer. The employer may use such a schedule only when the rebreather manufacturer has developed it according to the canister-testing protocol specified below in Condition 11, and must use the canister within the temperature range for which the manufacturer conducted its scrubber canister tests following that protocol. Variations above or below the range are acceptable only after the manufacturer adds that lower or higher temperature to the protocol.
- (i) When using CO<sub>2</sub>-sorbent replacement schedules, the employer must ensure that each rebreather uses a manufactured ( *i.e.*, commercially pre-packed), disposable scrubber cartridge containing a CO<sub>2</sub>-sorbent material that:
- (i) Is approved by the rebreather manufacturer;
  - (ii) Removes CO<sub>2</sub> from the diver's exhaled gas; and
  - (iii) Maintains the CO<sub>2</sub> level in the breathable gas ( *i.e.*, the gas that a diver inhales directly from the regulator) below a partial pressure of 0.01 ATA.
- (j) As an alternative to manufactured, disposable scrubber cartridges, the employer may fill CO<sub>2</sub> scrubber cartridges manually with CO<sub>2</sub>-sorbent material when:
- (i) The rebreather manufacturer permits manual filling of scrubber cartridges;
  - (ii) The employer fills the scrubber cartridges according to the rebreather manufacturer's instructions;
  - (iii) The employer replaces the CO<sub>2</sub>-sorbent material using a replacement schedule developed under paragraph 1(h) of this appendix; and
  - (iv) The employer demonstrates that manual filling meets the requirements specified in paragraph 1(i) of this appendix.
- (k) The employer must ensure that each rebreather has an information module that provides:

(i) A visual ( *e.g.*, digital, graphic, analog) or auditory ( *e.g.*, voice, pure tone) display that effectively warns the diver of solenoid failure (when the rebreather uses solenoids) and other electrical weaknesses or failures ( *e.g.*, low battery voltage);

(ii) For a semi-closed circuit rebreather, a visual display for the partial pressure of CO<sub>2</sub>, or deviations above and below a preset CO<sub>2</sub>partial pressure of 0.005 ATA; and

(iii) For a closed-circuit rebreather, a visual display for: partial pressures of O<sub>2</sub>and CO<sub>2</sub>, or deviations above and below a preset CO<sub>2</sub>partial pressure of 0.005 ATA and a preset O<sub>2</sub>partial pressure of 1.40 ATA or lower; gas temperature in the breathing loop; and water temperature.

(l) Before each day's diving operations, and more often when necessary, the employer must ensure that the electrical power supply and electrical and electronic circuits in each rebreather are operating as required by the rebreather manufacturer's instructions.

## 2. Special Requirements for Closed-Circuit Rebreathers

(a) The employer must ensure that each closed-circuit rebreather uses supply-pressure sensors for the O<sub>2</sub>and diluent ( *i.e.*, air or nitrogen) gases and continuously functioning sensors for detecting temperature in the inhalation side of the gas-loop and the ambient water.

(b) The employer must ensure that:

(i) At least two O<sub>2</sub>sensors are located in the inhalation side of the breathing loop; and

(ii) The O<sub>2</sub>sensors are: functioning continuously; temperature compensated; and approved by the rebreather manufacturer.

(c) Before each day's diving operations, and more often when necessary, the employer must calibrate O<sub>2</sub>sensors as required by the sensor manufacturer's instructions. In doing so, the employer must:

(i) Ensure that the equipment and procedures used to perform the calibration are accurate to within 1% of the O<sub>2</sub>fraction by volume;

(ii) Maintain this accuracy as required by the manufacturer of the calibration equipment;

(iii) Ensure that the sensors are accurate to within 1% of the O<sub>2</sub>fraction by volume;

(iv) Replace O<sub>2</sub>sensors when they fail to meet the accuracy requirements specified in paragraph 2(c)(iii) of this appendix; and

(v) Ensure that the replacement O<sub>2</sub>sensors meet the accuracy requirements specified in paragraph 2(c)(iii) of this appendix before placing a rebreather in operation.

(d) The employer must ensure that each closed-circuit rebreather has:

- (i) A gas-controller package with electrically operated solenoid O<sub>2</sub>-supply valves;
- (ii) A pressure-activated regulator with a second-stage diluent-gas addition valve;
- (iii) A manually operated gas-supply bypass valve to add O<sub>2</sub> or diluent gas to the breathing loop;  
and
- (iv) Separate O<sub>2</sub> and diluent-gas cylinders to supply the breathing-gas mixture.

### 3. O<sub>2</sub> Concentration in the Breathing Gas

The employer must ensure that the fraction of O<sub>2</sub> in the nitrox breathing-gas mixture:

- (a) Is greater than the fraction of O<sub>2</sub> in compressed air ( *i.e.*, exceeds 22% by volume);
- (b) For open-circuit SCUBA, never exceeds a maximum fraction of breathable O<sub>2</sub> of 40% by volume or a maximum O<sub>2</sub> partial pressure of 1.40 ATA, whichever exposes divers to less O<sub>2</sub>; and
- (c) For a rebreather, never exceeds a maximum O<sub>2</sub> partial pressure of 1.40 ATA.

### 4. Regulating O<sub>2</sub> Exposures and Diving Depth

(a) Regarding O<sub>2</sub> exposure, the employer must:

- (i) Ensure that the exposure of each diver to partial pressures of O<sub>2</sub> between 0.60 and 1.40 ATA does not exceed the 24-hour single-exposure time limits specified either by the 2001 National Oceanic and Atmospheric Administration Diving Manual (the “2001 NOAA Diving Manual”), or by the report entitled “Enriched Air Operations and Resource Guide” published in 1995 by the Professional Association of Diving Instructors (known commonly as the “1995 DSAT Oxygen Exposure Table”); and
- (ii) Determine a diver's O<sub>2</sub>-exposure duration using the diver's maximum O<sub>2</sub> exposure (partial pressure of O<sub>2</sub>) during the dive and the total dive time ( *i.e.*, from the time the diver leaves the surface until the diver returns to the surface).

(b) Regardless of the diving equipment used, the employer must ensure that no diver exceeds a depth of 130 feet of sea water (“fsw”) or a maximum O<sub>2</sub> partial pressure of 1.40 ATA, whichever exposes the diver to less O<sub>2</sub>.

### 5. Use of No-Decompression Limits

(a) For diving conducted while using nitrox breathing-gas mixtures, the employer must ensure that each diver remains within the no-decompression limits specified for single and repetitive air diving and published in the 2001 NOAA Diving Manual or the report entitled “Development and Validation of No-Stop Decompression Procedures for Recreational Diving: The DSAT

Recreational Dive Planner,” published in 1994 by Hamilton Research Ltd. (known commonly as the “1994 DSAT No-Decompression Tables”).

(b) An employer may permit a diver to use a dive-decompression computer designed to regulate decompression when the dive-decompression computer uses the no-decompression limits specified in paragraph 5(a) of this appendix, and provides output that reliably represents those limits.

## 6. Mixing and Analyzing the Breathing Gas

(a) The employer must ensure that:

(i) Properly trained personnel mix nitrox-breathing gases, and that nitrogen is the only inert gas used in the breathing-gas mixture; and

(ii) When mixing nitrox-breathing gases, they mix the appropriate breathing gas before delivering the mixture to the breathing-gas cylinders, using the continuous-flow or partial-pressure mixing techniques specified in the 2001 NOAA Diving Manual, or using a filter-membrane system.

(b) Before the start of each day's diving operations, the employer must determine the O<sub>2</sub> fraction of the breathing-gas mixture using an O<sub>2</sub> analyzer. In doing so, the employer must:

(i) Ensure that the O<sub>2</sub> analyzer is accurate to within 1% of the O<sub>2</sub> fraction by volume.

(ii) Maintain this accuracy as required by the manufacturer of the analyzer.

(c) When the breathing gas is a commercially supplied nitrox breathing-gas mixture, the employer must ensure that the O<sub>2</sub> meets the medical USP specifications (Type I, Quality Verification Level A) or aviator's breathing-oxygen specifications (Type I, Quality Verification Level E) of CGA G-4.3-2000 (“Commodity Specification for Oxygen”). In addition, the commercial supplier must:

(i) Determine the O<sub>2</sub> fraction in the breathing-gas mixture using an analytic method that is accurate to within 1% of the O<sub>2</sub> fraction by volume;

(ii) Make this determination when the mixture is in the charged tank and after disconnecting the charged tank from the charging apparatus;

(iii) Include documentation of the O<sub>2</sub>-analysis procedures and the O<sub>2</sub> fraction when delivering the charged tanks to the employer.

(d) Before producing nitrox breathing-gas mixtures using a compressor in which the gas pressure in any system component exceeds 125 pounds per square inch (psi), the:

(i) Compressor manufacturer must provide the employer with documentation that the compressor is suitable for mixing high-pressure air with the highest O<sub>2</sub> fraction used in the nitrox breathing-gas mixture when operated according to the manufacturer's operating and maintenance specifications;

(ii) Employer must comply with paragraph 6(e) of this appendix, unless the compressor is rated for O<sub>2</sub> service and is oil-less or oil-free; and

(iii) Employer must ensure that the compressor meets the requirements specified in paragraphs (i)(1) and (i)(2) of §1910.430 whenever the highest O<sub>2</sub> fraction used in the mixing process exceeds 40%.

(e) Before producing nitrox breathing-gas mixtures using an oil-lubricated compressor to mix high-pressure air with O<sub>2</sub>, and regardless of the gas pressure in any system component, the:

(i) Employer must use only uncontaminated air ( *i.e.*, air containing no hydrocarbon particulates) for the nitrox breathing-gas mixture;

(ii) Compressor manufacturer must provide the employer with documentation that the compressor is suitable for mixing the high-pressure air with the highest O<sub>2</sub> fraction used in the nitrox breathing-gas mixture when operated according to the manufacturer's operating and maintenance specifications;

(iii) Employer must filter the high-pressure air to produce O<sub>2</sub>-compatible air;

(iv) The filter-system manufacturer must provide the employer with documentation that the filter system used for this purpose is suitable for producing O<sub>2</sub>-compatible air when operated according to the manufacturer's operating and maintenance specifications; and

(v) Employer must continuously monitor the air downstream from the filter for hydrocarbon contamination.

(f) The employer must ensure that diving equipment using nitrox breathing-gas mixtures or pure O<sub>2</sub> under high pressure ( *i.e.*, exceeding 125 psi) conforms to the O<sub>2</sub>-service requirements specified in paragraphs (i)(1) and (i)(2) of §1910.430.

## 7. Emergency Egress

(a) Regardless of the type of diving equipment used by a diver ( *i.e.*, open-circuit SCUBA or rebreathers), the employer must ensure that the equipment contains (or incorporates) an open-circuit emergency-egress system (a “bail-out” system) in which the second stage of the regulator connects to a separate supply of emergency breathing gas, and the emergency breathing gas consists of air or the same nitrox breathing-gas mixture used during the dive.

(b) As an alternative to the “bail-out” system specified in paragraph 7(a) of this appendix, the employer may use:

- (i) For open-circuit SCUBA, an emergency-egress system as specified in §1910.424(c)(4); or
  - (ii) For a semi-closed-circuit and closed-circuit rebreather, a system configured so that the second stage of the regulator connects to a reserve supply of emergency breathing gas.
- (c) The employer must obtain from the rebreather manufacturer sufficient information to ensure that the bail-out system performs reliably and has sufficient capacity to enable the diver to terminate the dive and return safely to the surface.

## 8. Treating Diving-Related Medical Emergencies

(a) Before each day's diving operations, the employer must:

- (i) Verify that a hospital, qualified health-care professionals, and the nearest Coast Guard Coordination Center (or an equivalent rescue service operated by a state, county, or municipal agency) are available to treat diving-related medical emergencies;
  - (ii) Ensure that each dive site has a means to alert these treatment resources in a timely manner when a diving-related medical emergency occurs; and
  - (iii) Ensure that transportation to a suitable decompression chamber is readily available when no decompression chamber is at the dive site, and that this transportation can deliver the injured diver to the decompression chamber within four (4) hours travel time from the dive site.
- (b) The employer must ensure that portable O<sub>2</sub> equipment is available at the dive site to treat injured divers. In doing so, the employer must ensure that:
- (i) The equipment delivers medical-grade O<sub>2</sub> that meets the requirements for medical USP oxygen (Type I, Quality Verification Level A) of CGA G-4.3-2000 ("Commodity Specification for Oxygen");
  - (ii) The equipment delivers this O<sub>2</sub> to a transparent mask that covers the injured diver's nose and mouth; and
  - (iii) Sufficient O<sub>2</sub> is available for administration to the injured diver from the time the employer recognizes the symptoms of a diving-related medical emergency until the injured diver reaches a decompression chamber for treatment.

(c) Before each day's diving operations, the employer must:

- (i) Ensure that at least two attendants, either employees or non-employees, qualified in first-aid and administering O<sub>2</sub> treatment, are available at the dive site to treat diving-related medical emergencies; and
- (ii) Verify their qualifications for this task.

## 9. Diving Logs and No-Decompression Tables

(a) Before starting each day's diving operations, the employer must:

- (i) Designate an employee or a non-employee to make entries in a diving log; and
- (ii) Verify that this designee understands the diving and medical terminology, and proper procedures, for making correct entries in the diving log.

(b) The employer must:

- (i) Ensure that the diving log conforms to the requirements specified by paragraph (d) ("Record of dive") of §1910.423; and
- (ii) Maintain a record of the dive according to §1910.440 ("Recordkeeping requirements").

(c) The employer must ensure that a hard-copy of the no-decompression tables used for the dives (as specified in paragraph 6(a) of this appendix) is readily available at the dive site, whether or not the divers use dive-decompression computers.

## 10. Diver Training

The employer must ensure that each diver receives training that enables the diver to perform work safely and effectively while using open-circuit SCUBAs or rebreathers supplied with nitrox breathing-gas mixtures. Accordingly, each diver must be able to demonstrate the ability to perform critical tasks safely and effectively, including, but not limited to: recognizing the effects of breathing excessive CO<sub>2</sub> and O<sub>2</sub>; taking appropriate action after detecting excessive levels of CO<sub>2</sub> and O<sub>2</sub>; and properly evaluating, operating, and maintaining their diving equipment under the diving conditions they encounter.

## 11. Testing Protocol for Determining the CO<sub>2</sub> Limits of Rebreather Canisters

(a) The employer must ensure that the rebreather manufacturer has used the following procedures for determining that the CO<sub>2</sub>-sorbent material meets the specifications of the sorbent material's manufacturer:

- (i) The North Atlantic Treating Organization CO<sub>2</sub> absorbent-activity test;
- (ii) The RoTap shaker and nested-sieves test;
- (iii) The Navy Experimental Diving Unit ("NEDU")-derived Schlegel test; and
- (iv) The NEDU MeshFit software.

(b) The employer must ensure that the rebreather manufacturer has applied the following canister-testing materials, methods, procedures, and statistical analyses:

- (i) Use of a nitrox breathing-gas mixture that has an O<sub>2</sub> fraction maintained at 0.28 (equivalent to 1.4 ATA of O<sub>2</sub> at 130 fsw, the maximum O<sub>2</sub> concentration permitted at this depth);
- (ii) While operating the rebreather at a maximum depth of 130 fsw, use of a breathing machine to continuously ventilate the rebreather with breathing gas that is at 100% humidity and warmed to a temperature of 98.6 degrees F (37 degrees C) in the heating-humidification chamber;
- (iii) Measurement of the O<sub>2</sub> concentration of the inhalation breathing gas delivered to the mouthpiece;
- (iv) Testing of the canisters using the three ventilation rates listed in Table I below (with the required breathing-machine tidal volumes and frequencies, and CO<sub>2</sub>-injection rates, provided for each ventilation rate):

**Table I—Canister Testing Parameters**

<b>Ventilation rates (Lpm, ATPS<sup>1</sup>)</b>	<b>Breathing machine tidal volumes (L)</b>	<b>Breathing machine frequencies (breaths per min.)</b>	<b>CO<sub>2</sub> injection rates (Lpm, STPD<sup>2</sup>)</b>
22.5	1.5	15	0.90
40.0	2.0	20	1.35
62.5	2.5	25	2.25

<sup>1</sup>ATPS means ambient temperature and pressure, saturated with water.

<sup>2</sup>STPD means standard temperature and pressure, dry; the standard temperature is 32 degrees F (0 degrees C).

(v) When using a work rate (*i.e.*, breathing-machine tidal volume and frequency) other than the work rates listed in the table above, addition of the appropriate combinations of ventilation rates and CO<sub>2</sub>-injection rates;

(vi) Performance of the CO<sub>2</sub> injection at a constant (steady) and continuous rate during each testing trial;

(vii) Determination of canister duration using a minimum of four (4) water temperatures, including 40, 50, 70, and 90 degrees F (4.4, 10.0, 21.1, and 32.2 degrees C, respectively);

(viii) Monitoring of the breathing-gas temperature at the rebreather mouthpiece (at the “chrome T” connector), and ensuring that this temperature conforms to the temperature of a diver's exhaled breath at the water temperature and ventilation rate used during the testing trial;<sup>1</sup>

<sup>1</sup> NEDU can provide the manufacturer with information on the temperature of a diver's exhaled breath at various water temperatures and ventilation rates, as well as techniques and procedures used to maintain these temperatures during the testing trials.

- (ix) Implementation of at least eight (8) testing trials for each combination of temperature and ventilation-CO<sub>2</sub>-injection rates (for example, eight testing trials at 40 degrees F using a ventilation rate of 22.5 Lpm at a CO<sub>2</sub>-injection rate of 0.90 Lpm);
- (x) Allowing the water temperature to vary no more than  $\pm 2.0$  degrees F ( $\pm 1.0$  degree C) *between* each of the eight testing trials, and no more than  $\pm 1.0$  degree F ( $\pm 0.5$  degree C) *within* each testing trial;
- (xi) Use of the average temperature for each set of eight testing trials in the statistical analysis of the testing-trial results, with the testing-trial results being the time taken for the inhaled breathing gas to reach 0.005 ATA of CO<sub>2</sub>( *i.e.*, the canister-duration results);
- (xii) Analysis of the canister-duration results using the repeated-measures statistics described in NEDU Report 2-99;
- (xiii) Specification of the replacement schedule for the CO<sub>2</sub>-sorbent materials in terms of the lower prediction line (or limit) of the 95% confidence interval; and
- (xiv) Derivation of replacement schedules only by interpolating among, but not by extrapolating beyond, the depth, water temperatures, and exercise levels used during canister testing.

[69 FR 7363, Feb. 17, 2004]



## National Bridge Inspection Standards (NBIS)

*Please visit*

*<http://www.fhwa.dot.gov/bridge/nbis.htm>  
to obtain the most current version of the NBIS.*

Federal Register: December 24, 2009 (Volume 74, Number 246)  
Rules and Regulations  
Page 68377-68379  
From the Federal Register Online via GPO Access [wais.access.gpo.gov]  
DOCID:fr24de09-5

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**DEPARTMENT OF TRANSPORTATION**  
**Federal Highway Administration**  
**23 CFR Part 650**  
**[FHWA Docket No. FHWA-2009-0074]**  
**RIN 2125-AF33**

### **National Bridge Inspection Standards**

**AGENCY:** Federal Highway Administration (FHWA), DOT.

**ACTION:** Final rule.

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**SUMMARY:** The American Association of State Highway and Transportation Officials (AASHTO) Manual for Condition Evaluation of Bridges, 1994, second edition (also referred to as “the Manual”), together with the 2001 and 2003 Interim Revisions, is incorporated by reference in FHWA regulations, approved by the Federal Highway Administration, and recognized as a national standard for bridge inspections and load rating. The purpose of this final rule is to update the incorporation by reference language to incorporate the most recent version of the AASHTO Manual, now known as The Manual for Bridge Evaluation, First Edition, 2008.

**DATES:** This rule becomes effective January 25, 2010. The incorporation by reference of certain publications listed in the rule is approved by the Director of the Federal Register as of January 25, 2010.

**FOR FURTHER INFORMATION CONTACT:** Mr. Thomas Everett, Office of Bridge Technology, (202) 366-4675; or Mr. Robert Black, Office of the Chief Counsel, (202) 366-1359, Federal Highway Administration, 1200 New Jersey Ave., SE, Washington, DC 20590. Office hours are from 7:45 a.m. to 4:15 p.m., e.t., Monday through Friday, except Federal holidays.

### **SUPPLEMENTARY INFORMATION:**

#### **Electronic Access and Filing**

This document, the notice of proposed rulemaking (NPRM), and all comments received can be viewed online through the Federal eRulemaking portal at: <http://www.regulations.gov>. It is available 24 hours each day, 365 days each year.

An electronic copy of this document may also be downloaded from the Office of the Federal Register's home page at: <http://www.archives.gov> and the Government Printing Office's Web page at: <http://www.access.gpo.gov/nara>.

## Background

This Final Rule is being issued to announce the revision to the incorporation by reference of the AASHTO Manual in the National Bridge Inspection Standards (NBIS).

The Manual for Bridge Evaluation, First Edition (MBE) was adopted by the AASHTO Highways Subcommittee on Bridges and Structures in 2005. The MBE combines The Manual for Condition Evaluation of Bridges, Second Edition, and its 2001 and 2003 Interim Revisions with the Guide Manual for Condition Evaluation and Load and Resistance Factor Rating of Highway Bridges, First Edition, and its 2005 Interim Revisions. Revisions based on approved agenda items from annual AASHTO Subcommittee meetings in 2007 and 2008 are also incorporated into the MBE.

The MBE, First Edition, 2008, supersedes The Manual for Condition Evaluation of Bridges, Second Edition, and the 2001 and 2003 Interim Revisions, which are currently incorporated by reference at 23 CFR 650.317. The MBE offers assistance to bridge owners at all phases of bridge inspection and evaluation. The Manual serves as a standard and provides uniformity in the procedures and policies for determining the physical condition, maintenance needs, and load capacity of the Nation's highway bridges.

Because the information incorporated by reference at 23 CFR 650.317 has been superseded, the FHWA is updating the NBIS regulation to reflect the latest information contained in the AASHTO documents. The FHWA also is updating the definition for "AASHTO Manual" to reflect the updated document.

The FHWA proposed these revisions in its NPRM published in the **Federal Register** at 74 FR 44793 on August 31st. The FHWA did not receive any comments to the NPRM and therefore adopts the revisions as proposed.

## Rulemaking Analysis and Notices

### *Executive Order 12866 (Regulatory Planning and Review) and U.S. DOT Regulatory Policies and Procedures*

The FHWA has determined that this action would not be a significant regulatory action within the meaning of Executive Order 12866 or significant within the meaning of U.S. Department of Transportation regulatory policies and procedures. These changes are not anticipated to adversely affect, in any material way, any sector of the economy. The FHWA believes that the incorporation of the MBE within the NBIS regulation will greatly improve consistency and uniformity in the application of bridge inspection and load rating procedures. In addition, these changes would not create a serious

inconsistency with any other agency's action or materially alter the budgetary impact of any entitlements, grants, user fees, or loan programs. Therefore, a full regulatory evaluation is not required.

#### *Regulatory Flexibility Act*

In compliance with the Regulatory Flexibility Act (Pub. L. 96-354, 5 U.S.C. 601-612), the FHWA has evaluated the effects of these changes on small entities and has determined that this action would not have a significant economic impact on a substantial number of small entities.

#### *Unfunded Mandates Reform Act of 1995*

This Final Rule would not impose unfunded mandates as defined by the Unfunded Mandates Reform Act of 1995 (Pub. L. 104-4, 109 Stat. 48, March 22, 1995). This action would not result in the expenditure by State, local, and Tribal governments, in the aggregate, or by the private sector, of \$128.1 million or more in any one year (2 U.S.C. 1532).

#### *Executive Order 13132 (Federalism)*

This action has been analyzed in accordance with the principles and criteria contained in Executive Order 13132 dated August 4, 1999, and the FHWA has determined that this action would not have sufficient federalism implications to warrant the preparation of a federalism assessment. The FHWA has also determined that this rulemaking will not preempt any State law or State regulation or affect the States' ability to discharge traditional State governmental functions.

#### *Executive Order 13175 (Tribal Consultation)*

The FHWA has analyzed this action under Executive Order 13175, dated November 6, 2000, and believes that it would not have substantial direct effects on one or more Indian Tribes; would not impose substantial direct compliance costs on Indian Tribal governments; and would not preempt Tribal law. Therefore, a Tribal summary impact statement is not required.

#### *Executive Order 13211 (Energy Effects)*

The FHWA has analyzed this action under Executive Order 13211, Actions Concerning Regulations That Significantly Affect Energy Supply, Distribution, or Use. We have determined that it is not a significant energy action under that order because it is not likely to have a significant adverse effect on the supply, distribution, or use of energy. Therefore, a Statement of Energy Effects under Executive Order 13211 is not required.

*Executive Order 12372 (Intergovernmental Review)*

Catalog of Federal Domestic Assistance program Number 20.205, Highway Planning and Construction. The regulations implementing Executive Order 12372 regarding intergovernmental consultation on Federal programs and activities apply to this program.

*Paperwork Reduction Act*

Under the Paperwork Reduction Act of 1995 (PRA) (44 U.S.C. 3501, et seq.), Federal agencies must obtain approval from the Office of Management and Budget for each collection of information they conduct, sponsor, or require through regulations. The FHWA has determined that this action does not contain collection information requirements for purposes of the PRA.

*Executive Order 12988 (Civil Justice Reform)*

This action meets applicable standards in sections 3(a) and 3(b)(2) of Executive Order 12988, Civil Justice Reform, to minimize litigation, eliminate ambiguity, and reduce burden.

*Executive Order 13045 (Protection of Children)*

The FHWA has analyzed this action under Executive Order 13045, Protection of Children from Environmental Health Risks and Safety Risks. The FHWA certifies that this action would not concern an environmental risk to health or safety that may disproportionately affect children.

*Executive Order 12630 (Taking of Private Property)*

The FHWA does not anticipate that this action would affect a taking of private property or otherwise have taking implications under Executive Order 12630, Governmental Actions and Interference with Constitutionally Protected Property Rights.

*National Environmental Policy Act*

The agency has analyzed this action for the purpose of the National Environmental Policy Act of 1969 (42 U.S.C. 4321-4347) and has determined that it would not have any effect on the quality of the environment.

*Regulation Identification Number*

A regulation identification number (RIN) is assigned to each regulatory action listed in the Unified Agenda of Federal Regulations. The Regulatory Information Service Center publishes the Unified Agenda in April and October of each year. The RIN contained in

the heading of this document can be used to cross reference this action with the Unified Agenda.

### List of Subjects in 23 CFR Part 650

Bridges, Grant programs—Transportation, Highways and roads, Incorporation by reference, Reporting and recordkeeping requirements.

Issued on: December 15, 2009.

Victor M. Mendez,  
Administrator.

■ In consideration of the foregoing, the FHWA amends title 23, Code of Federal Regulations part 650 as follows:

### PART 650—BRIDGES, STRUCTURES, AND HYDRAULICS

■ 1. The authority citation for part 650 continues to read as follows:

Authority: 23 U.S.C. 109(a) and (h), 144, 151, 315, and 319; 33 U.S.C. 401, 491 et seq.; 511 et seq.; sec. 4(b) of Pub. L. 97-134, 95 Stat. 1699 (1981); sec. 161 of Pub. L. 97-424, 96 Stat. 2097, at 3135 (1983); sec. 1311 of Pub. L. 105-178, as added by Pub. L. 105-206, 112 Stat. 842 (1998); 23 CFR 1.32; 49 CFR 1.48(b); E.O. 11988 (3 CFR, 1977 Comp., p. 117); Department of Transportation Order 5650.2, dated April 23, 1979 (44 FR 24678).

### Subpart C—National Bridge Inspection Standards

■ 2. Amend Sec. 650.305 by revising the definition of “American Association of State Highway and Transportation Officials (AASHTO) Manual” to read as follows:

#### Sec. 650.305 Definitions.

\* \* \* \* \*

*American Association of State Highway and Transportation Officials (AASHTO) Manual.* “The Manual for Bridge Evaluation,” First Edition, 2008, published by the American Association of State Highway and Transportation Officials (incorporated by reference, see Sec. 650.317).

\* \* \* \* \*

■ 3. Revise Sec. 650.317 to read as follows:

#### Sec. 650.317 Reference manuals.

- (a) The materials listed in this subpart are incorporated by reference in the corresponding sections noted. These incorporations by reference were approved by the Director of the Federal Register in accordance with 5 U.S.C. 552(a) and 1 CFR part 51. These materials are incorporated as they exist on the date of the approval, and notice of any change in these documents will be published in the Federal Register. The materials are available for purchase at the address listed below, and are available for inspection at the National Archives and Records Administration (NARA). These materials may also be reviewed at the Department of Transportation Library, 1200 New Jersey Avenue, SE, Washington, DC 20590, (202) 366-0761. For information on the availability of these materials at NARA call (202) 741-6030, or go to the following URL: [http://www.archives.gov/federal\\_register/code\\_of\\_federal\\_regulations/ibr\\_locations.htm](http://www.archives.gov/federal_register/code_of_federal_regulations/ibr_locations.htm). In the event there is a conflict between the standards in this subpart and any of these materials, the standards in this subpart will apply.
- (b) The following materials are available for purchase from the American Association of State Highway and Transportation Officials, Suite 249, 444 N. Capitol Street, NW, Washington, DC 20001, (202) 624-5800. The materials may also be ordered via the AASHTO bookstore located at the following URL: <http://www.transportation.org>.
- (1) The Manual for Bridge Evaluation, First Edition, 2008, AASHTO, incorporation by reference approved for Sec. Sec. 650.305 and 650.313.
  - (2) [Reserved]

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**BILLING CODE 4910-22-P**

## 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.

**Aramid.** Aramid fibers are a class of heat-resistant and strong synthetic fibers.

**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 underlying 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, leveled 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 remuneration for diving activities.

**Composite.** Composite materials are engineered materials made from two or more constituent materials with significantly different physical or chemical properties. Composites use a polymer matrix material often called a resin solution. There are many different polymers available including polyester, vinyl ester, epoxy, phenolic, polyimide, polyamide, and polypropylene. The reinforcement materials are fibers or ground minerals.

**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-vestibular 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.

The 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 dimension 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.

**Exudation.** A white deposit found on the underside of concrete structures due to leaching of cement materials from the concrete matrix.

## 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.

**Fiberglass.** A material made from extremely fine fibers of glass. It is used as a reinforcing agent for many polymer products; the resulting composite material, properly known as fiber-reinforced polymer (FRP) or glass-reinforced plastic (GRP), is called "fiberglass" in popular usage.

**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).

## I

**Ice Floe.** A large flat free mass of floating ice.

**Isotropic.** Having the physical properties regardless of the direction of measurement.

## L

**Limnoria.** *Limnoria Tripunctata*, a free swimming crustacean (wood gribble) found in salt water and brackish water that attacks timber piles by burrowing into the outside surface, eventually producing an hour glass shape.

## 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 slowing stream in a flood plain.

**Modulus of Elasticity.** The tendency of an object to deform along an axis when opposing forces are applied along that axis; it is defined as the ratio of tensile stress to tensile strain.

**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.

**Non-isotropic.** Having different physical properties along different axis; e.g., unreinforced concrete is strong in compression, but relatively weak in tension

## 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 abutment.

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 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 of 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.

**Polymer.** See Composite.

**Pressure.** Force per unit of area. In diving, pressure denotes an exposure greater than surface pressure (1 ATM).

## R

**Reach.** A stretch, expanse, or segment of a waterway.

**Recompression.** An increase in pressure which is calculated to eliminate the symptoms of decompression sickness when applied to a diver in a pressure vessel for human occupancy as therapy.

**Resin.** See Composite.

**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.

## 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.

**Teredo.** *Teredo Navalis* a marine borer, mollusk (shipworm) that enters timber piles and burrows parallel to the grain of wood forming interior tunnels.

**Thermoplastic.** A polymer that turns to a liquid when heated and freezes to a very glassy state when cooled.

**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 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," "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 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 to 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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