Underwater Inspection
Of
Docks and Bridges

Bermuda

Annex D
Drawings and Reference Documents

Note: These documents are provided to establish the minimum level of quality that is required for these Works. The information supplied is not the complete document, but it is available online.

Date: January 9, 2017

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Underwater Bridge Inspection

Publication No. FHWA-NHI-10-027

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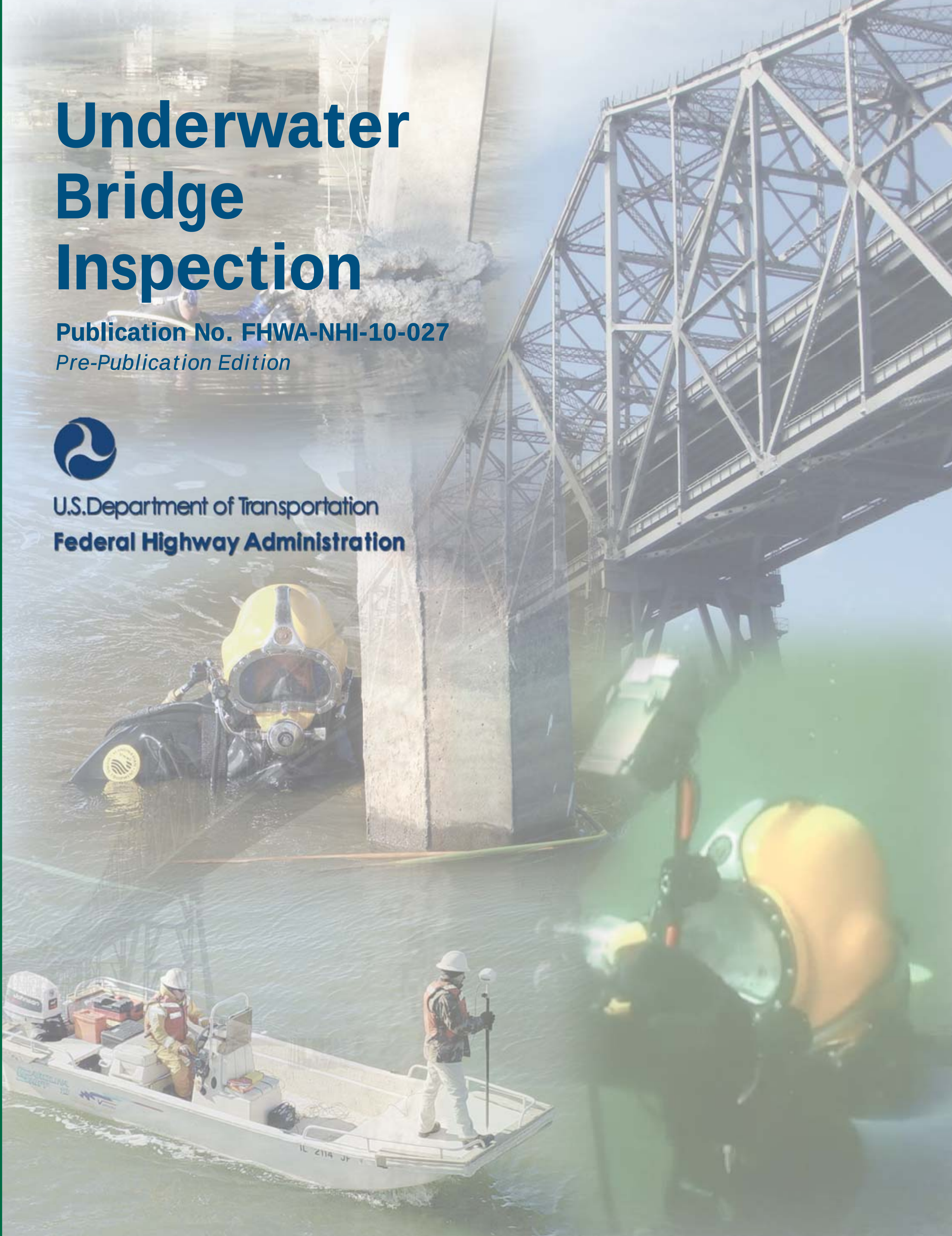

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The conduct of underwater bridge inspections may frequently require the use of divers. While this manual contains information on diving equipment and diver inspection techniques, it is neither intended to train personnel in diving nor enumerate all 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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16. Abstract:

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

The purpose of this manual is to provide guidelines for underwater bridge inspection; acquaint those responsible for bridge safety with underwater inspection techniques and equipment; and present commonly found defects. It should be of interest to bridge and maintenance engineers, divers, and inspectors.

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Underwater Bridge Inspection

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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.

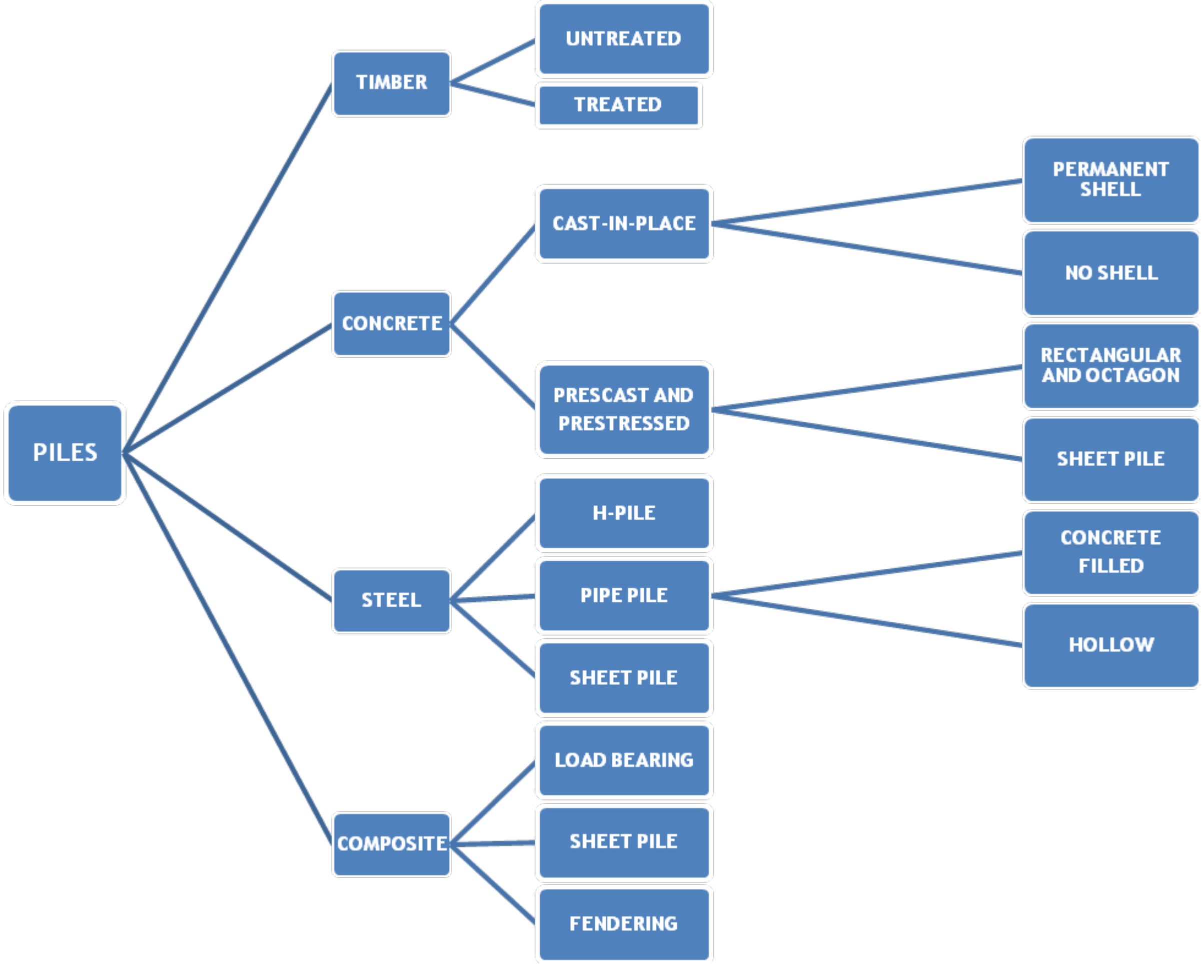


Figure 3-1 Typical Pile Types


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.

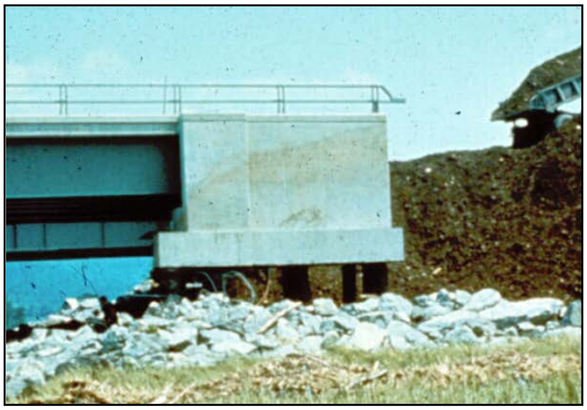


Figure 3-4 Exposed Timber Piles at Scoured Abutment

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.

Figure 3-5 Timber Pile at Underside of 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 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.

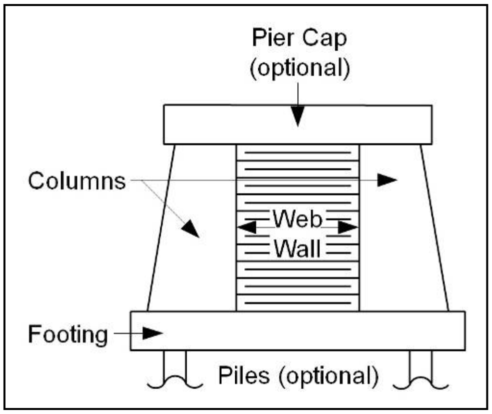


Figure 3-10 Typical Concrete Pier

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.

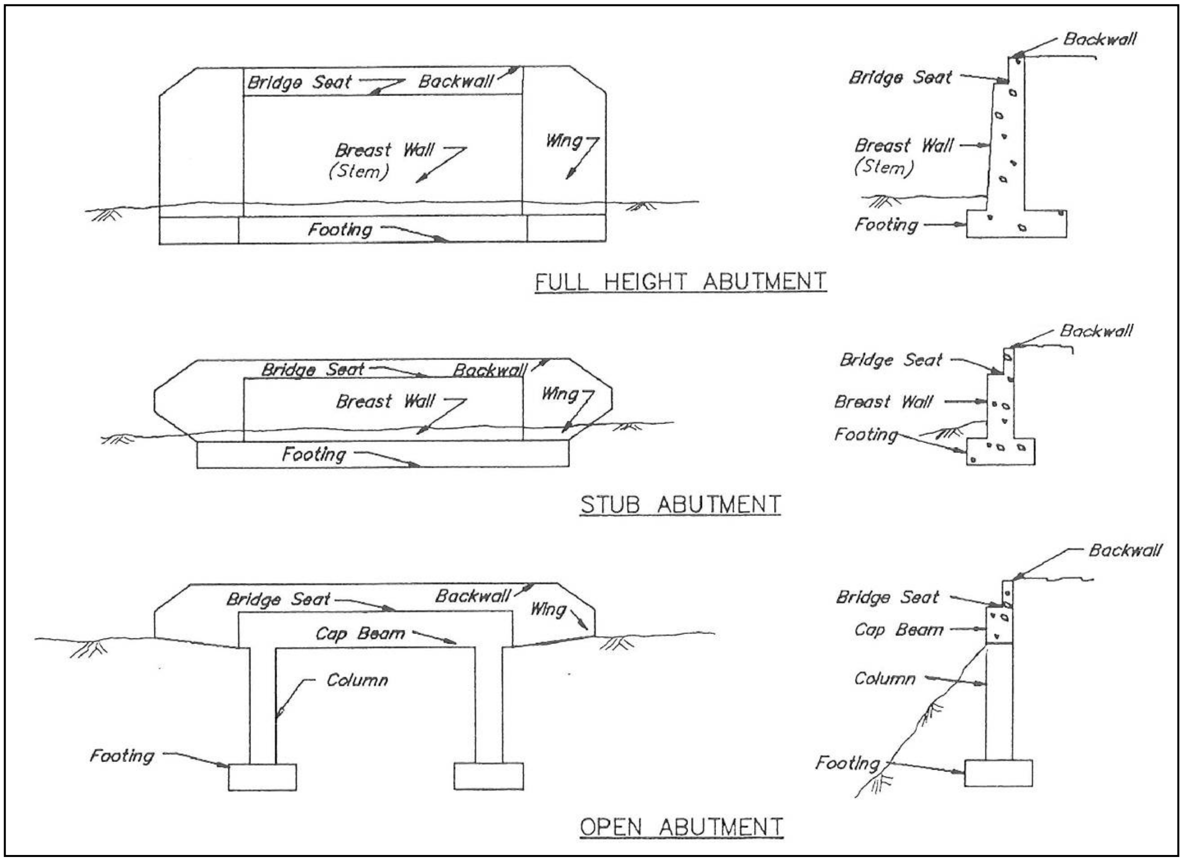


Figure 3-11 Abutment Types and Nomenclature

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.

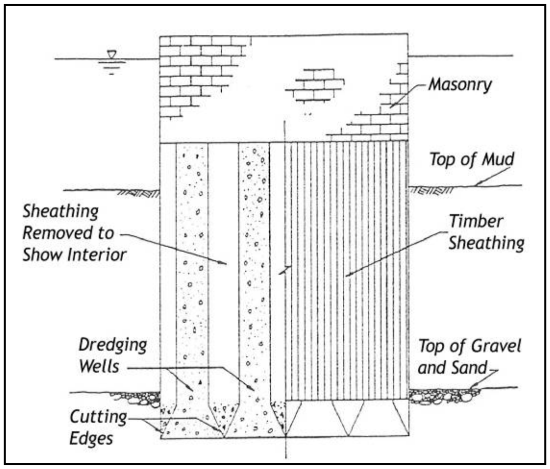


Figure 3-12 Floating Caisson

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.

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.

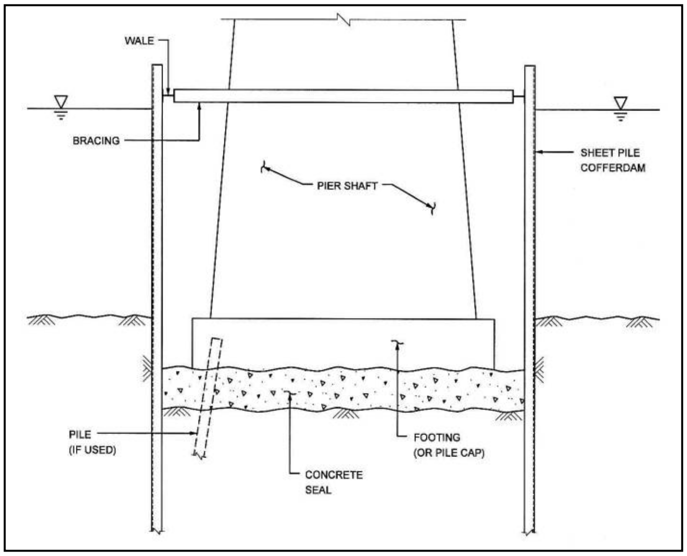


Figure 3-13 Pier Construction within Cofferdam

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

Figure 3-16 Steel Pipe Pile Dolphin with Concrete Cap

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 3-17 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

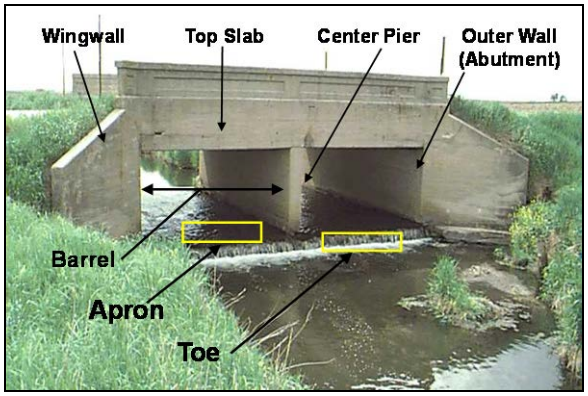


Figure 3-20 Culvert Nomenclature

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. <u>Cracking</u>. 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. <u>Scaling</u>. 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. <u>Spalling</u>. 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.

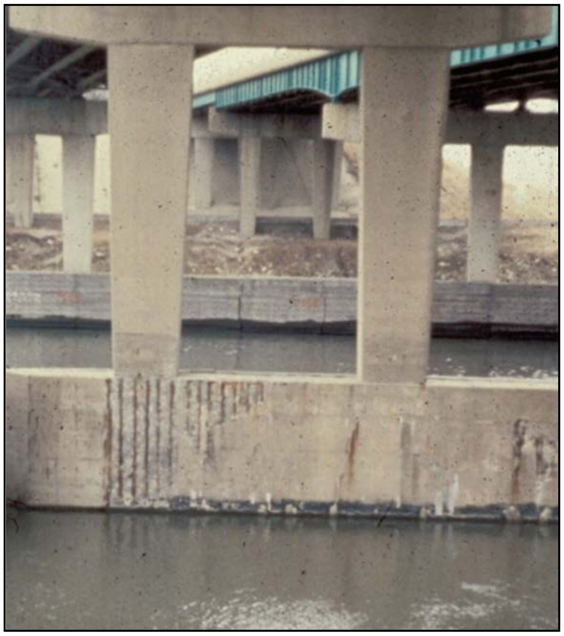


Figure 3-23 Spalling of Concrete at Waterline

Cracks in concrete over bars near the surface, due to shrinkage; cracks due to external damaging forces; and pores that occur naturally in concrete allow moisture and air (oxygen) to reach reinforcing steel near the surface. When the steel corrodes, the products of corrosion occupy up to ten times the volume of the parent material and can produce forces in excess of 5,000 psi. 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.

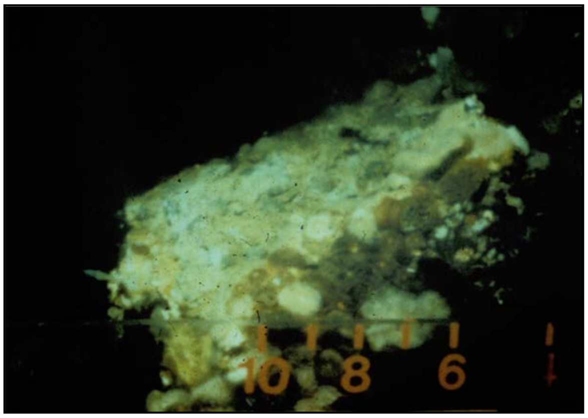


Figure 3-24 Sulfate Attack of Concrete Pier

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 ravels 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.

Figure 3-25 Pile Damaged by Delayed Ettringite Formation

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).

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.

Figure 3-26 Severely Corroded H-Pile

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.

Figure 3-27 H-pile Corrosion Below Concrete Encasement

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 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.

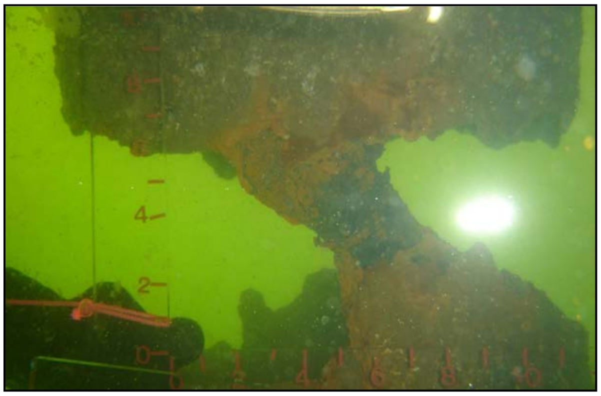


Figure 3-30 Steel Pipe Pile with ALWC

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. <u>Coatings</u>. 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. <u>Connections</u>. 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

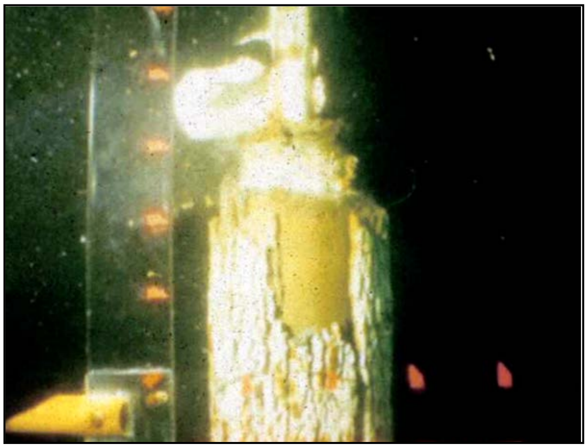


Figure 3-32 Impressed Current Anode

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

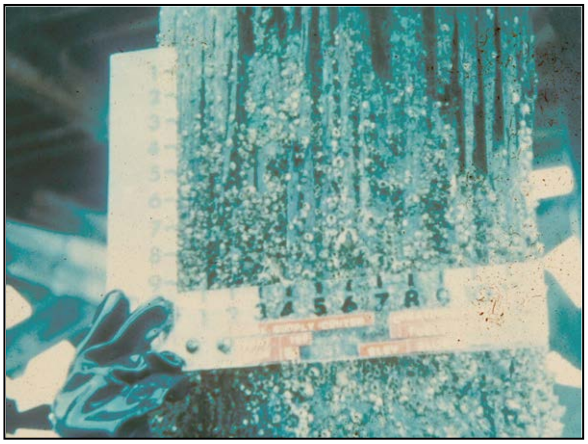


Figure 3-35 Decayed Timber Pile near Waterline

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.

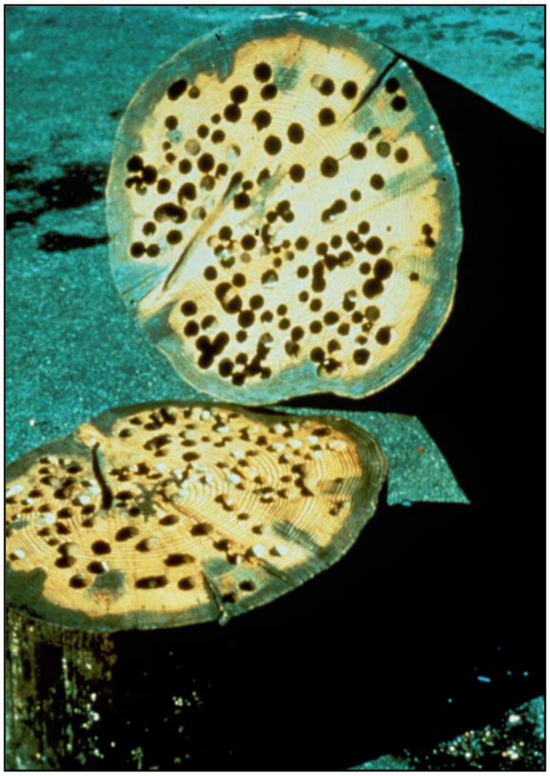


Figure 3-36 Timber Pile with Teredo Damage

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.

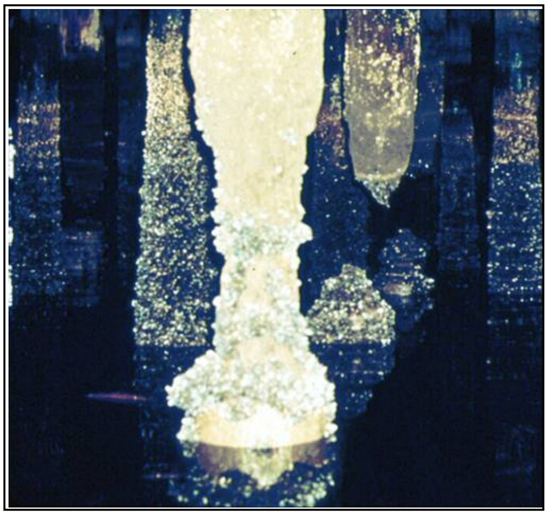


Figure 3-37 Timber Pile with Limnoria Damage

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.

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.

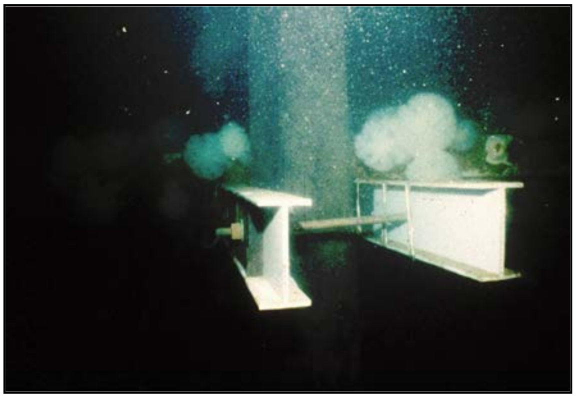


Figure 3-40 Composite I-Beams

Figure 3-41 Vessel Damage

CHAPTER 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.

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

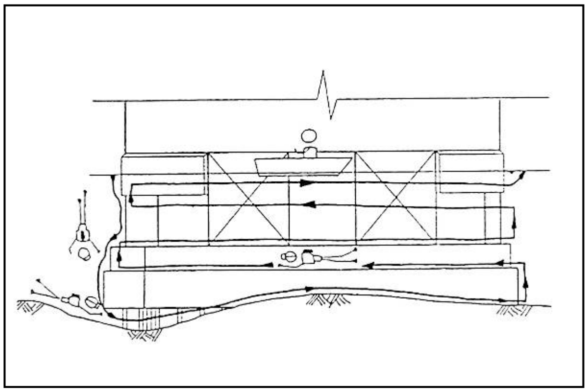


Figure 5-1 Schematic Representation of a Diver Inspecting a Pier

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.

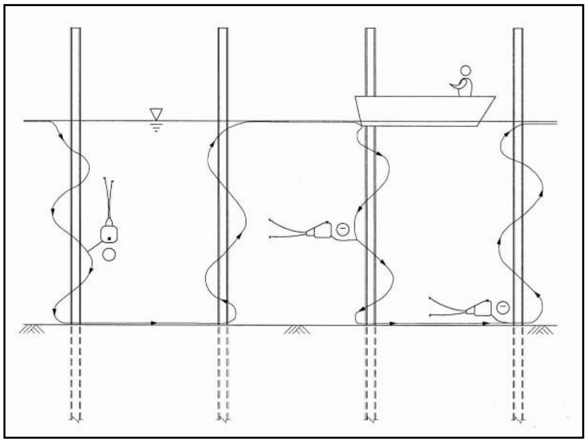


Figure 5-2 Schematic Representation of a Diver Inspecting a Pile Bent

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 need 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.

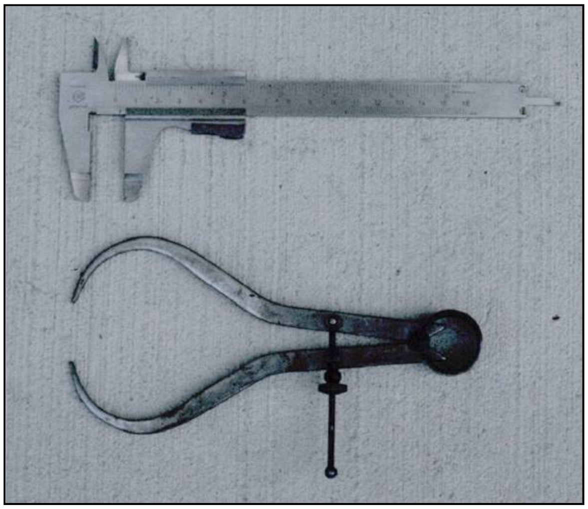


Figure 5-3 Calipers

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.

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

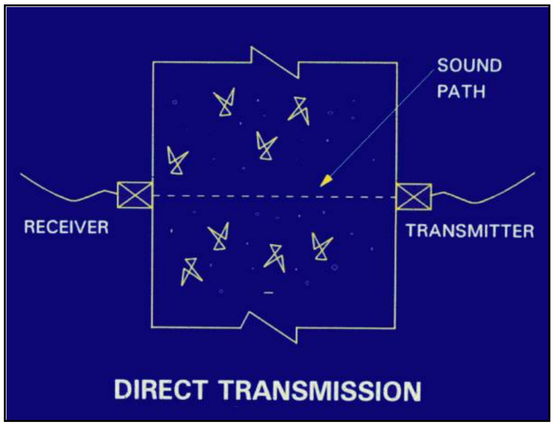


Figure 5-8 Direct Transmission Method

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.

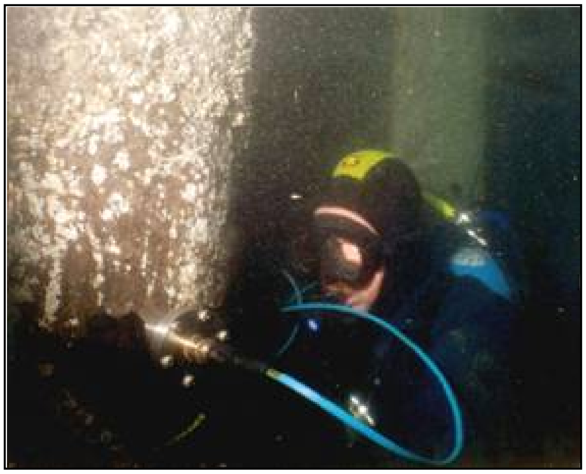


Figure 5-9 Diver Applying the Transducers to a Pile for the Direct Transmission Method

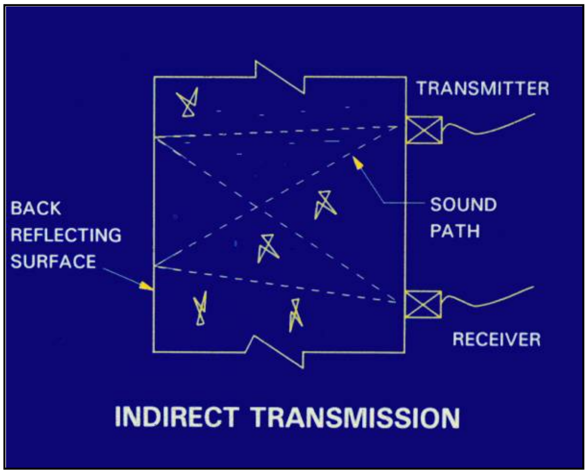


Figure 5-10 Indirect Transmission Method

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).

Figure 5-11 Waterproof Rebound Hammer

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

c. 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.

Figure 5-12 Rebar Locator in Waterproof Case

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 5-13 Concrete Cores

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.

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

Figure 5-15 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.

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 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.

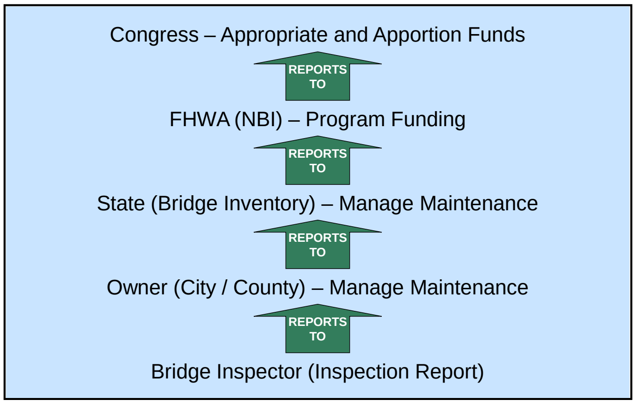


Figure 7-1 Bridge Inspection Reporting Hierarchy

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.

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.

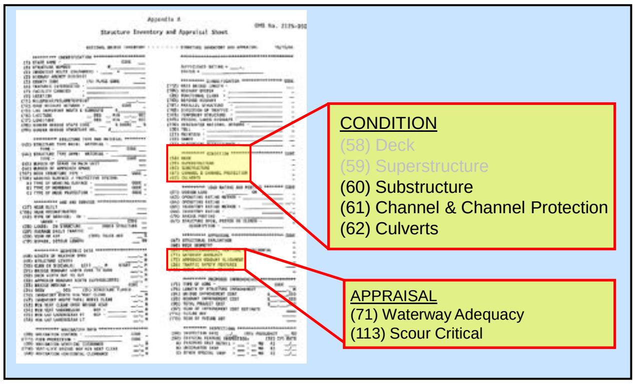


Figure 7-2 SI&A Sheet Underwater Components

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

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.

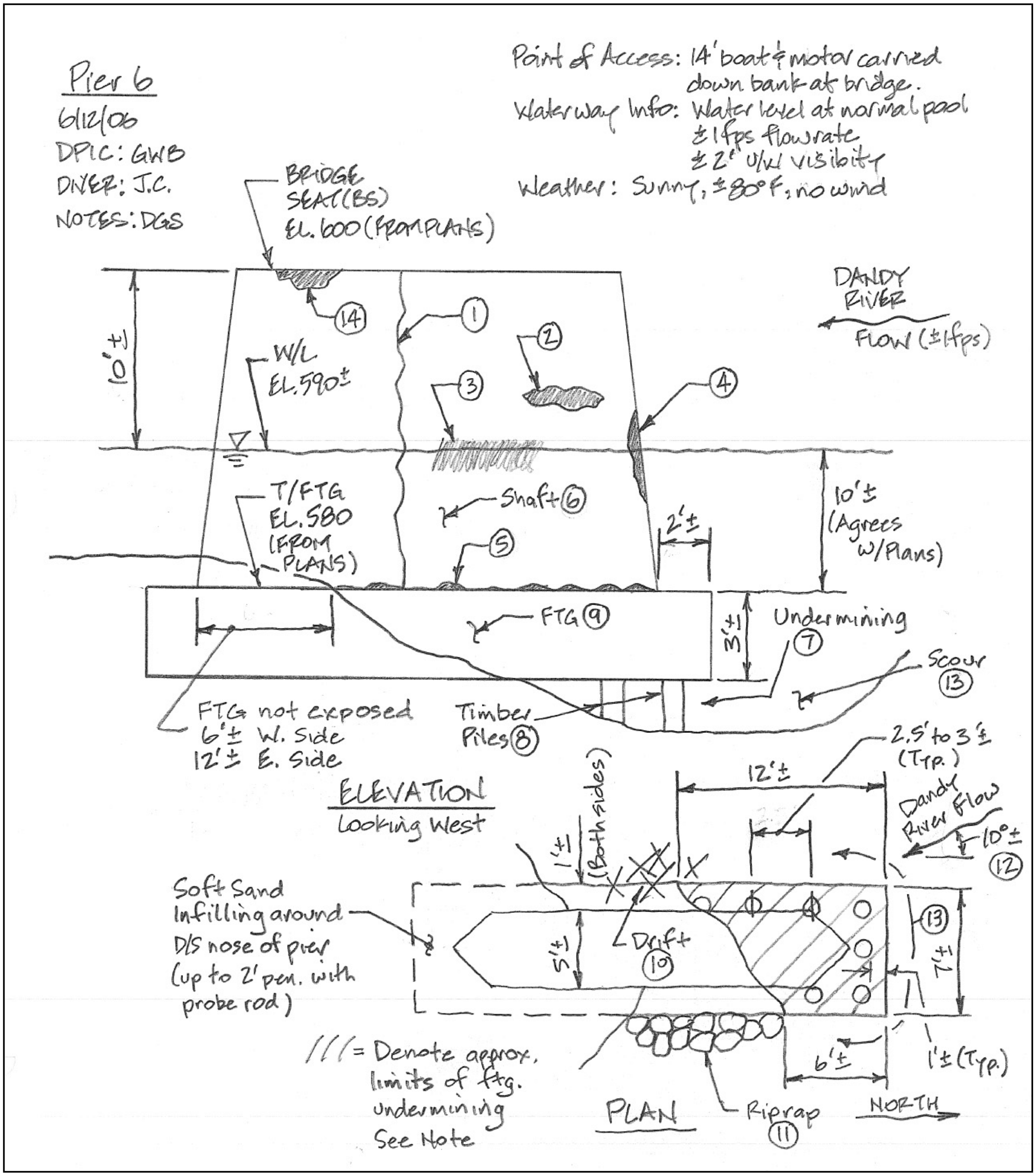
f. Water Depth Sounding Log Forms

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.

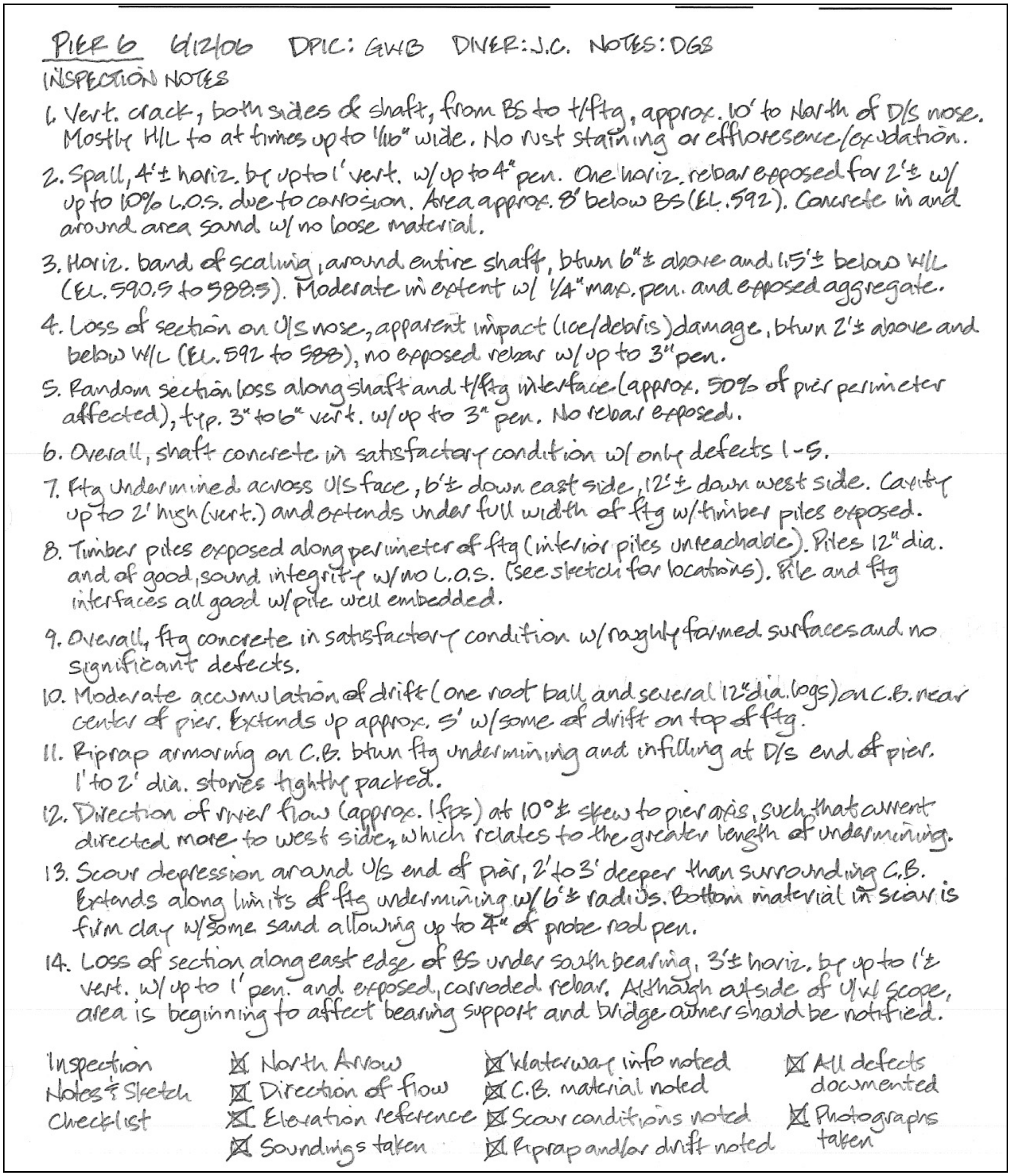


Pier 6
6/12/06
DPIC: GWB
DIVER: J.C.
NOTES: DGS

Point of Access: 14' boat & motor carried down bank at bridge.
Waterway Info: Water level at normal pool
±1fps flowrate
±2' U/W visibility
Weather: Sunny, ±80°F, no wind

Sample Inspection Notes

Sheet 1 of 4



PIER 6 6/12/06 DPIC: GWB DIVER: J.C. NOTES: DGS

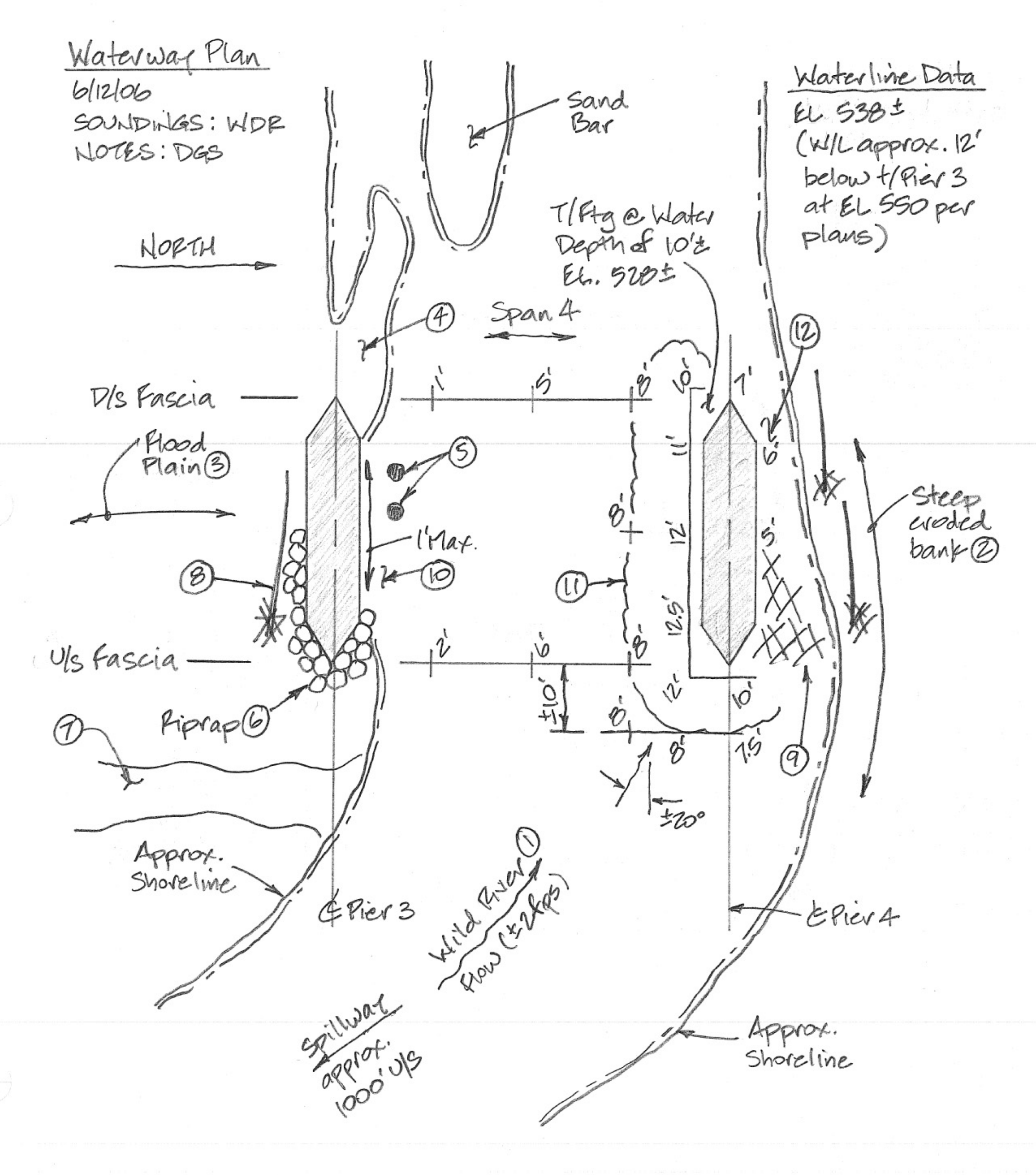
INSPECTION NOTES

1. Vert. crack, both sides of shaft, from BS to t/ftg, approx. 10' to North of D/S nose. Mostly H/L to at times up to 1/16" wide. No rust staining or effloresence/exudation.
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 sound 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 D/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/W scope, area is beginning to affect bearing support and bridge owner should be notified.

Inspection Notes & Sketch Checklist

☒ North Arrow
☒ Direction of flow
☒ Elevation reference
☒ Soundings taken
☒ Waterway info noted
☒ C.B. material noted
☒ Scour conditions noted
☒ Riprap and/or drift noted
☒ All defects documented
☒ Photographs taken

Sample Inspection Notes Sheet 2 of 4



Sample Inspection Notes Sheet 3 of 4

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

1. River at normal pool elevation (EL 538±) w/estimated current of ±2fps. Waterway bends ±45° (from NW to W flow) starting approx. 100' U/s of bridg
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
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 Pi
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 wit
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 cla
(infilling behind drift) allowing up to 1.5' of probe rod pen.

Waterway ☒ North Arrow ☒ Substructure designati

Sample Inspection Notes Sheet 4 of 4