Underwater Bridge Inspection Reference Manual

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7. Author(s) Michael D. Dukes, P.E.; James M Karalekas, P.E.; Dustin W. Noel, P.E.; Heath K. Pope, PE; David R. Reser, P.E.; Jeffrey B. Rowe, P.E.; Andrew Young, P.E.		8. Performing Organization Report No.
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Performing Organization's Principal Investigator: Jeffrey B. Rowe, P.E.
Performing Organization's Technical Leads: Michael D. Dukes, P.E. and David R. Reser, P.E.
FHWA Contracting Officer's Representative: Mignon Harris
FHWA Technical Consultant: Loren Wilson, P.E. and Darren Nebergall, P.E.
FHWA Technical Review Team: Wendy McAbee, P.E. and Nicholas Groves, S.E.
NHI Instructional Systems Designer (ISD): Gerald Lacosta

16. Abstract

To ensure public safety and to protect the capital investment in bridges over water, underwater members should be inspected to the extent necessary to determine their structural condition with certainty. Underwater inspections should also include the streambed. In shallow water, underwater inspections may be accomplished visually or tactilely from above the water's surface; in deep water, however, inspections 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 information 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.
The catalog for NHI Courses can be found on the National Highway Institute web site: https://www.nhi.fhwa.dot.gov/

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol (English)	When You Know	Multiply By	To Find	Symbol (Metric)
LENGTH				
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
AREA				
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
VOLUME				
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
NOTE: volumes greater than 1000L shall be shown in m^3				
MASS				
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
TEMPERATURE (exact degrees)				
^{o}F	Fahrenheit	5 (F-32)/g or (F-32/1.8	Celsius	^{o}C
ILLUMINATION				
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
FORCE and PRESSURE or STRESS				
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol (Metric)	When You Know	Multiply By	To Find	Symbol (English)
LENGTH				
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
AREA				
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yard	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
VOLUME				
mL	milliliters	0.034	milliliters	fl oz
L	liters	0.264	liters	gal
m^3	cubic meters	35.314	cubic meters	ft^3
m^3	cubic meters	1.307	cubic meters	yd^3
NOTE: volumes greater than 1000L shall be shown in m^3				
MASS				
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
TEMPERATURE (exact degrees)				
^{o}C	Celsius	1.8C+32	^{o}F	Fahrenheit
ILLUMINATION				
lx	lux	00929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
FORCE and PRESSURE or STRESS				
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

* SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised March 2003)
A Section 508 conformant version of the SI (Modern Metric) Conversion Factors table may be found at: http://www.fhwa.dot.gov/publications/convtabl.cfm

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LIST OF ABBREVIATIONS AND SYMBOLS

AASHTO	American Association of State Highway and Transportation Officials
ADE	Agency Defined Elements
ADT	Average Daily Traffic
ADTT	Average Daily Truck Traffic
AGE	Arterial Gas Embolism
ASR	Alkali-Silica Reactivity
ASTM	American Society for Testing and Materials
ATA	Atmosphere Absolute
BIRM	Bridge Inspector's Reference Manual
BME	Bridge Management Elements
CAD	Computer-Aided Design
CFR	Code of Federal Regulations
CO	Carbon Monoxide
CO_2	Carbon Dioxide
CP	Cathodic Protection
CS	Condition State
DCS	Decompression Sickness
DOT	Department of Transportation
FHWA	Federal Highway Administration
fsw	Feet of Seawater
ft	Foot or Feet
GPR	Ground Penetrating Radar
GPS	Global Positioning System
HDPE	High density polyethylene
HP	High Pressure
Hwy	Highway
I	Interstate
ID	Identification
JHA	Job Hazard Analysis
LP	Low Pressure
MBE	Manual for Bridge Evaluation (AASHTO)

MBEI	Manual for Bridge Element Inspection (AASHTO), Second Edition, 2019
MEL	Maritime Employers Liability
MPT	Magnetic Particle Testing
NBE	National Bridge Elements
NBI	National Bridge Inventory
NBIS	National Bridge Inspection Standards, 23 CFR 650 Subpart C
NDT	Nondestructive Testing
NHI	National Highway Institute
NHS	National Highway System
NOAA	National Oceanic and Atmospheric Administration
NSTM	Nonredundant steel tension member
O_2	Oxygen
OSHA	Occupational Safety and Health Administration
POA	Plan of action
PSC	Prestressed concrete
QA	Quality Assurance
QC	Quality Control
QTY	Quantity
RC	Reinforced concrete
ROV	Remotely operated vehicle
SCUBA	Self-contained underwater breathing apparatus
SI	International Symbol of Units
SNBI	Specifications for the National Bridge Inventory
SSA	Surface-supplied air
US	United States
UIP	Underwater Inspection Plan
USACE	United States Army Corps of Engineers
USCG	United States Coast Guard
USGS	United States Geological Survey
USL&H	United States Longshore & Harbor Workers' Compensation
WC	Workers' Compensation

GLOSSARY

A

AASHTO Manual. The term "AASHTO Manual" means the American Association of State Highway and Transportation Officials (AASHTO) *Manual for Bridge Evaluation* with sections 1.4, 2.2, 4.2, 6, and 8, excluding the 3rd paragraph in Article 6B.7.1. (23 CFR 650.317(a)(1)) (3rd edition, 2018)

AASHTO MBEI. *AASHTO Manual for Bridge Element Inspection* is a reference for standardized element definitions, element quantity calculations, condition state definitions, element feasible actions, and inspection conventions. This manual is used for element descriptions, quantity calculations, and condition state definitions. (23 CFR 650.317(a)(4)) (2nd edition, 2019)

Abrasion. Wearing or grinding away of material by friction; usually caused by sand, gravel, or stones, carried by wind or water.

Abutment. Part of bridge substructure at either end of bridge that transfers loads from superstructure to foundation and provides lateral support for the approach roadway embankment.

Aggradation. Progressive raising of a streambed by deposition of sediment.

Aggregate. Hard inert material such as sand, gravel, or crushed rock that may be combined with a cementing material to form mortar or concrete.

Alkali Silica Reactivity (ASR). An expansive reaction that results in swelling and expansion of concrete.

Annual Average Daily Traffic (AADT). The total annual volume of traffic passing a point or segment of a highway in both directions divided by the number of days in a year.

Annual Average Daily Truck Traffic (AADTT). The total annual volume of truck traffic passing a point or segment of a highway in both directions divided by the number of days in a year.

Anode. The positively charged pole of a corrosion cell at which oxidation occurs.

Apron. A form of scour (erosion) protection consisting of timber, concrete, riprap, paving, or other construction material placed adjacent to abutments and piers to prevent undermining.

Arterial Gas Embolism (AGE). An obstruction of blood flow caused by gas bubbles (emboli) entering the arterial circulation.

As-built Plans. Plans made after the construction of a project, showing all field changes to the final design plans (i.e., showing how the bridge was actually built).

Ascent Time. The time interval between leaving the deepest point of the dive and returning to the surface.

Axial Force. The force that acts through the longitudinal axis of a member.

B

Backfill. Material, usually soil or coarse aggregate, used to fill the unoccupied portion of a substructure excavation such as behind an abutment stem and backwall.

Backwall. The topmost portion of an abutment above the elevation of the bridge seat, functioning primarily as a retaining wall with a live load surcharge; it may serve also as a support for the extreme end of the bridge deck and the approach slab.

Bank. Sloped sides of a waterway channel or approach roadway, short for embankment.

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 another obstruction.

Base Course. A layer of compacted material found just below the wearing course that supports the pavement.

Base Metal. The surface metal of a steel element to be incorporated in a welded joint; also known as structure metal, parent metal.

Batter. The inclination of a surface in relation to a horizontal or a vertical plane; commonly designated on bridge detail plans as a ratio (e.g., 1:3, H:V); see **rake.**

Batter Pile. A pile driven in an inclined position to resist forces that 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. A support element transferring loads from superstructure to substructure while permitting limited movement capability.

Bearing Seat. A prepared horizontal surface at or near the top of a substructure unit upon which the bearings are placed.

Bedding. The soil or backfill material used to support pipe culverts.

Bedrock. The undisturbed rock layer below the surface soil.

Bending Moment. A combination of tension and compression forces developed when an external load is applied transversely to a bridge member, causing it to bend.

Bent. A substructure unit made up of two or more column or column-like members connected at their top-most ends by a cap, strut, or other member holding them in their correct positions.

Berm. (Berme.) The line, whether straight or curved, that 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.

Blanket. A protection against stream scour placed adjacent to abutments and piers and covering the streambed for a distance from these structures considered adequate.

Bottom Time. The total elapsed time from the time the diver leaves the surface to the time he leaves the bottom. Bottom times are measured in minutes and are rounded up to the next whole minute.

Box Culvert. A culvert of rectangular or square cross-section.

Bracing. A system of secondary members that maintains the geometric configuration of primary members.

Breathing Mixture. Air or a mixture of gases breathed by a diver that contains a physiologically appropriate proportion of oxygen.

Breastwall. 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; see **stem.**

Bridge. A structure, including supports erected over a depression or an obstruction, such as water, highway, or railway, that has a track or passageway for carrying traffic or other moving loads, and an opening measured along the center of the roadway of more than 20 feet between under copings of abutments or spring lines of arches, or extreme ends of openings for multiple boxes; it includes multiple pipes, where the clear distance between openings is less than half of the smaller contiguous opening.

Bridge Deficiency. A defect in a bridge component or member that makes the bridge less capable or less desirable for use.

Bridge Elements. Individual parts of a bridge that are subsets of bridge components, inventoried separately as functional groups. Elements inventoried on the bridge include: the total quantity for each element, and the element quantity that exists in each of four condition states reported to the NBI in accordance with 23 U.S.C. 144(d)(2).

Bridge Inspection Experience. Active participation in bridge inspections in accordance with the NBIS, in either a field inspection, supervisory, or management role. Some of the experience may come from relevant bridge design, bridge load rating, bridge construction, and bridge maintenance experience provided it develops the skills necessary to properly perform a NBIS bridge inspection.

Bridge Inspection Refresher Training. The National Highway Institute (NHI) "Bridge Inspection Refresher Training Course" [1] or other acceptable training as per 23 CFR 650.309(h) including State, federally, or tribally developed instruction aimed to improve quality of inspections, introduce new techniques, and maintain the consistency of the inspection program.

[1] The National Highway Institute training may be found at the following URL: (https://www.nhi.fhwa.dot.gov/home.aspx).

Bridge Inspector's Reference Manual (BIRM). A comprehensive FHWA manual on procedures and techniques for inspecting and evaluating a variety of in-service highway bridges.

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.

Bridge Site. The position or location of a bridge and its surrounding area.

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.

Built-up Member. A column or beam composed of plates and angles or other structural shapes united by bolting, riveting, or welding to enhance section properties.

Butt Weld. a weld joining two plates or shapes end to end; also splice weld.

C

Cable-stayed Bridge. A bridge in which the superstructure is directly supported by cables, or stays, passing over or attached to towers located at the main piers.

Caddisfly. A winged insect closely related to the moth and butterfly whose aquatic larvae seek shelter by digging small shallow holes into submerged timber elements.

Caisson. A rectangular or cylindrical chamber for keeping water or soft ground from flowing into an excavation.

Cap. The topmost portion of a pier or a pile bent serving to distribute the loads upon the columns or piles and to hold them in their proper relative positions; see **pier cap**, **pile cap.**

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.

Cast-in-place (CIP). The act of placing and curing concrete within formwork to construct a concrete element in its final position.

Cathode. The negatively charged pole of a corrosion cell that accepts electrons and does not corrode.

Cathodic Protection. A means of preventing metal from corroding by making it a cathode by impressed direct current or by attaching a sacrificial anode.

Catwalk. A narrow walkway for access to some part of a structure.

Causeway. An elevated roadway crossing a body of water.

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. A waterway connecting two bodies of water or containing moving water; a rolled steel member having a C-shaped cross-section.

Channel Profile. Longitudinal section of a channel along its centerline.

Checks. A crack in wood occurring parallel with the grain and through the rings of annual growth.

Chloride Contamination. The presence of recrystallized soluble salts, which causes accelerated corrosion of the steel reinforcement.

Chord. A generally horizontal member of a truss.

Coarse Aggregate. Aggregate that stays on a sieve of 5 mm (¼") square opening.

Coating. A material that provides a continuous film over a surface to protect or seal it; a film formed by the material.

Cofferdam. a temporary dam-like structure constructed around an excavation to exclude water; see **sheet pile cofferdam**.

Column. A general term applying to a vertical member resisting compressive stresses and having, in general, a considerable length in comparison with its transverse dimensions.

Column Bent. A bent shaped pier that uses columns incorporated with a cap beam.

Component. A general term reserved to define parts of a bridge, such as the bridge deck, superstructure, or substructure.

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 stone-like mass made from a mixture of aggregates and cementing material, which is moldable prior to hardening.

Condition Rating. A judgment of a bridge component condition in comparison to its original as-built condition.

Consolidation. The time dependent change in volume of a soil mass under compressive load caused by water slowly escaping from the pores or voids of the soil.

Construction Joint. A pair of adjacent surfaces in reinforced concrete where two pours have met, reinforcement steel extends through this joint.

Continuous Spans. Spans designed to extend without joints over one or more intermediate supports.

Contraction Scour. The removal of the material under the structure only.

Corrosion. The general disintegration of metal through oxidation.

Couplant. A viscous fluid material used with ultrasonic gages to enhance transmission of sound waves.

Course. A horizontal layer of bricks or stone.

Cover. The clear thickness of concrete between a reinforcing bar and the surface of the concrete; the depth of backfill over the top of a pipe or culvert.

Crack. A break without complete separation of parts; a fissure.

Creep. An inelastic deformation that occurs under a constant load, below the yield point, and increases with time.

Creosote. An oily liquid obtained by the distillation of coal or wood tar and used as a wood preservative.

Critical Finding. A structural or safety related deficiency that requires immediate action to ensure public safety.

Cross-section. The shape of an object cut transversely to its length.

Cross-sectional Area. The area of a cross-section.

Culvert. A drainage structure beneath an embankment (e.g., corrugated metal pipe, concrete box culvert).

Cylinder. A pressure vessel for the storage of gases.

D

Damage Inspection. An unscheduled inspection to assess structural damage resulting from environmental factors or human actions.

Dead Load. A static load due to the weight of the structure itself.

Debris. Material including floating wood, trash, suspended sediment, or bed load moved by a flowing stream.

Decay. The result of fungi feeding on the cell walls of the wood.

Decent Time. The total elapsed time from the time the diver leaves the surface to the time he reaches the bottom. Descent time is rounded up to the next whole minute for charting purposes.

Deck. That portion of a bridge that provides direct support for vehicular and pedestrian traffic, supported by a superstructure.

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 that recur during or after recompression therapy are classified as serious symptoms.

Defect. Flaw within a bridge material; with regards to element level evaluation, it is the method by which distress is categorized and assigned a condition state.

Deflection. Elastic movement of a structural member under a load.

Deformation. Distortion of a loaded structural member; may be elastic or inelastic.

Deformed Bars. Concrete reinforcement consisting of steel bars with projections or indentations (deformations) to increase the mechanical bond between the steel and concrete.

Degradation. General progressive lowering of a stream channel by scour.

Delamination. Surface separation of concrete into layers; separation of glue laminated timber piles.

Deepest Depth. The deepest depth recorded on the depth gauge during a dive.

Degradation. General, progressive lowering of the stream channel by erosion.

Deterioration. Decline in quality over time due to chemical or physical degradation.

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.

Differential Settlement. Uneven settlement of individual or independent elements of a substructure; tilting in the longitudinal or transverse direction due to deformation or loss of foundation material.

Dike. An earthen embankment constructed to retain or redirect water; when used in conjunction with a bridge, it prevents stream erosion and localized scour and so directs the stream current such that debris does not accumulate; see **spur.**

Discharge. The volume of fluid per unit of time flowing along a pipe or channel.

Diver. A specially trained individual who inspects the underwater portion of a bridge substructure and the surrounding channel.

Dolphin. A group of piles driven close together or a caisson placed to protect portions of a bridge exposed to possible damage by collision with river or marine traffic.

Downline. A piece of substantial cordage running from a point at the surface to the underwater workplace and kept under some tension. It can be used as a guideline for divers descending or ascending, for depth control, and as a guide for transfer of tools and equipment between surface and diver.

Dry Suit (variable volume). A diving suit capable of being inflated for buoyancy or insulation that keeps the diver's body essentially dry.

E

Ebb Tide. Flow of water from the bay or estuary to the ocean.

Efflorescence. A deposit on concrete, brick, stone, or mortar caused by crystallization of carbonates brought to the surface by moisture in the masonry or concrete. Efflorescence is a combination of calcium carbonate leached out of the cement paste and other recrystallized carbonate and chloride compounds.

Electrolyte. A medium of air, soil, or liquid carrying ionic current between two metal surfaces, the anode, and the cathode.

Element Level Bridge Inspection Data. Quantitative condition assessment data, collected during bridge inspections that indicates the severity and extent of defects in bridge elements. (23 CFR 650.305)

Elevation View. A drawing of the side view of a structure.

Embankment. A mound of earth constructed above the natural ground surface to carry a road or to prevent water from passing beyond desirable limits; also known as bank.

Epoxy. A synthetic resin that cures or hardens by chemical reaction between components, which are mixed shortly before use.

Erosion. Wearing away of soil by flowing water not associated with a channel; see **scour.**

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 the weight of a structure during the period of its construction and until it becomes self-supporting.

Fascia. An outside, covering member designed on the basis or 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. A structure that acts as a buffer to protect the portions of a bridge exposed to floating debris and water-borne traffic from collision damage; sometimes called an ice guard in regions with ice floes.

Fender Pier. A pier-like structure that 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.

FHWA SNBI *(FHWA Specifications for the National Bridge Inventory)*. A reference that provides the specifications for reporting data for highway bridges open to the public to the FHWA for inclusion in the National Bridge Inventory.

Fiber Reinforced Polymer Composite. Fiber reinforced polymer composite (FRP) is also known as fiberglass reinforced plastic and is a composite made from glass fiber or carbon fiber reinforcement in a plastic (polymer) matrix. With reinforcement of the plastic matrix, a wide variety of physical strengths and properties can be designed into the material. Additionally, the type and configuration of the reinforcement can be selected, along with the type of polymer and additives within the matrix.

Fill. Material, usually earth, used to change the surface contour of an area or to construct 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.

Fine Aggregate. Sand or grit for concrete or mortar that passes a No. 4 sieve (4.75 mm).

Flange. The (usually) horizontal parts of a rolled I-shaped beam or of a built-up girder extending transversely across the top and bottom of the web.

Floating Bridge. A bridge supported by floating on pontoons moored to the lakebed or riverbed; a portion may be removable to facilitate navigation.

Flood Frequency. The average time interval in years in which a flow of a given magnitude, taken from an infinite series, will recur.

Flood Plain. Area adjacent to a stream or river subject to flooding.

Flood Tide. Flow of water from the ocean to the bay or estuary.

Footing. The enlarged, 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; footer is a colloquial term for footing.

Forms. The molds that hold concrete in place while it is hardening; also known as form work, shuttering; see **lagging**, **stay-in-place forms**.

Foundation. The supporting material upon which the substructure portion of a bridge is placed.

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. See **pile**.

Foundation Seal. A mass of concrete placed underwater within a cofferdam for the base portion of structure to close or seal the cofferdam against incoming water; see **tremie.**

Foundation Stone. The stone or one of the stones of a course having contact with the foundation of a structure.

Freeboard. The vertical distance between the design flood water surface and the lowest point of the structure to account for waves, surges, drift, and other contingencies.

Freeze-thaw. Freezing of water within the capillaries and pores of cement paste and aggregate resulting in internal overstressing of the concrete, which leads to deterioration, including cracking, scaling, and crumbling.

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.

Full-face Diving Mask. A type of diving mask that seals the whole of the diver's face from the water and contains a mouthpiece, demand valve or constant flow gas supply that provides the diver with breathing gas.

G

Galvanic Action. Electrical current between two unlike metals.

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 free-flowing, used for filling (grouting) the joints in masonry, fixing anchor bolts, and filling cored spaces; usually a thin mix of cement, water, and sometimes sand or admixtures.

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.

Guide Banks. Dikes that extend upstream from the approach embankment at either or both sides of the bridge opening to direct flow through the opening.

H

Hands-on Inspection. Inspection within arm's length of the member. Inspection uses visual techniques that may be supplemented by nondestructive evaluation techniques. (23 CFR 650.305)

H-Beam. (H-Pile.) A rolled steel bearing pile having an H-shaped cross-section.

Hairline Cracks. Very narrow cracks that form in the surface of concrete due to tension caused by loading.

Hammerhead Pier. A pier with a single cylindrical or rectangular shaft and a relatively long, transverse cap; also known as a tee pier or cantilever pier.

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.

Head Loss. The loss of energy between two points along the path of a flowing fluid due to fluid friction; reported in feet of head.

Headwall. A concrete structure at the ends of a culvert to retain the embankment slopes, anchor the culvert, and prevent undercutting.

Headwater. The source or the upstream waters of a stream.

Heavy Gear Diving. Diving that uses standard deep-sea dress, including helmet and brass breastplate, rubberized canvas suit, and heavy weighted shoes.

Helical. Having the form of a spiral.

Helmet. (Open-circuit and surface-supplied). Breathing and protective equipment that encloses the diver's head.

Highway. The term "highway" includes: A) a road, street, and parkway; B) a right-of-way, bridge, railroad-highway crossing, tunnel, drainage structure, sign, guardrail, and protective structure, in connection with a highway; and C) a portion of any interstate or international bridge or tunnel and the approaches thereto, the cost of which is assumed by a State transportation department, including such facilities as may be required by the U.S. Customs and Immigration Services in connection with the operation of an international bridge or tunnel. (23 U.S.C. 101(a))

Honeycomb. An area in concrete where mortar has separated and left spaces between the coarse aggregate, usually caused by improper vibration during concrete construction.

Horizontal Alignment. A roadway's centerline or baseline alignment in the horizontal plane.

Hyperbaric Conditions. Pressure conditions in excess of surface pressure (1 ata).

Hypercapnia. An abnormally high level of carbon dioxide in the blood and body tissues.

I

Ice Floe. A large flat free mass of floating ice.

In-Depth Inspection. A close-up, detailed inspection of one or more bridge members located above or below water, using visual or nondestructive evaluation techniques as required to identify any deficiencies not readily detectable using routine inspection procedures. Hands-on inspection may be necessary at some locations. In-depth inspections may occur more or less frequently than routine inspections, as outlined in bridge specific inspection procedures. (23 CFR 650.305)

Initial Inspection. The first inspection of a new, replaced, or rehabilitated bridge. This inspection serves to record required bridge inventory data, establish baseline conditions, and establish the intervals for other inspection types. (23 CFR 650.305)

Inlet. An opening in the floor of a bridge leading to a drain; roadway drainage structure that collects surface water and transfers it to pipes.

Inspection Date. The date on which an inspection begins for a bridge.

Inspection Due Date. The last inspection date plus the current inspection interval. (23 CFR 650.305)

Inspection Interval. The interval with which the bridge is inspected.

Inspection Report. A document summarizing the bridge inspection findings, recommendations, and identifies the team leader responsible for the inspection and report. (23 CFR 650.305)

Inspector. A member of the bridge safety inspection team; where silent, this typically refers to the team leader.

Inventory Data. All data reported to the NBI in accordance with the SNBI. (23 CFR 650.317(b)(1)).

Isotropic. Having the same material properties in all directions, e.g., steel.

J

Jacket. A protective shell surrounding a pile made of fabric, concrete, or other material.

Jersey Barrier. A concrete barrier with sloping front face that was developed by the New Jersey DOT.

Joint. In masonry, the space between individual stones or bricks; in concrete, a division in continuity of the concrete; in a truss, the point at which members of a truss are joined.

L

Lagging. Horizontal members spanning between piles to form a wall; forms used to produce curved surfaces; see **forms.**

Lateral. A member placed approximately perpendicular to a primary member.

Lateral Bracing. The bracing assemblage engaging a member perpendicular to the plane of the member; intended to resist transverse movement and deformation; also keeps primary parallel elements in truss bridges and girder bridges aligned; see **bracing.**

Lateral Stream Migration. The relocation of the channel due to lateral streambank erosion.

Lead Line. A weighted cord incrementally marked, used to determine the depth of a body of water; also known as sounding line.

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 hourglass shape.

Load. A force carried by a structure component.

Load Posting. Regulatory signs installed in accordance with the Manual on Uniform Traffic Control Devices for Streets and Highways (“MUTCD”) and State or local law that represent the maximum vehicular live load which the bridge may safely carry. (23 CFR 650.305)

Load Rating. The analysis to determine the safe vehicular live load carrying capacity of a bridge using bridge plans and supplemented by measurements and other information gathered from an inspection. (23 CFR 650.305)

Local Buckling. Localized buckling of a beam’s plate element that can lead to failure of member.

Local Scour. The removal of streambed material adjacent to an obstruction in a waterway, that has been placed within the stream (such as a pier or abutment) and causes the acceleration of the flow induced by the obstruction.

M

Mask. (Open-circuit and surface-supplied). Breathing and protective equipment that covers a diver’s face.

Marine Borers. Mollusks and crustaceans that live in water and destroy wood by digesting it.

Masonry. That portion of a structure composed of stone, brick, or concrete block placed in courses and usually cemented with mortar.

Maximum Depth. The deepest depth obtained by the diver after correction of the depth gauge reading for error. When conducting SCUBA operations, the diver’s depth gauge is considered error free. The diver’s maximum depth is the deepest depth gauge reading. When conducting surface-supplied diving operations using a pneumofathometer to measure depth, maximum depth is the deepest reading on the pneumofathometer gauge plus the pneumofathometer correction factor. Maximum depth is the depth used to enter the decompression tables.

Meander. A twisting, winding action from side to side; characterizes the serpentine curvature of a narrow, slow flowing stream in a wide flood plain.

Member. An individual angle, beam, plate, or built component piece intended ultimately to become an integral part of an assembled frame or structure.

Midspan. A reference point halfway between the supports of a beam or span.

Modulus of Elasticity (E). The ratio between the stress applied and the resulting elastic strain; Young's modulus; the stiffness of a material.

Moisture Content. The amount of water in a material expressed as a percentage by weight.

Mortar. A paste of portland cement, sand, and water laid between bricks, stones, or blocks.

N

National Bridge Inspection Standards (NBIS). Federal regulations establishing national policy regarding bridge inspection organization, bridge inspection frequency, inspector qualifications, inventory requirements, report formats, and inspection and rating procedures, as described in 23 CFR 650 Subpart C.

National Bridge Inventory (NBI). An aggregation of State transportation department, Federal agency and Tribal government bridge and associated highway data maintained by the FHWA. The NBIS requires each State transportation department, Federal agency, and Tribal government to prepare and maintain a bridge inventory, which must be submitted to FHWA in accordance with these specifications on an annual basis or whenever requested. (23 CFR 650.315)

Navigable Waterway. Navigable waterways are determined by the Commandant of Coast Guard. 33 CFR 2.36 (a) defines navigable waterways as consisting of:

1. Territorial seas of the United States;
2. Internal waters of the United States that are subject to tidal influence; and
3. Internal waters of the United States not subject to tidal influence that:

a. Are or have been used, or are or have been susceptible for use, by themselves or in connection with other waters, as highways for substantial interstate or foreign commerce, notwithstanding natural or man-made obstructions that require portage, or
b. A governmental or non-governmental body, having expertise in waterway improvement, determines to be capable of improvement at a reasonable cost (a favorable balance between cost and need) to provide, by themselves or in connection with other waters, highways for substantial interstate or foreign commerce.

Nitrogen Narcosis. A state of euphoria and exhilaration that occurs when a diver breathes a gas mixture with a nitrogen partial pressure greater than approximately 4 ata.

No-decompression Diving. Diving that 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*.

Nondestructive Evaluation (NDE). Also referred to as nondestructive testing (NDT); any testing method of checking structural quality of materials that does not damage them.

Non-isotropic. Having different physical properties along different axis; e.g., unreinforced concrete is strong in compression, but relatively weak in tension.

Nose. A projection acting as a cut water on the upstream end of a pier; see **starling.**

NSTM Inspection. A hands-on inspection of a nonredundant steel tension member.

O

Offset. A horizontal distance measured at right angles to a survey line to locate a point off the line.

On Center. A description of a typical dimension between the centers of the objects being measured.

Orthotropic. Having different properties in two or more directions at right angles to each other (e.g., wood); see **anisotropy.**

Outlet. In hydraulics, the discharge end of drains, sewers, or culverts.

Oxidation. The chemical breakdown of a substance due to its reaction with oxygen from the air.

P

Pack Rust. Rust forming between adjacent steel surfaces in contact that tends to force the surfaces apart due to the increase in material volume.

Parapet. A low wall along the outmost edge of the roadway of a bridge to protect vehicles and pedestrians.

Pedestal. Concrete or built-up metal member constructed on top of a bridge seat for the purpose of providing a specific bearing seat elevation.

Penetration. When applied to creosoted lumber, the depth to which the surface wood is permeated by the creosote oil; when applied to pile driving; the depth a pile tip is driven into the ground.

Pier. A substructure unit that supports the spans of a multi-span superstructure at an intermediate location between its abutments.

Pier Cap. The topmost horizontal portion of a pier that distributes loads from the superstructure to the vertical pier elements.

Pile. A shaft-like linear member that carries loads to underlying rock or soil strata.

Pile Bent. A row of driven or placed piles extending above the ground surface supporting a pile cap; see **bent**.

Pile Cap. A slab or beam that acts to secure the piles in position laterally and provides a bridge seat to receive and distribute superstructure loads.

Pile Foundation. A foundation supported by piles in sufficient number and to a depth adequate to develop the bearing resistance required to support the substructure load.

Pile Splice. One of the means of joining one pile upon the end of another to provide greater penetration length.

Piling. Collective term applied to group of piles in a construction; see **pile**, **sheet piles.**

Plain Concrete. Concrete with no structural reinforcement except, possibly, light steel to reduce shrinkage and temperature cracking.

Plan View. Drawing that represents the top view of the road or a structure.

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.

Pop-out. Conical fragment broken out of a concrete surface by pressure from reactive aggregate particles.

Portland Cement. A fine dry powder made by grinding limestone clinker made by heating limestone in a kiln; this material reacts chemically with water to produce a solid mass.

Portland Cement Concrete (PCC). A mixture of aggregate, portland cement, water, and usually chemical admixtures.

Post-tensioning. A method of prestressing concrete in which the tendons are stressed after the concrete has been cast and hardens.

Precast Concrete. Concrete members that are cast and cured before being placed into their final positions on a construction site.

Pressure. Force per unit of area. In diving, pressure denotes an exposure greater than surface pressure (1 atm).

Prestressed Concrete. Concrete with strands, tendons, or bars that are stressed before the live load is applied.

Prestressing. Applying forces to a structure to deform it in such a way that it will withstand its working loads more effectively; see **post-tensioning**, **pre-tensioning.**

Pre-Tensioning. A method of prestressing concrete in which the strands are stressed before the concrete is placed; strands are released after the concrete has hardened, inducing internal compression into the concrete.

Primary Loads. Vertical loading from vehicular traffic and permanent vertical loads on the structure.

Primary Member. A member in the direct load path of primary loads; considered synonymous with the term "main member."

Private Bridge. A bridge open to public travel and not owned by a public authority as defined in 23 U.S.C. 101.

Probing. Investigating the location and condition of submerged foundation material using a rod or shaft of appropriate length; checking the surface condition of a timber member for decay using a pointed tool, e.g., an ice pick.

Procedures. Written documentation of policies, methods, considerations, criteria, and other conditions that direct the actions of personnel so that a desired end result is achieved consistently.

Professional Engineer (PE). An individual, who has fulfilled education and experience requirements and passed rigorous exams that, under State licensure laws, permits them to offer engineering services directly to the public. Engineering licensure laws vary from State to State, but, in general, to become a PE an individual needs to be a graduate of an engineering program accredited by the Accreditation Board for Engineering and Technology, pass the Fundamentals of Engineering exam, gain four years of experience working under a PE, and pass the Principles of Practice of Engineering exam.

Profile. A section cut vertically along the center line of a roadway or waterway to show the original and final ground levels.

Program Manager. The individual in charge of the program that has been assigned the duties and responsibilities for bridge inspection, reporting, and inventory, and has the overall responsibility to ensure the program conforms with the requirements of this subpart. The program manager provides overall leadership and is available to inspection team leaders to provide guidance.

Protective System. A system used to protect bridges from environmental forces that cause steel and concrete to deteriorate and timber to decay, typically a coating system.

Q

Quality Assurance (QA). The use of sampling and other measures to assure the adequacy of quality control procedures to verify or measure the quality level of the entire bridge inspection and load rating program. (23 CFR 650.305)

Quality Control (QC). Procedures that are intended to maintain the quality of a bridge inspection and load rating at or above a specified level. (23 CFR 650.305)

R

Rake. An angle of inclination of a surface in relation to a vertical plane; also known as batter.

Reach. Section of a stream or river along which similar hydrologic conditions exist, such as discharge, depth, area, and slope.

Rebar. See **reinforcing bar**.

Recompression. An increase in pressure, which is calculated to eliminate the symptoms of decompression sickness, when applied therapeutically to a diver in a pressure vessel for human occupancy.

Reinforced Concrete. Concrete with steel reinforcing bars embedded in it to supply increased tensile strength and durability.

Reinforcement. Rods or mesh embedded in concrete to strengthen it.

Reinforcing Bar. A steel bar, plain or with a deformed surface, that bonds to the concrete and supplies tensile strength to the concrete.

Repetitive Dive. Any dive conducted while the diver still has some residual nitrogen in their tissues from a prior dive.

Repetitive Group Designator. A letter used to indicate the amount of residual nitrogen remaining in the diver’s body following a previous dive.

Residual Nitrogen Time. The time that must be added to the bottom time of a repetitive dive to compensate for the nitrogen still in solution in a diver’s tissues from a previous dive. Residual nitrogen time is expressed in minutes.

Resin. See **composite**.

Retaining Wall. A structure designed to restrain and hold back a mass of earth.

Riprap. Stones, blocks of concrete or other objects placed upon river and stream beds and banks, lake, tidal or other shores to prevent scour by water flow or wave action.

Risk. The exposure to the possibility of structural safety or serviceability loss during the interval between inspections. It is the combination of the probability of an event and its consequence. (23 CFR 650.305)

River Training Structures. Devices that alter the flow of the river.

Runoff. The quantity of precipitation that flows from a catchment area past a given point over a certain period.

S

Scour. Erosion of streambed or bank material due to flowing water; often considered as being localized around piers and abutments of bridges. (23 CFR 650.305)

Scour Appraisal. A risk-based and data-driven determination of a bridge's vulnerability to scour, resulting from the least stable result of scour that is either observed, or estimated through a scour evaluation or a scour assessment. (23 CFR 650.305)

Scour Assessment. The determination of an existing bridge's vulnerability to scour, which considers stream stability and scour potential as described in HEC 20 and other scour-related data sources. (23 CFR 650.305)

Scour Critical Bridge. A bridge with a foundation element that has been determined to be unstable for the observed or evaluated scour condition. (23 CFR 650.305)

Scour Evaluation. The application of hydraulic analysis as described in HEC 18 and HEC 20 to estimate scour depths and determine bridge and substructure stability considering potential scour. (23 CFR 650.305)

Scour Plan of Action (POA). Procedures for bridge inspectors and engineers in managing each bridge determined to be scour critical or that has unknown foundations. (23 CFR 650.305)

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

Sheet Pile Cofferdam. A wall-like barrier composed of driven piling constructed to surround the area to be occupied by a structure and permit dewatering of the enclosure so that the excavation may be performed in the open air.

Sheet Piling. A general or collective term used to describe a number of sheet piles taken together to form a crib, cofferdam, bulkhead, etc.; also known as sheeting.

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 should be that which will pass a No. 200 sieve very finely divided siliceous or other hard rock material removed from its mother rock through erosive action rather than chemical decomposition. (ASTM D2487-17)

Slope. A term commonly applied to the inclined surface of an excavated cut or an embankment. The inclination of a surface expressed as a ratio of one unit of rise or fall for so many horizontal units.

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.

Sounding. Determining the depth of water by an echo-sounder or lead line; tapping a surface to detect delamination (concrete) or decay (timber).

Spur Dike. A projecting jetty-like construction placed adjacent to an abutment.

Stage. Water-surface elevation of a stream with respect to a reference elevation (HEC 20).

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.

Surface Interval. In the context of repetitive diving, the surface interval is the time a diver spends on the surface between dives. It begins as soon as the diver surfaces and ends as soon as he starts his next descent. In the context of surface decompression, the surface interval is the total elapsed time from when the diver leaves the 40 fsw water stop to the time he arrives at 50 fsw in the decompression chamber.

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. Water ponded below the outlet of a waterway, thereby reducing the amount of flow through the waterway; see **headwater**.

Team Leader. The on-site, nationally certified bridge inspector in charge of an inspection team and responsible for planning, preparing, performing, and reporting on bridge field inspections. (23 CFR 650.305)

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 into 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; also known as footwall.

Total Decompression Time. The total elapsed time from the time the diver leaves the bottom to the time he arrives on the surface. This time is also frequently called the total ascent time. The two terms are synonymous and can be used interchangeably.

Total Time of Dive. The total elapsed time from the time the diver leaves the surface to the time she arrives back on the surface.

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. A bridge structure consisting of spans supported on braced towers or frame bents.

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.

Underwater Bridge Inspection Diver. Diver who performs inspection of the underwater portion of the bridge and has completed FHWA-approved underwater bridge inspection training scoring 70% or greater on an end-of-course assessment. (23 CFR 650.309(e))

Underwater Inspection. Inspection of the underwater portion of a bridge substructure and the surrounding channel, which cannot be inspected visually at low water or by wading or probing, and generally requiring diving or other appropriate techniques. (23 CFR 650.305)

Unknown Foundations. Foundations of bridges over waterways where complete details are unknown because either the foundation type and depth are unknown, or the foundation type is known, but its depth is unknown, and therefore cannot be appraised for scour vulnerability. (23 CFR 650.305)

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 roadway embankment.

Work Site. A vessel or surface structure from which dives are supported or the underwater location where work is performed.

IMAGE SOURCES

The following organization provided a figure in this reference manual:

- PCL Construction.
  Figure 50. Photo. Conventional cofferdam around a bridge pier.

FHWA is the source for all other figures in this manual.

CHAPTER 1. MANAGING AN UNDERWATER INSPECTION TEAM

1.1 REGULATIONS GOVERNING UNDERWATER BRIDGE INSPECTION

1.1.1 Need for Underwater Inspections

The National Bridge Inventory (NBI) of the United States includes approximately 628,207 highway bridges (FHWA, 2021). Of those, more than 80 percent cross some type of waterway, many with submerged substructure components. Therefore, underwater inspections are an integral part of a comprehensive bridge safety and asset preservation program. The bridge shown in Figure 1 is one of several that collapsed during the 1980s, with underwater deficiencies contributing to the bridge failure.

The Federal Highway Administration (FHWA), through the National Bridge Inspection Standards (NBIS), established the requirements for bridge owners to implement a comprehensive bridge inspection program in accordance with Federal law. The NBIS requires bridge owners to inspect bridge members underwater and evaluate the channel around the bridge to determine their condition for public safety and serviceability. To achieve that goal, bridge owners may employ one or more of the techniques below:

- Underwater inspection with divers
- Underwater inspection by remotely operated vehicle (ROV)
- Underwater acoustic imaging
- Underwater photography
- Wading or probing
- Hydrographic surveying
- Channel sounding
- Material testing or sampling
- Aerial photography

Figure 1. Photo. Schoharie Creek bridge failure (1987). (Source FHWA).

Underwater inspections are performed as part of, or in coordination with, a multi-disciplinary team of technical experts to document the overall condition of a bridge and surrounding channel. This comprehensive approach helps provide information critical to managing, maintaining, and repairing the Nation’s bridges.

1.1.2 National Bridge Inspection Standards

The NBIS requires that all highway bridges located on public roads be inspected regularly (23 CFR 650.301 – 650.317). This requirement includes highway bridges on and off Federal-aid highways, including tribally and federally owned bridges and privately owned bridges connected to public roads on both ends. Temporary bridges and those under construction with portions open to traffic are also subject to the NBIS. In addition, the NBIS specifies the minimum standard for the proper safety inspection and evaluation of bridges and establishes the requirement that the FHWA maintains all important bridge-related data as part of the NBI.

1.1.3 Specifications for the National Bridge Inventory

The Specifications for the National Bridge Inventory (SNBI) provide information about coding all bridge data for the NBI. The SNBI is incorporated by reference into the NBIS. The underwater inspection team is responsible for coding the component condition ratings for the following NBI items, at a minimum, in coordination with other inspection personnel:

- B.C.09 Channel Condition Rating
- B.C.10 Channel Protection Condition Rating
- B.C.11 Scour Condition Rating
- B.C.15 Underwater Inspection Condition

The NBI Item B.C.15 rating represents the condition of underwater members of the substructure based on the underwater inspection. The condition of the underwater members is incorporated into the NBI Item B.C.03 Substructure Condition Rating. When determining the condition rating code for B.C.15, the condition of protective coatings, fenders, and other substructure protection systems should not be considered, except to the extent that these items indicate distress of, or adversely affect, the substructure; substructure protection systems are discussed in Section 3.7. Similarly, the presence of drift, debris, and soil buildup should not be considered when determining the B.C.15 condition rating, except to the extent that these items are causing distress in the substructure. For example, timber debris buildup on a pile may affect the B.C.15 rating if the debris applies a lateral load that causes distress on the pile. The B.C.11 condition rating is considered when evaluating Item B.C.15 if observed conditions are inconsistent with the scour design or assumptions used in the scour appraisal.

1.2 UNDERWATER INSPECTION PROCESS

1.2.1 Types of Inspections

The SNBI specifies eight inspection types and scour monitoring, with each having an associated one-digit numerical code. These inspection codes are recorded in NBI Item B.IE.01 of the bridge record and are listed in Table 1.

When an underwater inspection is required, Item B.IR.03 of the bridge record is coded “Y.” This code indicates all portions of the bridge substructure and surrounding channel cannot be adequately inspected at normal flow levels during a routine inspection using wading and probing techniques.

As discussed in the NBIS, if this item was previously reported as Y because an underwater inspection is generally required, it should continue to be reported as Y even for instances of unusually low flow. Item B.IR.03 should continue to be reported as Y only if the low-flow condition is truly unusual and is not likely to recur during the next inspection interval. The reported code for Item B.IR.03 may change in rare circumstances where long-term environmental conditions change for inspection access to underwater portions of the substructure. For example, removing a dam on a river, which subsequently lowers the water level, eliminates the need for underwater inspections in the future.

Table 1. Inspection types and codes, SNBI - B.IE.01.

Code	Inspection Type
1	Initial
2	Routine
3	Underwater
4	NSTM
5	Damage
6	In-Depth
7	Special
8	Service
9	Scour Monitoring

1.2.1.1 Initial Inspection

The first inspection of a new, replaced, or rehabilitated bridge. This inspection serves to record required bridge inventory data, establish baseline conditions, and set the intervals for other inspection types.

1.2.1.2 Routine Inspection

Regularly scheduled comprehensive inspection consisting of observations and measurements needed to determine the physical and functional condition of the bridge and identify changes from previously recorded conditions. Findings during the routine inspection could trigger additional inspection types needed to gather information and document observed conditions in more detail.

1.2.1.3 Underwater Inspection

Inspection of the underwater portion of a bridge substructure and the surrounding channel, that cannot be inspected visually at low water or by wading or probing, generally requiring diving or other appropriate techniques. An underwater inspection typically includes both Level 1 and Level 2 inspection techniques. Findings may also trigger the need for Level 3 investigations to better document conditions. Inspection levels are defined in Section 1.2.4.

1.2.1.4 NSTM Inspection

A hands-on inspection of a nonredundant steel tension member. These members are generally located above the waterline.

1.2.1.5 Damage Inspection

An unscheduled inspection to assess structural damage resulting from environmental factors or human actions. A visual inspection is performed for all elements affected by the event. The inspection should be extensive enough to determine if closure or emergency load restrictions for the affected bridge are warranted. In some cases, an underwater inspection will be performed as part of the damage inspection. Possible examples where a damage inspection may include an underwater inspection include:

- Vessel impact of a bridge substructure
- Flood events causing scour or bank erosion
- Ice flow or timber debris buildup that could cause scour
- Earthquake
- Tsunami or storm surge event

Some State agencies may offer specific examples of when an underwater inspection should be included as part of the damage inspection. When available, refer to the State's *Bridge Inspection Manual* for State-specific examples of when an underwater inspection is completed as part of a damage inspection.

1.2.1.6 In-depth Inspection

A close-up, detailed inspection of one or more bridge members located above or below water, using visual or nondestructive evaluation (NDE) techniques as required to identify any deficiencies not readily detectable using routine inspection procedures. Hands-on inspection may be necessary at some locations. In-depth inspections may occur more or less frequently than routine inspections, as outlined in bridge-specific inspection procedures.

1.2.1.7 Special Inspection

An inspection scheduled at the discretion of the bridge owner, used to monitor a particular known or suspected deficiency, or to monitor special details or unusual characteristics of a bridge that do not necessarily have defects.

1.2.1.8 Service Inspection

An inspection to identify major deficiencies and safety issues, performed by personnel with general knowledge of bridge maintenance or bridge inspection.

1.2.1.9 Scour Monitoring Inspection

An inspection performed during or after a triggering storm event as required by a Scour Plan of Action (POA) by personnel with qualifications required by the agency (SNBI, Definitions). This inspection is a separate code from the scour documentation performed by divers during the underwater bridge inspection. Scour monitoring can include periodic remote electronic readings of streambed changes when required in the POA. If multiple site visits occur for a triggering storm event, record this item once for that storm event.

1.2.2 Inspection Interval

The first underwater inspection for each bridge and for each bridge with portions underwater that have been rehabilitated should be performed as soon as practical but within 12 months of the bridge opening to traffic. After the initial inspection, each bridge is inspected at regular intervals, not to exceed the interval established using one of two risk-based methods.

Method 1 uses a simplified assessment of risk to classify each bridge into one of three categories; regular, reduced, and extended, and is the most common assessment method. Each of the three categories are detailed in the following subsections.

Method 2 uses a more rigorous assessment of risk to classify each bridge, or a group of bridges, into one of three categories with an underwater inspection interval not to exceed 24, 60, and 72 months. The policy and criteria that establish intervals under this method must be submitted by the bridge owner for FHWA approval prior to implementation (23 CFR 650.311(b)(2)). This method is less common and therefore, not discussed in detail within this manual.

1.2.2.1 Regular Interval

The most common underwater inspection interval is 60 months. There is up to a three-month inspection interval tolerance to complete the inspection after the inspection due date. The inspection due date is the last inspection date plus the current inspection interval (23 CFR 650.305). If the inspection occurs after the inspection due date, the interval is based on the actual underwater inspection date. When inspections are completed after the due date, care should be taken to avoid the inspection due date creeping to a less favorable time of year when environmental hazards may be more prevalent. Environmental hazards, such as frozen waterways or heavy rainfall, can limit inspection access and increase safety risks. Keeping to regular inspection intervals helps avoid these obstacles by maintaining seasonal schedules. Refer to Section 1.2.2.4 for additional information on inspection interval tolerance.

1.2.2.2 Reduced Interval

A bridge owner has the option to reduce the inspection interval to less than 60 months by establishing a set of criteria to follow that would warrant a reduction. The considerations can include the following:

- Structure type
- Design materials
- Age
- Condition ratings
- Scour
- Environmental
- Average daily traffic (ADT) and average daily truck traffic (ADTT)
- History of vessel or vehicle impact
- Load rating
- Other known deficiencies

While a bridge owner can elect to perform inspections less frequently than 60 months, the NBIS requires a reduced inspection frequency not to exceed 24 months if any of the following conditions exist:

- Underwater portions of the bridge are in serious or worse condition, as recorded by Item B.C.15 coded three or less.
- The channel or channel protection is in serious or worse condition, as recorded by Item B.C.09 and B.C.10 coded three or less.
- The observed scour condition is three or less, as recorded by Item B.C.11.

When the condition that causes the Underwater Inspection Condition Item B.C.15 to be coded a three or less is a localized deficiency, a special inspection can be used to meet the reduced underwater inspection frequency requirement. The special inspection should be limited to those underwater deficiencies causing the low rating. When a special inspection is performed to monitor an underwater defect, it does not replace the regularly scheduled underwater inspection for the bridge.

1.2.2.3 Extended Interval

While underwater components in poor condition can warrant a reduced inspection frequency, the inspection frequency can be extended when underwater elements and the channel are in good condition. The maximum inspection frequency can be extended up to 72 months when a bridge meets all the following criteria (23 CFR 650.311(b)(1)(iii)):

- The underwater portions of the bridge are in satisfactory condition or better, as recorded by NBI Item B.C.15 coded six or greater.
- The channel and channel protection are in satisfactory or better condition, as recorded by Items B.C.09 and B.C.10 coded six or greater.
- The bridge site is stable for potential scour and Scour Vulnerability Item B.AP.03 is coded A or B, and the Scour Condition Rating is a satisfactory condition or better with Item B.C.11 coded six or greater.

When a State transportation department, Federal agency, or Tribal government implements a program to extend the inspection interval as outlined above, the FHWA must be notified in writing in advance (23 CFR 650.311(b)(1)(iii) (B)). Factors to consider include the same items for a reduced frequency.

1.2.2.4 Inspection Interval Tolerance

While completing inspections before the inspection due date is acceptable, the NBIS requires inspections completed after the due date to be within the acceptable tolerance period. The interval tolerance period depends on the inspection interval established during the previous inspection:

- The acceptable tolerance for intervals of less than 24 months for the next inspection is up to two months after the month in which the inspection was due.
- The acceptable tolerance for intervals of 24 months or greater for the next inspection is up to three months after the month in which the inspection was due.

Exceptions to the inspection interval tolerance due to rare and unusual circumstances must be approved by FHWA in advance of the inspection due date, plus the tolerance guidelines outlined above (23 CFR 650.311(e)).

1.2.3 Supplemental Inspection Tools

Alternative tools are available to supplement the requirements of an underwater bridge inspection when diving operations are not feasible. Site conditions may make diving conditions unsafe or impractical. Examples of situations where divers may not be able to safely perform an inspection include:

- Flood conditions
- Heavy timber debris
- High flow velocity
- Hazardous environmental conditions

The two primary tools available to supplement an underwater inspection are acoustic imaging technology and ROVs.

1.2.3.1 Acoustic Imaging

Acoustic imaging technology uses sound waves that are transmitted from a sonar head and bounced off the bridge substructure element and surrounding channel bottom to create an image of the objects or conditions below the waterline. Figure 2 was created by combining an acoustic image of the below-water portion of a bridge pier with a photograph of the above-water portion. Smaller defects, such as narrow cracks, are generally not visible in acoustically generated images. Refer to Section 4.4.2 for more details on acoustic imaging.

Figure 2. Graphic. Combined acoustic 2D image of a bridge pier. (Source FHWA).

Acoustic imaging can be performed using 2D (single beam) or 3D (multi-beam) techniques. The advantage of the 3D technique is that volumes can be calculated from the results, which is helpful if scour countermeasures are being designed. See Figure 3 for an example of a 3D image of a bridge pier and the surrounding channel bottom. However, there are also disadvantages to using 3D imaging techniques. For instance, data collection while in motion requires continuous

GPS coverage, which can be lost when passing beneath a bridge superstructure or under heavy cloud coverage. Another disadvantage is the data can require significant post-processing effort.

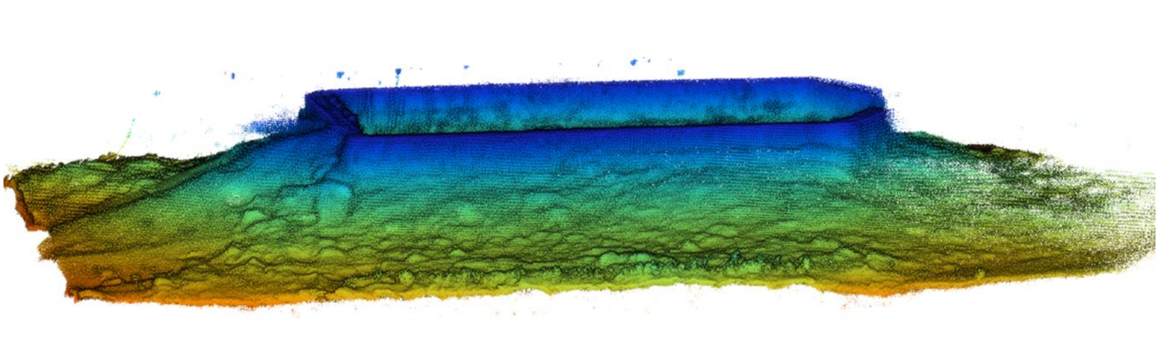


Figure 3. Graphic. 3D image of a bridge pier and the surrounding channel bottom.(Source FHWA).

1.2.3.2 ROV

Underwater inspections performed by an ROV (Figure 4) are generally limited to underwater conditions with very little flow or current, such as in lakes, reservoirs, and ocean environments. Using an ROV in most rivers is impractical due to the turbulence typically found around the bridge piers. Additionally, if inspecting substructure units at depths of 100 fsw or greater, ROV use can be a safe and cost-effective alternative when approved by the bridge owner.

Figure 4. Photo. Example of ROV system used for underwater bridge inspection. (Source FHWA).

When selecting an ROV to perform an underwater inspection, it is important to ensure it is capable of documenting in real-time direction and depth so the operator can maintain their orientation on the substructure. Larger ROVs can have mechanical arms capable of manipulating instruments or tools to measure deficiencies. Additionally, some ROVs have imaging capabilities when outfitted with sonar technology.

1.2.4 Diver Levels of Inspection

During the last 30 years, the underwater bridge inspection industry has harmonized inspection terminology related to the inspection level of effort. The U.S. Navy originally developed these descriptions to guide their worldwide underwater structure inspection program. The three inspection levels include the following:

Level 1: Visual and tactile inspection only requiring cleaning when a defect is found.
Level 2: Visual and tactile inspection with regular cleaning at a specified frequency.
Level 3: Highly detailed visual and tactile inspection of all surfaces with non-destructive testing (NDT) or partially destructive testing techniques and extensive cleaning of surfaces.

1.2.4.1 Level 1 Inspection

A Level 1 inspection includes visually examining all submerged portions of the bridge. It is typically adequate to detect obvious damage and compare the configuration to the as-built plans. In low visibility conditions, divers inspect all surfaces using a sweeping motion with their hands to perform a tactile inspection of all surfaces. Divers typically use lights, cameras, and various measuring devices to aid the inspection. The Level 1 inspection may reveal damage or deterioration that could require a more detailed Level 2 or Level 3 inspection.

The Level 1 inspection also includes probing the channel bottom around the substructures to identify bottom material type and measure scour and infilling. A steel rod, typically less than a ½-inch diameter, is generally adequate for probing into the channel bottom. Infill material is often smaller and less compact than the normal bed material. Generally, infill material allows for penetration with a probe rod more easily than the natural channel bottom. Probing the extent of the infill allows the inspector to determine the approximate limits of scour that occurred during previous high-flow events.

1.2.4.2 Level 2 Inspection

A Level 2 inspection requires cleaning all marine growth and other debris or silt from specific substructure areas. The purpose of this additional cleaning is to identify deficiencies that are not obvious when the Level 1 inspection is performed and to document the general condition of the surfaces when marine growth is removed.

Cleaning marine growth can be difficult in salt or brackish water, potentially requiring mechanical cleaning equipment in extreme situations. Alternatively, cleaning can be quite easy in freshwater, typically only needing the diver to wipe growth and sediment off with their hand.

For pile- and column-supported substructures, 10 percent of the total pile or column count should be selected for a Level 2 inspection. Refer to the example shown in Figure 5. When selecting piles/columns to clean, the team leader should target piles/columns that may be more easily damaged or subjected to faster rates of deterioration. For instance, the upstream piles on a pile bent in a river could be impacted by timber debris during a flood and more easily damaged.

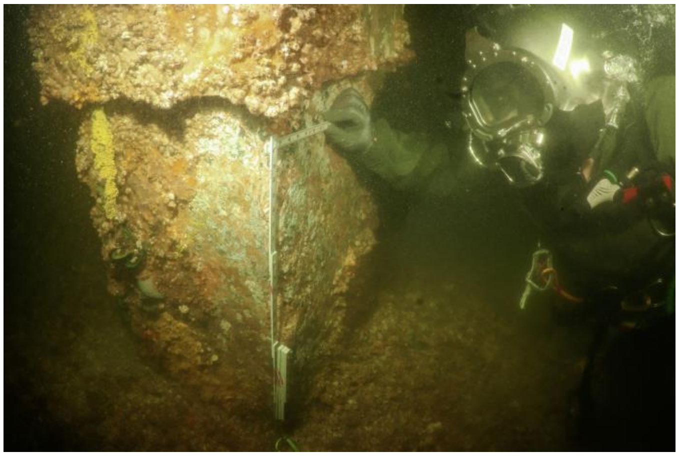


Figure 5. Photo. Level 2 inspection of a concrete pile at channel bottom. (Source FHWA).

The piles selected for Level 2 inspection should be cleaned at three locations: near the waterline, mid-depth, and near the channel bottom. An approximately 12-inch-high band should be cleaned at each location for a minimum of three-quarters (¾) of the pile perimeter. Refer to the drawing of a 10-pile bent in Figure 6 detailing the locations of a Level 2 inspection.

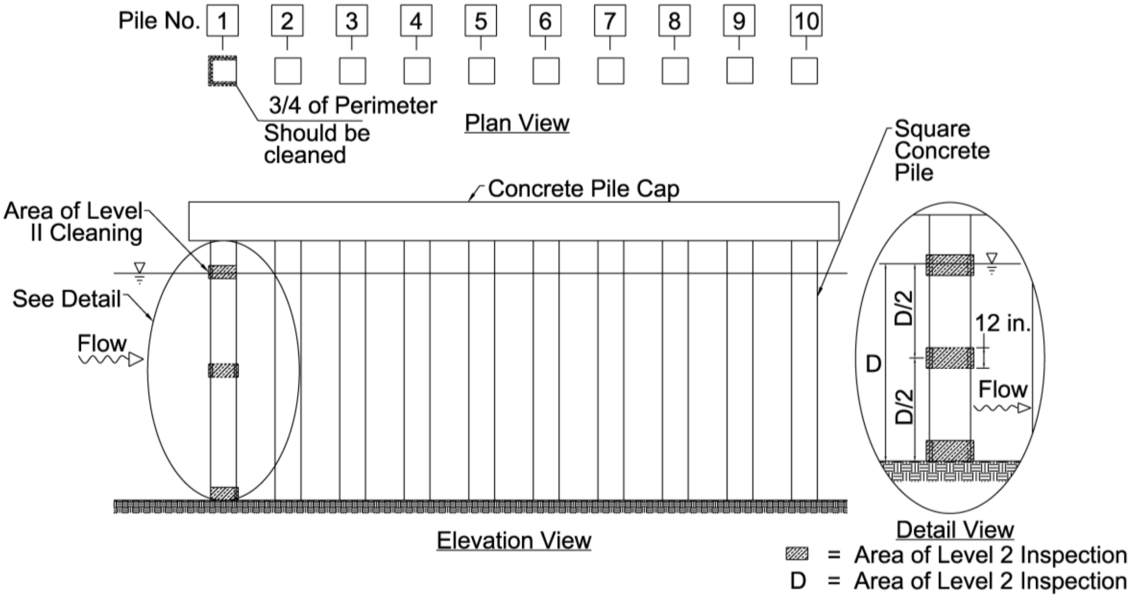


Figure 6. Sketch. 10-pile bent with upstream pile showing the location of Level 2 cleaning bands.

The Level 2 inspection of piers or abutments includes the cleaning of a 1-foot square area at three locations, typically one on each side and one on the nose of the substructure and at locations where defects are found. Refer to Figure 7 and Figure 8. As with a pile bent, the three locations to clean should be at the waterline, mid-depth, and near the channel bottom. The diver should also target locations where defects are common such as the upstream nose of a bridge pier.

Figure 7. Photo. Example of 1-sq-ft level 2 cleaning on a reinforced concrete (RC) pier wall. (Source FHWA).

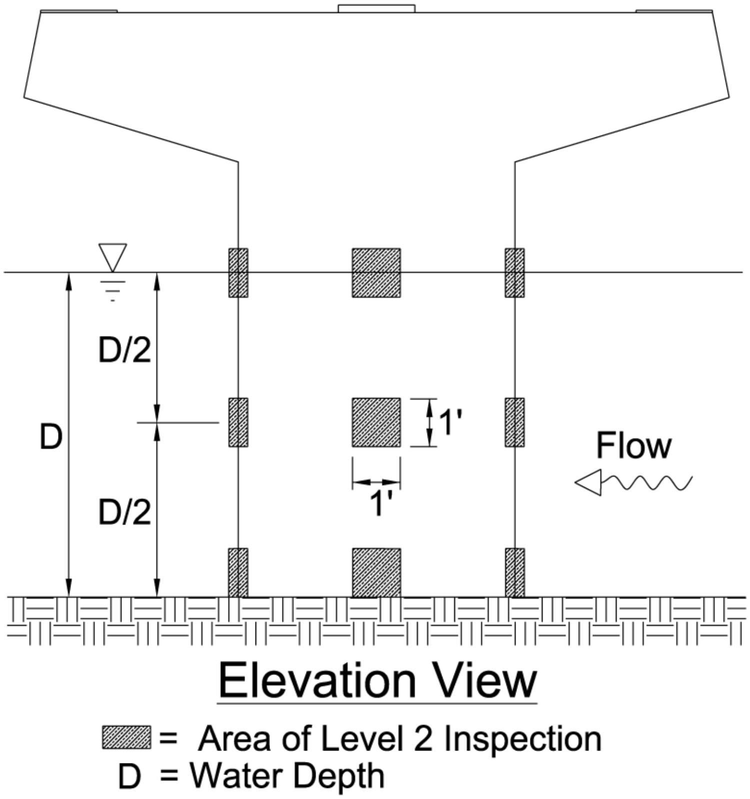


Figure 8. Illustration. Locations of Level 2 inspection areas on a bridge pier wall.

Level 2 inspections help to detect damaged and deteriorated areas underneath marine growth, silt, or rust scale and document general conditions. The diver should be careful not to damage any substructure coatings, if present, when cleaning the substructure.

1.2.4.3 Level 3 Inspection

The Level 3 inspection is the most in-depth form of inspection. It includes extensive cleaning beyond the cleaning discussed as part of the Level 2 inspection and specialized testing techniques to help identify and document deficiencies. These specialized testing techniques are inclusive of destructive and nondestructive methods. Some examples of specialized techniques, which are discussed in detail in Section 5.3, include:

- Ultrasonic thickness measuring of steel
- Cathodic protection gun potential readings of steel
- Magnetic particle testing of steel
- Ultrasonic pulse velocity measurements on concrete
- Rebound hammer testing of concrete
- Rebar locator testing of concrete
- Concrete coring
- Resistance drill measuring of timber
- Timber coring

1.3 PREPARING SCOPE OF WORK

1.3.1 General

The scope of work for routine underwater inspections should provide the information needed to perform the inspections effectively. The following items should be included:

- Owner contact information
- List of bridges
- Inspection due dates
- Estimated timeline
- Governing regulations:
    - NBIS
    - Occupational Safety and Health Administration (OSHA)
    - Agency regulations
    - Other
- References and manuals:
    - SNBI
    - Bridge Inspector’s Reference Manual (BIRM)
    - Underwater Inspection Manual
    - Manual for Bridge Evaluation (MBE)
    - Manual for Bridge Element Inspection (MBEI)
    - Other References (State or Federal)
- Insurance requirement
- Level of inspection required
- Data collection requirements (database used)
- Inspection report deliverable:
    - Format
    - Photos
    - Soundings
    - Drawings
- Critical finding reporting procedures
- Personnel requirements:
    - NBIS inspector qualifications
    - OSHA commercial diver qualifications
    - Agency-specific qualifications
    - Supporting documents needed
- Special equipment needs
- Emergency response criteria
- Other considerations:
    - Invoicing schedule, contract
    - Compensation type

1.3.2 Selection of Structures

Bridges that cannot be adequately inspected using wading and probing methods during a typical routine inspection typically have an underwater inspection. NBI Item B.IR.03 typically is coded Y to identify these bridges. If this item was previously reported as Y because an underwater inspection is generally required, it should continue to be reported as Y even if current low flow conditions do not require an underwater inspection. This applies if the low flow condition is genuinely unusual and is unlikely to reoccur during the next inspection interval. The reported code for this item may change in rare circumstances where long-term environmental conditions change inspection access to underwater portions of the bridge.

1.3.3 Underwater Inspection Plan

An underwater inspection plan is needed for each bridge requiring an underwater inspection. This plan identifies all elements to be inspected underwater and describes the procedures needed to execute the inspection. Underwater inspection plans are discussed in more detail in Section 5.1.2 of this manual.

1.3.4 Channel Bottom Soundings

Depth soundings should be taken during each underwater inspection. At a minimum, the channel profile on the upstream fascia of the bridge and depth readings around each substructure with submerged elements should be taken in enough detail to document the channel bottom accurately. The soundings should be compared with as-built conditions and previous inspection reports to assess scour over time. It is important to be consistent in how soundings are collected during each underwater inspection cycle to compare data over time. Figure 9 is an example of a bathymetric (hydrographic) survey around a bridge pier. The data can be collected using survey equipment or manually taking depth measurements at regular intervals across the waterway at a specified distance upstream and downstream from the bridge. Manual measurements are less accurate than data collected with survey equipment.

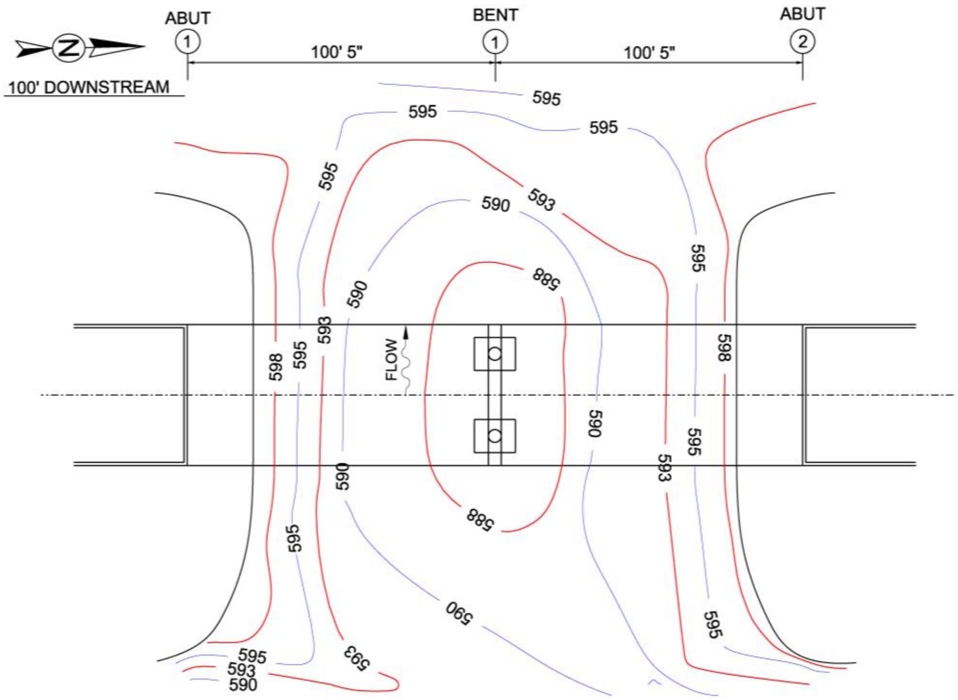


Figure 9. Illustration. Bathymetric survey around a bridge pier.

Figure 10 illustrates a simple channel cross-section with the sounding data plotted to represent the channel profile below each bridge fascia. Data can be collected on one or both facias of the bridge using a weighted reel measuring tape or electronic means.

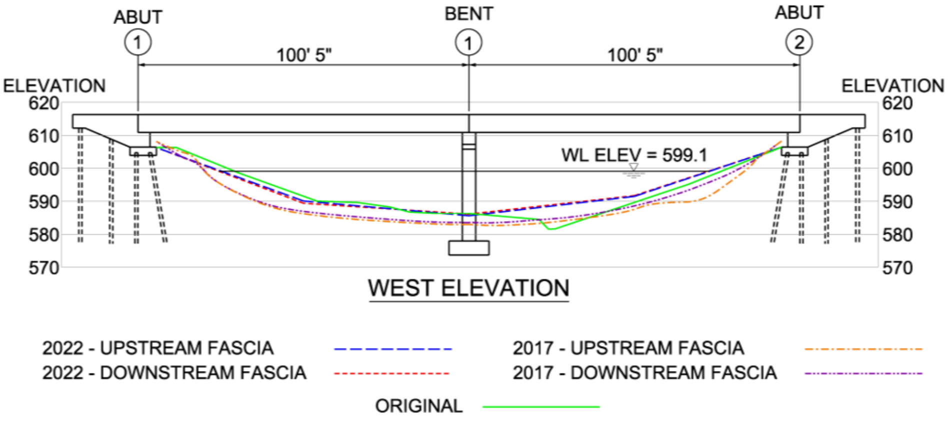


Figure 10. Illustration. Simple cross-section on bridge fascia.

1.3.5 Scheduling Considerations

Underwater inspections are most efficiently scheduled during normal seasonal low water. For most rivers, this is typically summer to fall time frame. The U.S. Army Corps of Engineers (USACE) and U.S. Geological Survey (USGS) publish historical hydrographs, which can be used to plan the underwater inspection schedule. When planning a schedule, the weather should also be considered. Conducting diving operations in cold weather can significantly reduce efficiency and increase the cost of an underwater inspection. The quality of data collection can also be adversely impacted in cold weather.

There may be external constraints that impact an inspection schedule as well. For instance, local regulations may limit diving operations during fish spawning season, or boat traffic during the summer may make diving operations impractical during certain times of the year. Bridge owners should consider local schedule constraints to minimize disruption during the inspection.

Due to the substantial number of bridges over water and the NBIS inspection interval requirements (Section 1.2.2), there may be instances when inspection due dates occur during unfavorable environmental conditions or other constraints. However, the NBIS allows for inspections to be completed before the inspection due date. When the inspection is completed early, the due date is reset, and the inspection interval is based on the adjusted inspection date.

1.3.6 Reporting and Documentation

Bridge owners typically use a bridge management system or database to collect and maintain bridge condition information and report NBI data to the FHWA. Many State departments of transportation (DOTs) use a proprietary interface to gather data in the field using a laptop or tablet, which then synchronizes with the bridge management system or database and can generate hard copy reports if required. All bridge owners must report their data to the FHWA through a formal process, often in coordination with the State DOT (23 CFR 650.315 (a)).

The items listed below are examples of information included in an underwater inspection report:

- Bridge location and description
- Description of site conditions
- Component condition ratings
- Element condition states
- Deficiency descriptions and photos
- Repair recommendations
- Critical findings (if any)
- Channel cross-section information
- Underwater inspection plan

Other report items that could be considered:

- Drawings of substructures with defects
- Acoustic imaging (if used)
- Expanded channel information
- Additional photos or video
- Dive plan
- Risk assessment
- Cost estimates for repair
- Load rating calculations
- Personnel certifications/credentials

Underwater inspection reports are submitted to the owner for approval. Submittals can be hard copy or electronic, depending on the owner’s process. The inspection report should be signed by the inspection team leader and may require a professional engineer’s seal.

1.3.7 Underwater Bridge Inspection Diver and Team Leader Qualifications

Divers and team leaders must have minimum qualifications as required by the NBIS (23 CFR 650.309(e)). These qualifications include both diver and inspector training. The minimum requirements are discussed in detail in Chapter 2. The Underwater Inspection Team of this manual.

1.3.8 Insurance

There are some additional insurances that are typically needed for working in the underwater arena. The following highlights these additional insurances that may be needed.

Longshoreman and Harbor Workers' Insurance

The US Longshoreman & Harbor Workers' Act (LHWCA) is supplemental insurance that is used to provided additional workers' compensation for employees working on navigable US waterways. Navigable waterways include any body of water that can support commercial boat traffic.

Jones Act Maritime Insurance

The Jones Act is LHWCA, except it provides coverage for the crews of vessels. Many companies obtain Marine Employers Liability insurance to comply with the Jones Act and is typically under a separate policy.

1.4 DIVER REGULATIONS AND TRAINING

1.4.1 Diving Regulations

Most bridge inspection diving operations are governed by Federal OSHA regulations, 29 CFR Part 1910, Subpart T-Commercial Diving Operations, with applicable updates and directives. Federal OSHA governs commercial diving operations for private-sector employees in States under Federal OSHA enforcement authority. Some States have their own OSHA that governs diving within that State.

Generally, States have promulgated a commercial diving safety standard either identical to 29 CFR Part 1910, Subpart T, or at least as effective as the OSHA standard. The states of California, Michigan, Oregon, and Washington have state diving safety standards that differ from OSHA's. Federal OSHA does not have authority over state and local government employees.

The latest changes to the standard and directives related to the standard may be found at www.OSHA.gov.

1.4.2 Diver Training

Federal OSHA considers a diver to meet the training standard necessary to perform as a commercial diver if they provide documentation meeting any of the methods described below and listed in OSHA Directive Number CPL 02-00-151, 29 CFR Part 1910, Subpart T – Commercial Diving Operations:

- Diver training to the appropriate level (such as a surface-supplied air diver certificate or a surface-supplied mixed-gas diver certificate) at a commercial (private), military, or other Federal (such as the USACE) diving school.
- A graduation certificate from a school accredited by the Association of Commercial Diving Educators (ACDE).
- Documented evidence showing they meet the training requirements specified by the national consensus standard published by the American National Standards Institute (ANSI) ANSI/ACDE-01-2009, American National Standard for Divers-Commercial Diver Training – Minimum Standard.
- A diver has a valid commercial diver certification card issued by the Association of Diving Contractors International (ADCI) indicating the appropriate training level.

1.5 DIVING CONSIDERATION

Underwater bridge inspection has several specialty diving considerations. This section outlines some of the special considerations that underwater bridge inspection divers should consider.

1.5.1 Flying After Diving

When flying after diving, the ascent to altitude increases the risk of decompression sickness (DCS) because of the additional reduction in atmospheric pressure. The higher the altitude, the greater the risk.

Cruising cabin pressure in commercial aircraft is usually maintained at a constant value regardless of the actual altitude of the flight. The equivalent effective cabin altitude generally ranges from 6,000 to 8,000 feet, though it varies somewhat by aircraft type. Therefore, divers typically wait as long as 24 hours after diving before they can fly.

1.5.2 Altitude Diving

Bridges over water can be found in many places with altitudes that are higher than sea level. At these higher altitudes, there is reduced atmospheric pressure. Therefore, dives conducted at altitude require more decompression than identical dives at sea level. The normal air decompression tables, therefore, cannot be used as written. Divers typically adjust for any dives more than 1,000 feet in elevation.

1.5.3 Contaminated Waterways

Several of the waterways in the United States are considered contaminated. The contamination may be naturally occurring or come from a variety of sources, including industrial discharge or sewer effluent. When contaminants are suspected at the bridge site, testing of the water type typically is conducted prior to the commencement of diving operations to identify any possible hazardous materials in the water. Special diving operations and disinfection procedures are typically used when diving in contaminated waterways.

1.6 QUALITY CONTROL AND QUALITY ASSURANCE

1.6.1 General

Accurate bridge data reporting for inclusion in the NBI is a principal element of a successful bridge management program. Quality assurance (QA) and quality control (QC) are critical to meet this objective. The bridge owner establishes the expectations regarding their deliverables and monitors compliance by the bridge inspection organization. QC and QA reviews must be performed by personnel other than the individual who completed the original report or calculations (23 CFR 650.313(p)(2)).

1.6.2 Quality Assurance

QA includes policies and procedures implemented by the inspection organization to prevent errors in the inspection process. This methodology includes broad agency and company policies and specific adherence to NBIS requirements. Items typically included in a QA plan include:

- Maintaining NBIS inspector training and education documentation
- Publishing a safe diving practices manual
- Conducting periodic audits on diving operations
- Calibrating testing equipment regularly
- Maintaining diving physical records
- Conducting regularly scheduled OSHA safety training

1.6.3 Quality Control

QC is a subset of QA. It is a set of procedures intended to ensure that a bridge inspection report is accurate and meets a set of quality criteria. It typically includes a series of independent checks performed at various stages of the inspection and reporting process to ensure quality standards are met. The following procedures are examples of QC checks that can be performed on an underwater inspection report:

- Equipment loadout checklist
- Onsite checklist to ensure all data is collected
- Dive safety checklist
- Report completion checklist to track each QC check of a report

CHAPTER 2. THE UNDERWATER INSPECTION TEAM

2.1 INTRODUCTION

This section describes the FHWA requirements of the underwater inspection dive team per the FHWA 23 CFR Part 650 NBIS. Diver training requirements for bridge inspectors are described in the OSHA 29 CFR Part 1910, Subpart T – Commercial Diving Operations.

2.1.1 General

The underwater inspection team is composed of individuals that meet the bridge inspection team member qualifications specified by the NBIS. The underwater inspection team leader is often a qualified commercial diver and can serve in dual roles on the inspection team. For example, if the team leader is a commercial diver and qualified by training and experience, they may serve as the designated person in charge, or diving supervisor, of the dive team. When the inspection team leader is not a commercial diver, the dive team must be fully staffed to levels required by OSHA and the complexity of the diving environment, which is in addition to the inspection team leader (29 CFR 1910.410).

2.1.2 Team Leader

The NBIS requires that at least one team leader is on-site during an underwater bridge inspection. To qualify as a team leader, an individual must complete an FHWA-approved comprehensive bridge inspection training course as outlined in 23 CFR 650.313(j) and meet one of the four qualification criteria listed below:

- Be a registered professional engineer and have six months of bridge inspection experience.
- Have five years of bridge inspection experience.
- Have all of the following:
    - A Bachelor’s degree in engineering or engineering technology from a college or university accredited by or determined as substantially equivalent by the Accreditation Board for Engineering and Technology; and
    - Successfully passed the National Council of Examiners for Engineering and Surveying Fundamentals of Engineering examination; and
    - Have two years of bridge inspection experience.
- Have all the following:
    - An associate degree in engineering or engineering technology from a college or university accredited by or determined as substantially equivalent by the Accreditation Board for Engineering and Technology; and
    - Have four years of bridge inspection experience.

Additionally, the team leader must complete a cumulative total of 18 hours of FHWA-approved bridge inspector refresher training during each subsequent 60-month period after completing the initial comprehensive course (23 CFR 650.309(b)(3)).

2.1.3 Underwater Inspectors

The underwater bridge inspection diver should be a trained commercial diver as required by OSHA and have successfully completed an FHWA-approved underwater bridge inspection course in accordance with 23 CFR 650.309(e). Divers who completed an FHWA-approved comprehensive bridge inspection or underwater bridge inspection course in accordance with FHWA regulations prior to June 6, 2022, also qualify as an underwater inspector under the current NBIS.

The underwater inspector must have the education, knowledge, and ability to recognize structural deteriorations and site conditions detrimental to the structure encountered underwater. Additionally, they need to effectively communicate the inspection findings to topside personnel, which requires technical competence and the use of proper terminology commensurate with the degree of inspection.

2.1.4 Additional Considerations

Underwater conditions vary by site location, which requires the diver to navigate various hazards adeptly. Potential hazards the diver might encounter are swift-moving water, low visibility or dark water, polluted water, marine traffic, floating and submerged timber debris, and construction debris. The diver should have the appropriate diving knowledge and skills to access the structure safely and conduct a thorough and accurate inspection.

2.2 PLANNING UNDERWATER BRIDGE INSPECTION OPERATIONS

The designated person-in-charge, or diving supervisor, is responsible for planning the dive; conducting the inspection (including the pre- and post-dive briefing); and tracking and recording the dive information for the diver(s). The inspection team leader is responsible for documenting and reporting the bridge inspection results. As previously discussed, it is common for one person to serve on an underwater inspection team in both capacities.

Forms and checklists can be used to ensure a systematic approach to planning. A multi-page example of such a form is included in Appendix B. Sample Field Book. In addition, Section 5.1 of this manual provides a detailed discussion of planning for an underwater bridge inspection.

CHAPTER 3. MATERIALS AND UNDERWATER STRUCTURAL DEFECTS

3.1 INTRODUCTION

Accurate identification and documentation of structural components and their defects are critical to ensure a successful underwater bridge inspection. Typically, material defects on bridge substructures occur at or near the waterline. Material defects are commonly caused by mechanical damage due to vessel or debris impact or material deterioration resulting from environmental factors.

Scour around bridge foundations is a significant cause of bridge failures nationwide. Scour may go undetected without proper monitoring and documentation. Documenting scour conditions is an important part of an underwater bridge inspection. Bridge scour is discussed in detail in Chapter 6. Scour And Channel Inspections of this manual.

3.2 SUBSTRUCTURE MATERIALS

The SNBI identifies the material used to construct a bridge's substructure in Item B.SB.03, Substructure Material. Common materials used for submerged substructures are listed below:

- Concrete
- Steel
- Masonry
- Timber
- Composites

Some substructures use a combination of two or more materials, such as a pile bent constructed with a concrete cap and steel H-piles. Also, substructure types may vary on a single bridge as well. An example would be a bridge with approach spans supported by precast concrete pile bents and RC piers supporting the channel piers. When multiple material types are present, the most common type is coded in Item B.SB.03 of the bridge record.

Each material has different mechanical and physical properties that impact strength and how they react to the environment. Underwater bridge inspectors should understand the basic characteristics of commonly used substructure materials to complete a thorough inspection.

3.2.1 Concrete

Concrete is the most common material used to construct bridge substructures. Concrete has high compressive strength but relatively low tensile strength. The compressive strength of concrete commonly used in bridges varies from 3,000 to 11,000 pounds per square inch. Reinforcing or prestressing steel is added to the concrete to provide tensile strength.

The SNBI lists six types of concrete elements that can be used for a bridge substructure. This is the code that is placed in Item B.SB.03, Substructure Material, in the bridge record:

- C01 RC – cast-in-place
- C02 RC – precast
- C03 Prestressed concrete – pre-tensioned
- C04 Prestressed concrete – cast-in-place post-tensioned
- C05 Prestressed concrete – precast post-tensioned
- CX Concrete – other

Most concrete bridge substructures are built using reinforced or prestressed concrete. Code C01 is used for cased and uncased cast-in-place concrete piles, and for driven corrugated, fluted, or spiral-welded shell-cased concrete piles.

Plain concrete substructures lacking reinforcing steel are uncommon but may be found on very old bridges. Substructures of plain concrete are coded as CX.

3.2.1.1 Reinforced Concrete

Reinforced concrete is coded in Item B.SB.03 in the bridge record as C01 for cast-in-place concrete or C02 for precast concrete. Reinforced concrete contains steel reinforcement bars to increase tensile strength, making it an ideal material for structural bridge elements. Reinforced concrete is commonly used in the following types of substructure elements:

- Bent and pier caps
- Piles
- Columns
- Pier walls
- Drilled shafts
- Pile cap footings
- Spread footings

Cast-in-place concrete is constructed on-site by placing formwork and reinforcement per the specifications in the design plans (Figure 11). The materials used to construct formwork are typically timber planks, plywood, steel pipe, or steel sheets. Precast concrete is generally made offsite and then assembled at the bridge site.

Figure 11. Photo. Construction of a cast-in-place bridge substructure. (Source FHWA).

3.2.1.2 Prestressed Concrete

Prestressed concrete (PSC), coded in Item B.SB.03 in the bridge record as C03 for pre-tensioned, C04 for cast-in-place post-tensioned, or C05 for precast post-tensioned, uses high tensile strength steel strands to induce internal compressive forces within the concrete member. These internal forces help counterbalance the tensile forces produced when an external load is applied to the member.

Pre-tensioning is the most common method used for superstructure members but is less common for substructure elements. Prestressed concrete piles are an example of a pre-tensioned concrete bridge element used in substructure construction (Figure 12). PSC and RC piles can be difficult to differentiate in the field when bridge plans are not available, but the age of the bridge, unbraced pile length, and other factors can help determine the correct pile type in the absence of plans.

Post-tensioning and combination methods are commonly used when constructing superstructure elements like beams but are seldom used for substructures.

Figure 12. Photo. Example of a PSC pile. (Source FHWA).

3.2.2 Steel

Steel is widely used for bridge substructures due to its high strength, ductility, and versatility. As previously discussed, steel is also a major component of concrete bridge elements to provide tensile strength.

Steel reinforcing bars, commonly referred to as rebar, are circular with raised ribs on the surface to provide good bonding with the concrete (Figure 13). Before 1947 rebar specifications varied and square rebar was commonly used with or without raised ribs on the surface.

Steel prestressing strands consist of multiple wires helically wrapped around a single center wire. Multiple strands are typically placed around the perimeter of a member.

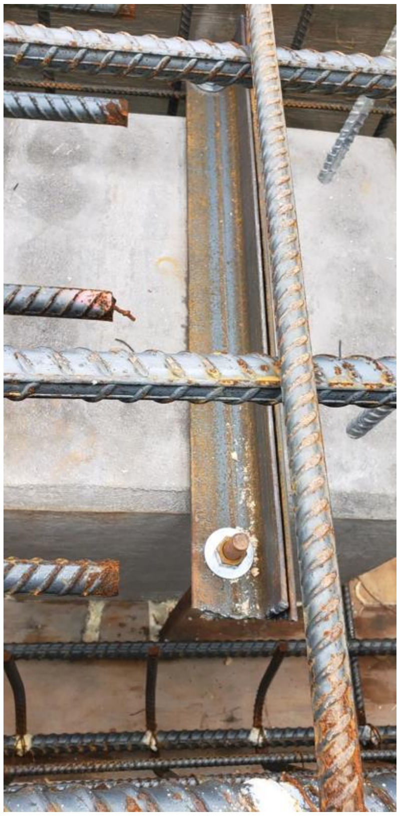


Figure 13. Photo. Example of a modern reinforcing bar. (Source FHWA).

When a bridge member is entirely comprised of steel, the SNBI lists seven types of steel shapes that are used to code Item B.SB.03 in the bridge record. Steel rolled shapes and pipe piles are the most common application for submerged substructures:

- S01 Steel – rolled shapes
- S02 Steel – welded shapes
- S03 Steel – bolted shapes
- S04 Steel – riveted shapes
- S05 Steel – bolted and riveted shapes
- S06 Steel – pipe (hollow or concrete filled)
- SX Steel – other

Rolled steel shapes, coded as S01, refer to structural steel that is pressed into a desired shape by placing bulk structural steel through a series of rollers. Rolled shapes, such as H-piles, are the dominant steel type used to create submerged substructure members, as shown in Figure 14 and Figure 15. Steel sheet piles are used as stay-in-place forms for pier foundations or abutments.

Figure 14. Graphic. Bridge pier supported by steel H-piles. (Source FHWA).

Figure 15. Photo. Example of a steel H-pile bent. (Source FHWA).

Built-up shapes, coded as S02, S03, S04, or S05, refer to a steel member consisting of multiple rolled shapes riveted, bolted, or welded together to form the desired shape. These types of shapes are not commonly used on submerged substructure elements because the crevices make them more susceptible to corrosion.

Similar to the rolled steel shapes, steel pipe piles, coded as S06, are commonly used in bridge substructure elements. They can be hollow or concrete filled. However, if the steel casing serves as a form for a reinforced concrete pile, the element should be coded as a concrete pile, as discussed in Section 3.2.1. Figure 16 illustrates the use of steel pipe piles on an intermediate pile bent.

Figure 16. Photo. Example of steel pipe piles. (Source FHWA).

3.2.3 Masonry

Masonry was commonly used to construct bridge substructures prior to 1930 (Figure 17). In modern construction, masonry is generally used only as an ornamental facing. SNBI Item B.SB.03, Substructure Material, is coded as M01 for masonry made from bricks or concrete blocks, and it is coded as M02 if it is made from natural stone such as granite, limestone, or sandstone. Mortar is the binding agent that secures the stone or blocks together and is primarily composed of sand, cement, lime, and water.

Figure 17. Photo. Example of a masonry bridge pier. (Source FHWA).

3.2.4 Timber

Several different types of timber materials are used in the construction of bridge substructures. The structural capacities of timber vary depending on properties such as tree species, age, grading, and shape. The codes below are placed in Item B.SB.03, substructure material, based on the type of timber used for the substructure:

- T01 Timber – glue laminated
- T02 Timber – nail laminated
- T03 Timber – solid sawn
- T04 Timber – stress laminated
- TX Timber – other

Piles and solid-sawn timber members are the most common timber substructure elements encountered by an underwater inspector. Timber piles may be untreated or pressure treated with preservatives. The use of preservatives, such as creosote, creosote-coal tar, and arsenate solutions have a commercial history dating back to the mid-1800s. Timber piles generally have butt diameters in the range of 10 to 18 inches and maximum lengths of about 40 to 50 feet.

Timber pile bents are the most common application of timber in bridge substructures. Solid-sawn timber members are used as bracing members as part of a timber pile bent. Item B.SB.03 is coded as T03 for timber pile bents (Figure 18). However, if the timber bent has a concrete cap, the substructure material type is coded as reinforced concrete (Figure 19).

Figure 18. Photo. Example of timber pile bent, coded as T03. (Source FHWA).

Figure 19. Photo. Timber pile bent with RC cap. (Source FHWA).

Timber piles may also be used as foundation piles to support concrete footings. In the past, when timber foundation piles were designed to be installed below grade, untreated timber piles were often used. These untreated timber piles can become exposed due to scour. On rare occasions, untreated timber piles may still have their bark in place on very old bridges.

3.2.5 FRP Composites

Fiber reinforced polymer (FRP) composites have gained popularity recently as a material for bridge construction. The type of fiber material used for reinforcement can vary. The codes below apply to Item B.SB.03, Substructure Material, based on the type of fiber used in the composite material:

- F01 FRP composite – aramid fiber
- F02 FRP composite – carbon fiber
- F03 FRP composite – glass fiber
- FX FRP composite – other

While FRP material use in bridges is becoming more prevalent, currently, it is primarily used for substructure protective structures such as fender systems and dolphins. Refer to Figure 20 for an example of an FRP fender system with FRP material used for the piles and wales. FRP materials also have bridge repair applications, which is discussed more in the *Underwater Bridge Repair, Rehabilitation, and Countermeasures Reference Manual*.

Figure 20. Photo. FRP bridge fender system. (Source FHWA).

3.3 DETERIORATION OF STRUCTURAL MATERIALS

Structural materials deteriorate at different rates depending on several variables. An inspector should be proficient in identifying and reporting the extent and severity of deterioration of all accessible substructure elements. Deterioration of structural materials is reported to the FHWA as element-level bridge inspection data. Element level bridge inspection data is a quantitative condition assessment collected during bridge inspections that indicates the severity and extent of defects in bridge elements (23 CFR 650.305). Each inspected element is assigned a condition state (CS) ranging from one to four. Refer to Table 2 for a general description of each condition state. For element defect and condition state definitions, refer to the SNBI (Section 7.3), which further references the AASHTO MBEI, 2nd Edition, 2019.

Table 2. General description of element level conditions states.

Condition State	General Condition Description
One (CS1)	Good
Two (CS2)	Fair
Three (CS3)	Poor
Four (CS4)	Severe

Inspectors need to be able to identify not only the various types of deficiencies but also the causes of the deficiencies and how to examine them. The following subsections detail the main types of deterioration for each of the material types in Section 3.2.

3.3.1 Concrete

An underwater bridge inspector should be able to recognize the various modes of deterioration associated with concrete. Inspectors should also understand the causes of each deficiency to help identify the contributing factors or underlying issues. Below is a list of deficiencies commonly observed on concrete structures:

- Cracking (structural and non-structural)
- Scaling and abrasion
- Delamination
- Spalling
- Chloride contamination
- Freeze-thaw
- Efflorescence
- Alkali-silica reactivity (ASR)
- Ettringite formation
- Honeycombing
- Pop-outs
- Impact damage
- Overload damage
- Internal steel corrosion
- Loss of prestress
- Carbonation
- Construction defects

The BIRM discusses these deficiencies in detail. This manual focuses on the most anticipated modes of concrete deterioration for submerged bridge elements. The four types of deterioration most commonly observed on concrete substructures are: cracking, scaling, spalling, and chemical attack. Concrete structures are also subject to damage from external forces such as impact and abrasion.

3.3.1.1 Cracking

Concrete cracking is common in concrete structures and can be structural or non-structural. Nonstructural cracks form due to internal stresses resulting from temperature or moisture content changes.

Even when the cracks themselves are not structurally significant, they may be early indicators of more serious deterioration and can lead to accelerated deterioration by providing a pathway for water and deleterious substances to enter the concrete. Due to concrete having little to no tensile strength, non-structural cracks usually result from volumetric changes caused by temperature variances as the concrete expands and contracts (Figure 21). Cracks can also indicate an overload event, corrosion of the underlying reinforcement, or settlement of the substructure unit.

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

Cracking can also occur during the fabrication or installation of precast concrete members. Overdriving, for example, can cause cracking of concrete piles often hidden below water as shown in (Figure 22).

Figure 21. Photo. Shrinkage cracks on RC pier wall. (Source FHWA).

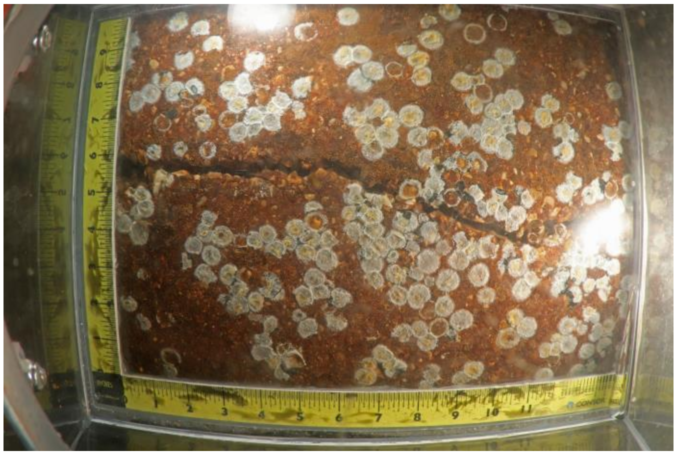


Figure 22. Photo. Cracking in precast concrete pile due to overdriving during installation. (Source FHWA).

Table 3 provides descriptions used to rate the condition state of cracks based on various characteristics. There are different ratings for reinforced concrete and prestressed concrete, as shown in the table.

Table 3. Condition state descriptions for concrete element cracking defects from the AASHTO MBEI as referenced by the SNBI (Section 7.2).

Defects[1]	**CS 1**	**CS 2**	**CS 3**	**CS 4**
	GOOD	**FAIR**	**POOR**	**SEVERE**
Cracking (RC or Other) (1130)	Insignificant cracks or moderate-width cracks that have been sealed. *Widths less than 0.012 inch.*	Unsealed moderate width cracks or unsealed moderate pattern (map) cracking. *Widths 0.012 – 0.05 inch.*	Wide cracks or heavy pattern (map) cracking. *Widths greater than 0.05 inch.*	The condition warrants a structural review to determine the effect on the strength or serviceability of the element or bridge; OR a structural review has been completed, and the defects impact strength or serviceability of the element or bridge.
Cracking (PSC) (1110)	Insignificant cracks or moderate-width cracks that have been sealed. *Widths less than 0.004 inch or spacing greater than 3 ft.*	Unsealed moderate width cracks or unsealed moderate pattern (map) cracking. *Widths 0.004 – 0.009 inch or spacing 1.0 to 3.0 ft.*	Wide cracks or heavy pattern (map) cracking. *Widths greater than 0.009 inch or spacing less than 1 ft.*	

Inspectors should use judgment when utilizing the condition state definitions, especially for concrete cracking (MBEI, 3.2.1.3). The defect description definitions in Table 3 describe generalized distress, but several factors should be considered when evaluating cracks or other defects. Factors such as width, spacing, location, orientation, and structural or nonstructural nature of cracks should all be considered when applying defect condition states.

A measuring device, such as a crack comparator, should be used when collecting crack width measurements. Additionally, erosion along the surface of a crack can result in the collection of exaggerated crack width measurements. The actual crack width does not include the width of surface erosion (Figure 23).

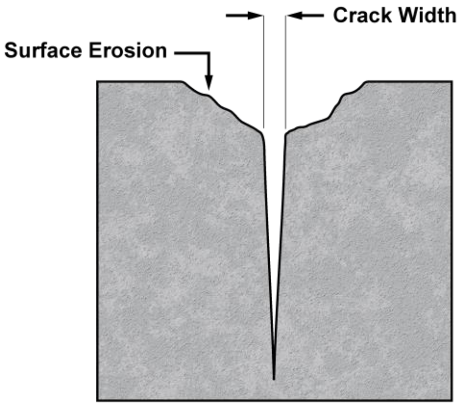


Figure 23. Illustration. Crack width measurement.

3.3.1.2 Scaling and Abrasion

Scaling is the gradual disintegration of a concrete surface due to the failure of the cement paste caused by chemical attack or freeze-thaw cycles. Abrasion can appear similar to scaling but is caused by water flowing over concrete or a mechanical mechanism. The same element defect is used to document this condition.

Scaling is commonly found near the waterline on piers and bents (Figure 24). The most common form of scaling is caused by freeze-thaw action and 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.

Figure 24. Photo. Scaling of concrete pier at waterline. (Source FHWA).

When reporting scaling, the inspector should note the location of the defect in relation to a fixed point, the size of the area, and the depth of penetration of the defect. A standard format and nomenclature should be used consistently to avoid confusion in reporting defects. Location should be reported by horizontal distance from a known point and vertical distance from a fixed elevation on the substructure unit (this distance is often referenced to the waterline, which is then tied to a fixed elevation on the bridge that does not change). The extent of the defect should be reported as height by width by depth; with height referring to vertical distance, width referring to horizontal distance, and depth referring to the distance the defect penetrates the member.

Table 4 provides descriptions that are used to rate the condition state of abrasion or scaling based on various characteristics.

Table 4. Condition state description for concrete element abrasion/wear defect from the AASHTO MBEI as referenced by the SNBI (Section 7.2).

Defect	**CS 1**	**CS 2**	**CS 3**	**CS 4**
	GOOD	**FAIR**	**POOR**	**SEVERE**
Abrasion/Wear (PSC/RC) (1190)	No abrasion or wear.	Abrasion or wearing has exposed coarse aggregate but the aggregate remains secure in the concrete.	Coarse aggregate is loose or has popped out of the concrete matrix due to abrasion or wear.	The condition warrants a structural review to determine the effect on the strength or serviceability of the element or bridge; OR a structural review has been completed, and the defects impact strength or serviceability of the element or bridge.

3.3.1.3 Spalling

Spalling is a depression in the surface of concrete caused by impact or internal tension stresses when the reinforcing steel corrodes, as shown in Figure 25. Reinforcing steel begins to corrode when water has a pathway into the concrete or when chloride ion concentration reaches a high level at the reinforcing steel. When steel corrodes, the products of corrosion occupy up to five times the volume of the parent material and can produce forces of more than 5,000 psi. These expansive forces crack the concrete and “pop-off” areas on the concrete exposing the underlying reinforcing steel to the environment. Once exposed, the process accelerates, resulting in large areas of spalling.

The environment at the waterline of bridges is especially conducive to spalling. Constant abrasion and wet-dry cycles can provide the initial paths for moisture and oxygen to reach the underlying reinforcing. Saltwater 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, enlarging cracks, and accelerating the spalling process.

Figure 25. Photo. Surface spall with exposed and corroded reinforcing steel. (Source FHWA).

The spalling process can sometimes occur over a large area but hidden by the surface concrete. Internal fracture planes develop below the surface of the concrete, forming areas known as closed spalls or delaminations. These areas are generally detected by the hollow sound produced by striking the surface with an inspection hammer, also referred to as sounding.

Reinforcing steel placed with insufficient cover can accelerate corrosion and subsequent deterioration. Additionally, it is not uncommon to find pieces of reinforcing steel and tie wires protruding from concrete structures below water. Steel rods used to tie formwork together on piers, steel beams used to brace cofferdams, and wire rope lifting loops on concrete piles are also typically found below water. Over time, this steel can also corrode causing surface spalling.

When inspecting concrete substructure units, the diver should look for visual signs of spalling near the waterline and in the splash zone (Figure 26). These areas should also be sounded with a hammer to determine if there is delamination due to fracture planes hidden below the surface. Particular attention should be paid to intermittently wet and dry areas, tidal zones, etc., and areas adjacent to construction accessories noted below the water surface.

Figure 26. Photo. Spall in splash zone. (Source FHWA).

When reporting spalls, the inspector should note the location, dimensions, and whether there is exposed reinforcement. The location of a spall should specify the affected face, quadrant, or nose of the element, along with horizontal and vertical distances from clear reference points. For example, the location of a spall on a pier wall could be described as “east face, 36 inches below the cap, 3 ft. from the upstream nose.” The dimensions of a spall are recorded as height, width or length, and depth.

Table 5 below provides descriptions used to rate the condition state of spalls based on various characteristics.

Table 5. Condition state descriptions for concrete element delamination, spall, and patched area defects from the AASHTO MBEI as referenced by the SNBI (Section 7.2).

Defect	**CS 1**	**CS 2**	**CS 3**	**CS 4**
	GOOD	**FAIR**	**POOR**	**SEVERE**
Delamination/ Spall/Patched Area (1080)	None	Delaminated or spall 1 inch or less deep or 6 inch or less in diameter. Patched area that is sound.	Spall greater than 1 inch deep or greater than 6-inch diameter. Patched area that is unsound or showing distress. Does not warrant structural review.	The condition warrants a structural review to determine the effect on the strength or serviceability of the element or bridge; OR a structural review has been completed, and the defects impact strength or serviceability of the element or bridge.
Exposed Rebar (1090)	None	Present without measurable section loss.	Present with measurable section loss but does not warrant structural review.	

3.3.1.4 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, surrounding 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.

Chlorides may also enter concrete from salt water, deicing agents, or admixtures. Chlorides make water a better electrolyte, accelerating the spalling process. Chlorides migrate through the concrete over time and ultimately reach the reinforcing steel, which then begins to corrode.

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 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 27).

Figure 27. Photo. Example of ASR. (Source FHWA).

Sulfates are present in seawater and are common in ground waters, especially where there are high proportions of certain clays present. Sulfates react with tri-calcium aluminate to form ettringite, which swells and causes cracks. Sulfates also react with calcium hydroxide to form gypsum. Sulfate attack is usually detected as a softening of the surface of the concrete. With further deterioration, the surface erodes as material is easily chipped away. The newly exposed surface is often white in color. Structures in seawater can suffer sulfate attacks in the tidal zone.

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.

3.3.2 Steel

Steel is a common material used in bridge construction. Pile bents are often constructed using H-piles or pipe piles, while footings can have steel piles providing load transfer to bearing soils or bedrock. Steel sheet piles are often used for retaining walls at bridge sites, and in certain instances, can be designed to carry bridge loads as a part of the foundation. Common deficiencies found during an underwater inspection include:

- Coating failure
- Corrosion
- Overload damage
- Impact damage

3.3.2.1 Coating Failure

Coatings are the first line of defense to prevent steel corrosion. Coatings are typically applied to all exposed surfaces of a steel member after fabrication. Some common coating systems used for bridge substructures are concrete, galvanizing, epoxy, and paint.

Steel coatings can degrade over time when exposed to environmental conditions or can be damaged by mechanical impact or abrasion (Figure 28). Any crack in the coating system can cause localized accelerated corrosion.

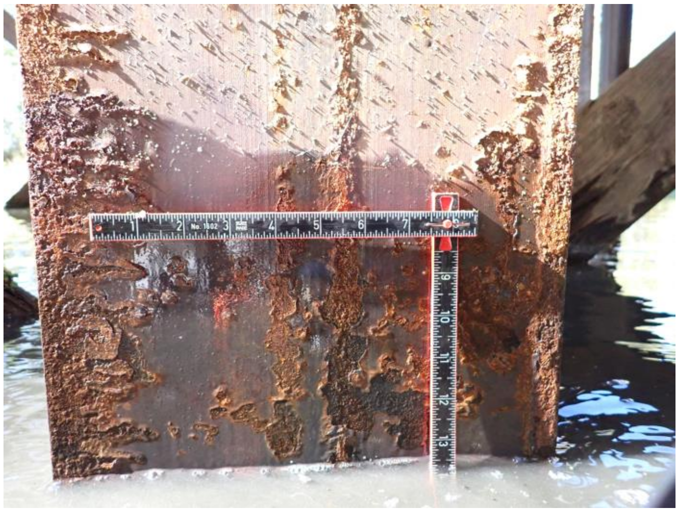


Figure 28. Photo. Example of coating failure of a steel pile. (Source FHWA).

The underwater inspector should document all coating system damage and evaluate its effectiveness. Inspectors should be careful not to damage the coating system when cleaning marine growth for inspection. Aggressive mechanical cleaning devices are discouraged because they can remove the coating along with the marine growth causing more damage to the element.

Table 6 illustrates the condition state descriptions used to document coating failure conditions for steel.

Table 6. Condition state descriptions for steel element coating defects from the AASHTO MBEI as referenced by the SNBI (Section 7.2).

Defects	**CS 1**	**CS 2**	**CS 3**	**CS 4**
	GOOD	**FAIR**	**POOR**	**SEVERE**
Chalking (Steel Protective Coatings) (3410)	None	Surface dulling	Loss of pigment	Not applicable
Peeling/ Bubbling/ Cracking (Steel Protective Coatings) (3420)	None	Finish coats only	Finish and primer coats	Exposure of bare metal
Oxide Film Degradation Color/Texture Adherence (Steel Protective Coatings) (3430)	Yellow-orange or light brown for early development. Chocolate-brown to purple-brown for fully developed. Tightly adhered, capable of withstanding hammering or vigorous wire brushing.	Granular texture	Small flakes, less than ½-inch diameter	Dark black color. Large flakes, ½-inch diameter or greater, or laminar sheets of nodules.
Effectiveness (Steel Protective Coatings) (3440)	Fully effective	Substantially effective	Limited effectiveness	Failed; no protection of the underlying metal

3.3.2.2 Corrosion

Corrosion is the most common defect found on submerged steel substructure elements. The most important factors influencing and producing corrosion are the presence of oxygen, moisture, chemicals, pollution, stray electrical currents, and water velocity. Corrosion can be especially severe when the bridge is in salt water or brackish water (Figure 29).

Heavy marine growth is common in saltwater and can be present in certain freshwater environments. Marine growth can sometimes inhibit corrosion. However, it can also hide severe distress. During the inspection, it is suggested that a minimum of 10 percent of the substructures receive a Level II cleaning to remove marine growth.

Figure 29. Photo. Example of corrosion on a steel pile. (Source FHWA).

The corrosion rate is much higher in the splash zone where conditions most favorable for corrosion are present. 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. Bridges in industrial areas, where there may be many stray electrical currents, may experience severe corrosion problems.

Detailed corrosion notes should be recorded for proper documentation. Location, extent, severity, and remaining cross-section are needed to effectively report corrosion defects. Remaining cross-section can typically be measured with calipers or an ultrasonic thickness gauge.

Table 7 illustrates the condition state descriptions used to document corrosion in steel.

Table 7. Condition state descriptions for steel element corrosion defect from the AASHTO MBEI as referenced by the SNBI (Section 7.2).

Defect	**CS 1**	**CS 2**	**CS 3**	**CS 4**
	GOOD	**FAIR**	**POOR**	**SEVERE**
Corrosion (1000)	None	Freckled rust. Corrosion of the steel has initiated.	Section loss is evident, or pack rust is present but does not warrant structural review.	The condition warrants a structural review to determine the effect on the strength or serviceability of the element or bridge; OR a structural review has been completed, and the defects impact strength or serviceability of the element or bridge.

3.3.2.3 Galvanic Corrosion

Severe corrosion of steel H-piles can occur in salt water and brackish water. Relatively lightweight piles are driven into a massive soil channel bottom and 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 that go into solution. Often the most severe corrosion occurs near the underside of the concrete or near the waterline (Figure 30).

Figure 30. Photo. Galvanic corrosion of steel H-pile. (Source FHWA).

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 the adjacent 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.

3.3.2.4 Microbial-Induced Corrosion

Microbial-induced corrosion (MIC) is a form of localized, rapid corrosion that can occur at or below the water. 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 particularly severe form of MIC is known as accelerated low water corrosion (ALWC).

A bright orange sulfurous deposit on the steel near the waterline indicates the possible presence of MIC, but it must be removed to test and confirm the presence of MIC. The orange deposits can generally be easily removed by wiping with a gloved hand. When removed, there will be a layer of gray, black, often flakey, corrosion product of iron sulfide. If the iron sulfide is removed, the underlying steel is generally pitted and shiny.

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

3.3.2.5 Connections

Most steel bridge substructures are constructed without connections below water; however, there are instances where underwater connections may be encountered, such as at splices in piles, bracing connections, and wales attached to sheet pile bulkheads. Connections are also often found in the splash zone for bracing members.

Connections, including bolts, welds, and interlocking areas along sheet piling, are potential areas of corrosion. Corrosion can be caused by dissimilar metals, which create corrosion cells or by discontinuities in the metal.

Connections such as H-pile splices should be examined at the welds. The dissimilarities between the weld metal and the base metal can cause corrosion. 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. Figure 31 and Figure 32 show a welded splice detail for a submerged H-Pile.

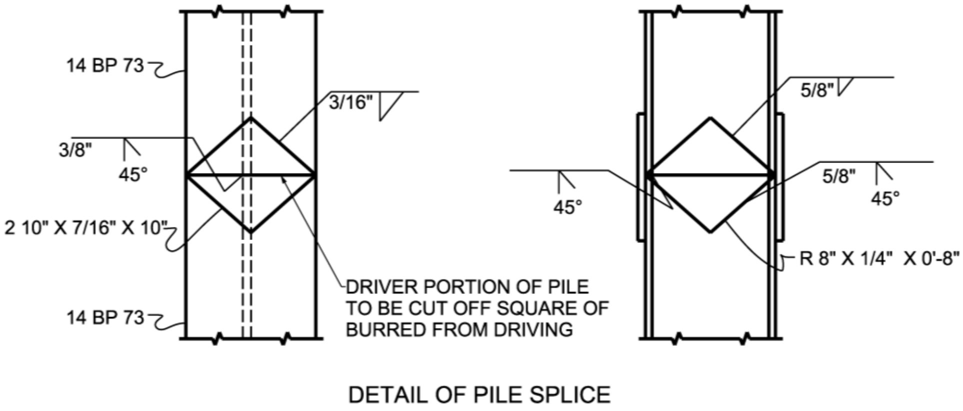


Figure 31. Illustration. Steel pile splice detail from bridge plans.

Figure 32. Photo. Example of steel pile splice. (Source FHWA).

3.3.2.6 Cathodic Protection

Cathodic protection is not commonly used to protect submerged bridge elements from corrosion; however, it may be encountered on coastal structures in rare situations.

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. 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 or suspended from steel cables (Figure 33). The anodes should not be painted because they must have electrical continuity with the structure to offer protection. The anodes and electrical cables should be inspected to verify continuity. Some loss of anode material is to be expected if the system is working properly, but the anodes should exhibit some remaining life.

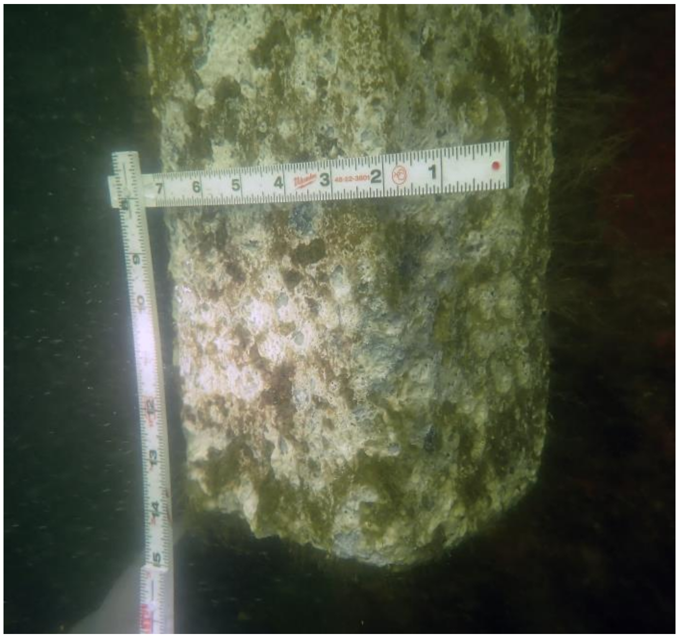


Figure 33. Photo. Sacrificial anode of a steel pile. (Source FHWA).

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 structure without excessive current. The above-water rectifier should be inspected to verify it is operational. Electrical wiring and impressed current anodes should also be inspected for damage.

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. Electric potential measurements can be collected at frequent locations along a steel member to assess cathodic protection. Refer to Section 5.3.1.2 for additional information on evaluating cathodic protection of steel member.

3.3.3 Masonry

Masonry is not a common material used in modern 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 defects found in masonry structures include displacement, cracking, scaling, and deteriorated pointing/mortar.

Masonry is naturally porous and is susceptible to deterioration induced by freezing and thawing. The stone may fracture and break off, and the man-made mortar can deteriorate. More rapid deterioration, such as cracking along bedding planes, may also occur in stone of lower quality.

Masonry mortar joints near the waterline are usually most susceptible to freeze-thaw damage. It is common 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 to note the length, width, and penetration of the defect.

Repairs made to older masonry structures typically use masonry or concrete materials. Inspectors should also note the condition of the repairs.

Table 8 illustrates the condition state descriptions used to document various deficiencies on masonry structures.

Table 8. Condition state descriptions for masonry defects from the AASHTO MBEI as referenced by the SNBI (Section 7.2).

Defect	CS 1	CS 2	CS 3	CS 4
	GOOD	FAIR	POOR	SEVERE
Mortar Breakdown (Masonry) (1610)	None	Cracking or voids in less than 10% of joints.	Cracking or voids in 10% or more of the joints.	The condition warrants a structural review to determine the effect on the strength or serviceability of the element or bridge; OR a structural review has been completed, and the defects impact strength or serviceability of the element or bridge.
Exposed Rebar (1090)	None	Present without measurable section loss.	Present with measurable section loss but does not warrant structural review.	
Patched Area (Masonry) (1630)	None	Sound patch.	Unsound patch.	
Masonry Displacement (1640)	None	Block or stone has shifted slightly out of alignment.	Block or stone has shifted significantly out of alignment or is missing but does not warrant structural review.	

3.3.4 Timber

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

3.3.4.1 Decay

Due to the material properties of timber, fungi feed on the cell walls of wood. Fungi thrive in conditions that include sufficient moisture, oxygen, and warmth. These conditions are most prevalent near the waterline of timber elements. Micro-organisms can easily penetrate untreated timber or older timber where the preservative has become ineffective. In the early stages, decaying members appear slightly discolored.

In advanced stages of decay, the wood becomes spongy, stringy, crumbly, and splintered (Figure 34). Members with internal decay may appear slightly splintered and produce a hollow sound when sounded 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.

Figure 34. Photo. Timber pile with severe decay. (Source FHWA).

When reporting decay, the inspector should note location, severity, dimensions, and mode. The location should be descriptive and referenced from clear reference points. The mode of decay is generally noted as internal or external. The extent of external decay can be mapped by removing the decayed material or probing with an awl. The extent of internal decay can be mapped by sounding with a hammer. However, quantifying the severity of internal decay typically requires the use of advanced inspection methods, which are discussed in Section 5.3.3.

3.3.4.2 Marine Borers

Two types of marine borers are most common in saltwater environments: molluscan borers and crustacean borers. Because of their destructive capabilities, teredo and bankia, which have similar characteristics, are the most important molluscan borers, and 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.

Teredo or bankia, which is also known as 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 6 feet long. The hole made by the teredo varies from one-quarter to one-half inch in diameter, as shown in Figure 35, with some species of bankia growing to three-quarters of an inch in diameter.

Figure 35. Photo. Marine borer damage in timber pile. (Source FHWA).

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 teredo, limnoria (also called wood louse or gribble) is a surface boring crustacean. 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 hourglass shape commonly found in wood piles in the splash zone as shown in Figure 36.

Figure 36. Photo. Example of hourglass shape as a result of marine borer damage. (Source FHWA).

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 preservatives can be used to protect against both borers, although environmental regulations may preclude their use in some areas.

3.3.4.3 Bacterial Degradation

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. Core samples can be collected to assess the presence of bacterial decay. The collection of timber core samples is discussed in Section 5.3.3.2.

Bacterial decay in timber members can also attract other destructive organisms, such as caddisflies, which is an aquatic insect closely related to the moth and butterfly. The caddisfly is generally found in fresh or brackish water. These insects can dig small holes into the timber for protection during the larva and pupa stages of their life cycle.

Table 9 illustrates the condition state descriptions used to document various deficiencies on timber members.

Table 9. Condition state descriptions for timber element defects from the AASHTO MBEI as referenced by the SNBI (Section 7.2).

Defect	**CS 1**	**CS 2**	**CS 3**	**CS 4**
	GOOD	**FAIR**	**POOR**	**SEVERE**
Connection (1020)	Connection is in place and functioning as intended.	Loose fasteners or pack rust without distortion is present, but the connection is in place and functioning as intended.	Missing bolts, rivets, or fasteners; broken welds; or pack rust with distortion but does not warrant a structural review.	The condition warrants a structural review to determine the effect on the strength or serviceability of the element or bridge; OR a structural review has been completed, and the defects impact strength or serviceability of the element or bridge.
Decay/Section Loss (1140)	None	Affects less than 10% of the member section	Affects 10% or more of the member but does not warrant structural review	
Check/Shake (1150)	Surface penetration of less than 5% of the member thickness regardless of location.	Penetrates 5% - 50% of the thickness of the member and not in a tension zone	Penetrates more than 50% of the thickness of the member or penetrates more than 5% of the thickness of the member in the tension zone. Does not warrant structural review.	
Crack (Timber) (1160)	None	Crack that has been arrested through effective measures	Identified crack that is not arrested but does not require structural review	
Split/ Delamination (Timber) (1170)	None	Length less than the member depth or arrested with effective actions taken to mitigate	Length equal to or greater than the member depth but does not require structural review	
Abrasion/ Wear (Timber) (1180)	None or no measurable section loss	Section loss of less than 10% of the member thickness	Section loss of 10% or more of the member thickness but does not warrant structural review.	

3.3.5 FRP Composite Materials

Like traditional materials, most mechanical defects of FRP composite materials are due to impact and abrasion or construction-related events. Because of their physical properties, composite materials are seldom used as primary structural members for bridge foundations. However, they are commonly used for fender systems or other pier protection devices that are inspected underwater.

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 to and may result in the yielding or splitting of the composite materials.

Sometimes, while inspecting composite members underwater, it is difficult to identify that the member is composite. Many composites have shapes similar to dimensional lumber and timber piles. It may be easier to identify the material type above the water where marine growth does not cover the element.

Due to the unique physical properties of FRP composites, the modes of deterioration can vary from other structural materials. Unlike timber members, composites are not susceptible to marine borers due to their inorganic composition. However, composites are susceptible to fire and ultra-violet ray degradation, but admixtures and coatings can reduce their effects on members. Major forms of deficiencies in FRP composites:

- Blistering
- Voids and delaminations
- Discoloration
- Wrinkling
- Fiber exposure
- Scratches
- Cracking

3.3.6 Vessel Damage

All bridges located in water are susceptible to damage from external forces such as vessel impact. Damage from vessel collisions may be visible above-water, as shown in Figure 37, but the extent of damage below water cannot be properly assessed without a detailed underwater inspection. Damage can extend beyond the immediate area of impact. Due to the large lateral load exerted onto a bridge member during a vessel impact, there may be extensive damage to surrounding members, such as the footing or cap. Additionally, lateral deflection of the entire substructure can occur in instances involving larger vessels.

Figure 37. Photo. Vessel impact on bridge pier. (Source FHWA).

3.4 SUBSTRUCTURE TYPES

The bridge substructure is the portion of the bridge below the bearings or below the spring line of an arch that transfers the load to the foundation. Various substructure types achieve this load transfer with different components and materials. The underwater inspector should be able to identify and understand each substructure type and be able to document the deterioration appropriate for the material.

While there are a variety of different substructure types, each type falls under one of the three general substructure configuration designations:

- Abutment – located at the end of a bridge and provides lateral support for the approach roadway embankment.
- Pier or Bent – provides intermediate support for multi-span superstructures located between abutments.
- Widening – the widened portion of an abutment, pier, or bent that facilitates a widened superstructure. The widened portion can be of a different type than the original design, as shown in Figure 38.

Figure 38. Photo. Widened substructure unit with two different substructure types. (Source FHWA).

3.4.1 Bents

The two bent groups are pile bents and column bents. Both bent groups are generally constructed using concrete, steel, or timber.

3.4.1.1 Pile Bents

Pile bents are substructure units that consist of two or more piles driven in place supporting a continuous pile cap. Superstructure loads are distributed through the piles from the pile cap to the underlying soil or rock. Pile bents are generally constructed of concrete, steel, timber, or a combination of these materials. Pile bents can be used for intermediate supports or abutments. Figure 39 is an example of an intermediate concrete pile bent. Piles can also be used as foundation supports for footings, which is further discussed in Section 3.5.2.1.

Figure 39. Photo. Example of concrete pile bent. (Source FHWA).

Cast-in-place concrete piles are usually constructed by driving a metal casing into the ground and using the casing as a form for the concrete. Usually, the shell is thin steel and not considered to add structural capacity to the pile. This is not always the case, as some shells can be considered structural, especially in an environment where ice is prevalent. Reinforcing steel is normally added within the concrete, especially near the top of the pile, where it may be subject to lateral loads. Plans and design details are usually needed to know for certain if the steel shell is providing any structural capacity to the cast-in-place pile.

Uncased, cast-in-place concrete piles can be constructed by driving a casing into the soil and removing the casing after the concrete cures. Concrete may also be placed in augured holes without a casing in very firm soils. Large diameter, cast-in-place concrete piles are commonly referred to as drilled shafts. Drilled shafts are discussed in Section 3.5.2.2 of this chapter.

Precast and prestressed concrete piles, which may be solid or hollow, generally have a square, rectangular, or octagonal cross-section with one end tapered to better facilitate driving. They commonly range in size from about 12 inches to 30 inches in diameter.

3.4.1.2 Column Bents

Column bents are substructure units consisting of two or more columns supported by individual footings. An example of a column bent is shown in Figure 40. Superstructure loads are distributed through the columns and into the footings below. Column bents may have a web wall between the columns to provide lateral bracing, but the web wall does not transfer the superstructure load to the footings. Typically, if a web wall is present, the wall will terminate above the footings.

Column bents are typically constructed of concrete but can also be timber, steel, or masonry. Column bents can be very similar in appearance to pile bents, but there are a few distinguishing characteristics that can help an inspector discern between pile or column bents:

Column bent characteristics:

- Will not always have a bent cap
- Will not have battered columns
- Always supported on footings or deep foundation

Pile bent characteristics:

- Always has a bent cap
- May have battered piles
- Never supported on footings

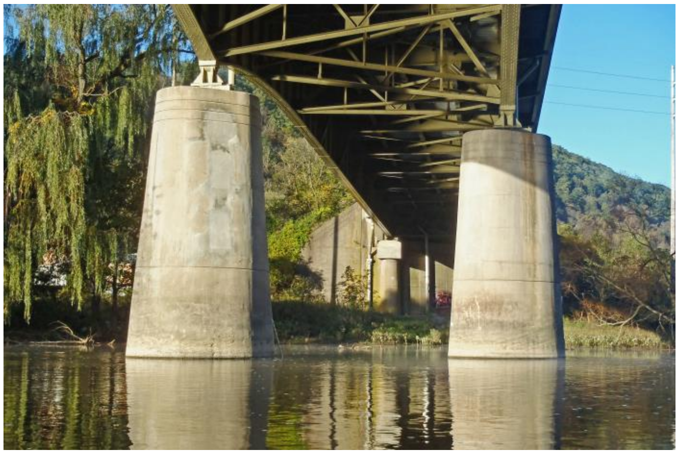


Figure 40. Photo. Example of RC column bent. (Source FHWA).

3.4.2 Piers

Piers are transverse, intermediate supports constructed of concrete, masonry, timber, steel, or a combination. There are several different pier types, but they all consist of three basic elements:

- Pier cap
- Column(s), large shaft, or wall
- Footing

3.4.2.1 Pier Walls

Pier walls are typically constructed of reinforced concrete or masonry and transmit superstructure loads from the pier cap to the footing. The shape and size of pier walls can vary, but they are usually aligned parallel with the flow of the waterway.

Reinforced concrete pier walls (Figure 41) are typically cast-in-place and supported by either a pile-supported footing or a spread footing. One or both ends of a pier wall are typically rounded or tapered to reduce potential scour or debris collection.

Figure 41. Photo. Example of a pier wall. (Source FHWA).

Masonry pier walls (Figure 42) consist of large blocks of stone stacked in a running bond pattern and grouted together. They are either footing supported or placed on a caisson. Bearings are located directly on the top course of stone or on a concrete cap.

Figure 42. Photo. Example of a masonry pier. (Source FHWA).

3.4.2.2 Single Column Piers

Single-column piers, such as hammerhead piers (Figure 43), usually support a pier cap element and are tall and slender in design. They transmit loads from the pier cap into the footing. Column piers are constructed from reinforced concrete and can be round or rectangular in shape. They can be founded on pile-supported footings, spread footings, or drilled shafts.

Figure 43. Photo. Example of a single-column hammerhead pier. (Source FHWA).

3.4.2.3 Multiple Column Piers

Multiple-column piers are often indiscernible from column bents if bridge plans are not available but provide the same function by transferring loads from the cap to the foundations. However, unlike column bents, multiple-column piers have a single footing for all the columns. The columns are typically constructed with reinforced concrete and are founded on pile-supported footings or spread footings (Figure 44).

Figure 44. Photo. Example of a multi-column pier. (Source FHWA).

3.4.2.4 Tower Piers

Tower piers are typically used for complex bridges, such as cable-stayed and suspension bridges, with the substructure extending above the superstructure to provide anchoring points for the cables. Refer to Figure 45 for an example of a tower pier supporting a cable-stayed bridge. The portion of tower piers below the superstructure appears and functions similar to multiple column piers or a pier wall and will not be discussed in detail in this manual.

Figure 45. Photo. Cable-stayed bridge with tower pier substructure. (Source FHWA).

3.4.2.5 Movable Bridge Piers

Moveable bridge piers can consist of pile bents, column bents, pier walls, or multiple column piers and can be made from reinforced concrete, prestressed concrete, steel, or timber. This type of pier supports the movable part of the bridge and transfers its load to the foundation or ground. From an underwater inspection standpoint, movable bridge piers are inspected in the same manner as the type of pier it consists of and therefore, will not be discussed in detail in this manual.

3.4.3 Abutments

An abutment provides end support for a bridge and retains the approach embankment. Abutments, classified according to their locations, are full height (closed), stub, or spill-through (open). Pile bents may also be used as abutments. Wing walls are abutment extensions on the sides of an abutment, which enclose the approach fill.

3.4.3.1 Full-Height Abutments

Full-height abutments are used when there is a need to keep the superstructure span at a minimum, or there are terrain or right-of-way constraints. The abutment transfers superstructure loads and retains the backfill of the approach. Full-height abutments typically have wing walls that help retain the approach roadway embankment on the sides (Figure 46).

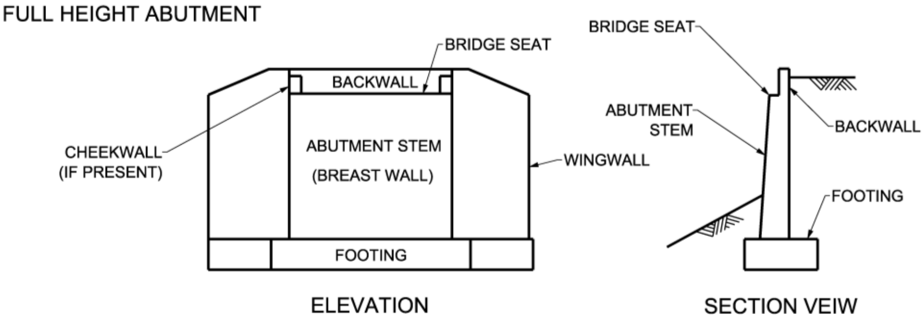


Figure 46. Illustration. Full-height abutment.

3.4.3.2 Stub Abutments

Stub abutments are used to help reduce substructure costs and keep the abutment away from the waterway. Stub abutments can be supported by piles or spread footings and typically have a slope pavement or embankment scour countermeasures to protect against erosion (Figure 47).

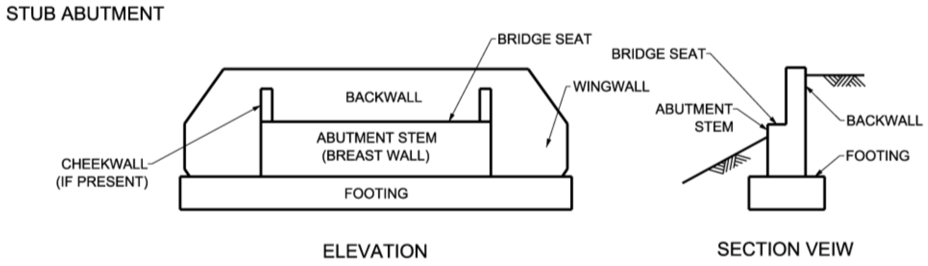


Figure 47. Illustration. Stub abutment.

3.4.3.3 Open or Spill-Through Abutments

Open or spill-through abutments are constructed like multi-columns piers. The approach roadway embankment spills through the abutment and forms the fore slope, which is protected with riprap or other erosion countermeasures. Spill-through abutments are not normally used at river crossings because of the threat of scour (Figure 48).

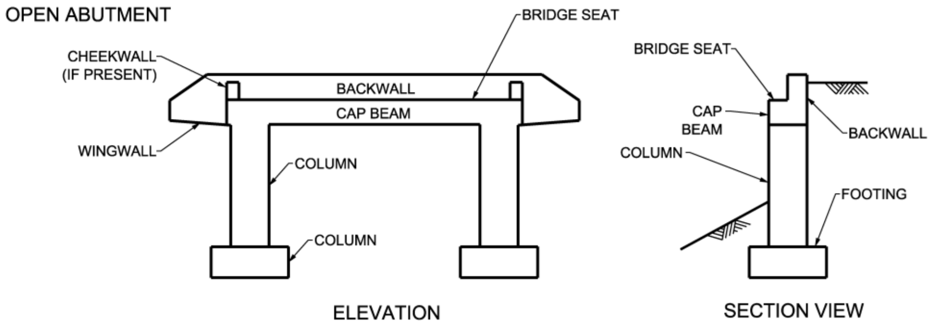


Figure 48. Illustration. Spill through abutment.

3.4.3.4 Integral and Semi-Integral Abutments

Integral abutments eliminate the bearings and joints at the abutment by designing the superstructure and substructure as one connected unit that moves together. These abutments can appear like a stub abutment with slope pavement or embankment scour countermeasures that protect against scour. The identifying characteristic of an integral abutment is the lack of bearings and the girders being cast into the cap (Figure 49).

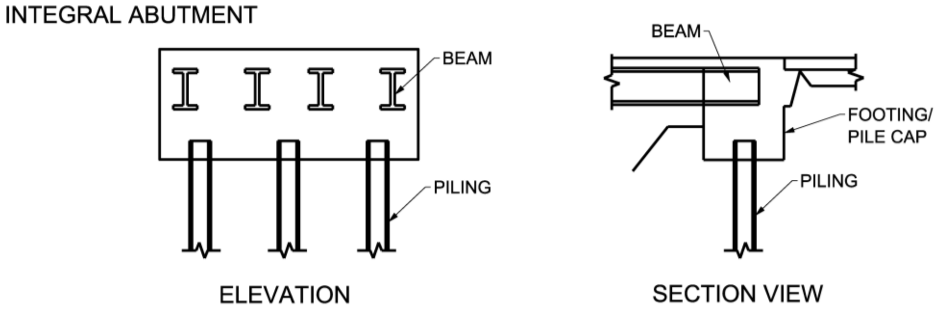


Figure 49. Illustration. Integral abutment.

3.5 FOUNDATION TYPES

Pier footings can be founded on driven piles, drilled shafts, caissons, or a spread footing bearing directly on soil or rock. Each configuration has specific characteristics that match the soil conditions for optimum performance.

3.5.1 Spread Footings

Spread footings are cast-in-place using reinforced concrete and distribute loads from columns or pier walls into the ground. Spread footings are typically used when bedrock is near the surface. However, older bridges may be founded on erodible rock or soil because of limited geotechnical information at the time of construction.

3.5.2 Deep Foundations

Deep foundations are used when the soil near the ground surface is not suitable to carry loads from the bridge. These foundations transfer loads below the surface to a suitable soil layer or use skin friction to transfer loads.

3.5.2.1 Pile Foundations

Pile foundations use skin friction or end bearing, or a combination of both to support the structure. Piles can be made of reinforced concrete, prestressed concrete, steel, or timber. The piles can be attached directly to a cap, as with a pile bent, or they can tie into a reinforced concrete footing supporting a column or pier wall.

3.5.2.2 Drilled Shafts

Drilled shafts are common in newer bridges. Although larger in size than a pile, they behave in a similar manner. Drilled shafts are friction or end bearing and are formed by drilling out a shaft in the ground and then filling the cylinder with a reinforcing cage and concrete. A steel casing is used above the ground to form the shaft and is either removed after construction or kept in place.

3.5.2.3 Caissons

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.

3.5.3 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 50).

In many situations, before the cofferdam is dewatered, a concrete seal is 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 can be 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 50. Photo. Cofferdam used to dewater for footing construction.
(Source PCL Construction).

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. Often, the ends of these cut off members remain exposed, and corrosion of the steel may be present. A box may also be constructed around the bracing so that the bracing may be removed when the rest of the cofferdam is removed. The resulting void through the foundation may be left open or patched with concrete.

3.6 CULVERTS

A culvert is a small bridge normally constructed entirely below the elevation of the roadway surface and having no part or portion integral to the roadway. Culverts may have one or multiple openings and may be constructed of concrete, steel, masonry, or timber. Structures with over a 20-foot clear span, measured parallel to the centerline of the roadway, are commonly referred to as a bridge culvert; 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 BIRM for an in-depth discussion of culverts and their inspection.

Culverts that cannot be inspected in the dry should be inspected by diving or some other means as necessary to determine their structural condition with certainty. Culverts with limited freeboard may require a penetration dive to inspect.

3.7 PROTECTION DEVICES

Dolphins, fenders, and shear fences are placed around substructure units to protect them from vessels. These devices are designed to absorb some of the energy of physical vessel impact and redirect smaller vessels.

Dolphins are generally constructed of a group of piles clustered together to form a structure. 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 that bind them together. Figure 51 shows a typical timber dolphin used as a bridge pier protection.

Figure 51. Photo. Example of a timber dolphin. (Source FHWA).

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. Figure 52 shows an example of a steel sheet pile dolphin.

Figure 52. Photo. Example of a steel sheet pile dolphin cell. (Source FHWA).

A fender system usually consists of timber or steel members attached directly to the substructure unit or piles driven adjacent to the substructure unit connected by horizontal members forming a protective structure. Fender components can be made of concrete, steel, timber, or composite materials. Figure 53 shows a pile-supported fender system used to protect a movable bridge pier.

Figure 53. Photo. Example of a fender system. (Source FHWA).

CHAPTER 4. UNDERWATER INSPECTION EQUIPMENT

This chapter is intended to provide general information only and its contents should not be construed as a FHWA recommendation. Professionals in this area should be consulted for guidance regarding the information found in this chapter.

4.1 THE DIVER'S ENVIRONMENT

The hazards presented by waterways, such as high flow velocities, limited underwater visibility, potential for entanglement, and poor water quality, contribute to the hostile nature of the diver's work environment. Divers typically rely on external life support systems while working under limitations such as diminished sensory and perceptual capabilities, impaired cognitive capabilities, and reduced motor skills. Reduced physical working capacity, physiological, and psychological stress also can limit diver efficacy.

Divers are also exposed to physiological hazards such as pressure, temperature extremes, oxygen deficiency, and nitrogen narcosis. Nitrogen narcosis, a disorder resulting from the anesthetic properties of nitrogen breathed under pressure, can result in a loss of orientation and judgment by the diver.

To work effectively, a diver will need to acclimate to the environment, be familiar with the diving equipment, and select methods appropriate for the task. A diver cannot properly conduct an underwater inspection if their sole concern is survival; therefore, a diver should feel safe and comfortable while working to perform a quality inspection.

Atmospheric air is the most common breathing medium for diving, which consists of approximately 79 percent nitrogen and 21 percent oxygen. When air is breathed under pressure, nitrogen and other trace gases diffuse into the body's tissues. 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 dissipate, 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 decompression sickness. For this reason, a diver's depth and bottom time, along with their ascent rate, should be carefully monitored.

Combinations of deep dives and dives of long duration may require the diver to decompress in stages by spending time at intermediate depths throughout their ascent; alternatively, the diver may decompress on the surface in a decompression chamber, allowing sufficient time for the nitrogen 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 typically needed. Such dives are referred to as no-decompression (No "D") dives. Table 10 indicates the no-decompression time limits for various depths of diving.

Although decompression is not normally a concern for dives within the no-decompression time limits, an amount of nitrogen remains in the diver's tissues after every dive. For repetitive dives, the diver should consider the effects of residual nitrogen in evaluating the adjusted no-decompression times for subsequent dives and assessing the need for planned decompression. The Repetitive Group Designators shown in Table 10 are used in conjunction with the Residual

Nitrogen Time Table for Repetitive Air Dives in the *U.S. Navy Diving Manual* to calculate residual nitrogen time.

Table 10. No-decompression limits and repetitive group designators for no-decompression air dives, *US Navy Diving Manual*.

Depth (fsw)	No-Stop Limit	Repetitive Group Designation															
		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	Z
10	Unlimited	57	101	158	245	426	*										
15	Unlimited	36	60	88	121	163	217	297	449	*							
20	Unlimited	26	43	61	82	106	133	165	205	256	330	461	*				
25	1102	20	33	47	62	78	97	117	140	166	198	236	285	354	469	992	1102
30	371	17	27	38	50	62	76	91	107	125	145	167	193	223	260	307	371
35	232	14	23	32	42	52	63	74	87	100	115	131	148	168	190	215	232
40	163	12	20	27	36	44	53	63	73	84	95	108	121	135	151	163	
45	125	11	17	24	31	39	46	55	63	72	82	92	102	114	125		
50	92	9	15	21	28	34	41	48	56	63	71	80	89	92			
55	74	8	14	19	25	31	37	43	50	56	63	71	74				
60	63	7	12	17	22	28	33	39	45	51	57	63					
70	48	6	10	14	19	23	28	32	37	42	47	48					
80	39	5	9	12	16	20	24	28	32	36	39						
90	33	4	7	11	14	17	21	24	28	31	33						
100	25	4	6	9	12	15	18	21	25								
110	20	3	6	8	11	14	16	19	20								
120	15	3	5	7	10	12	15										
130	12	2	4	6	9	11	12										
140	10	2	4	6	8	10											
150	8		3	5	7	8											
160	7		3	5	6	7											
170	6			4	6												
180	6			4	5	6											
190	5			3	5												

*Highest repetitive group that can be achieved at this depth regardless of bottom time.

4.1.1 General

The diver's environment will dictate the type of protective suit that will need to be worn to complete diving inspections. At a minimum, the skin should be protected from abrasion hazards such as marine growth, wildlife, construction debris, timber debris, and other items encountered around bridges. The temperature of the water throughout the water column should also be considered, as the water temperature at depth can vary significantly from the temperature at the surface. The diver may have to pass through multiple thermoclines during an inspection, with temperatures at the bottom more than 20 degrees Fahrenheit lower than the temperature at the surface. Contamination hazards in the waterway should also be considered.

4.1.2 Selection of Diving Suit

A diver immersed in water at a temperature less than the core body temperature rapidly loses body heat. Even in relatively warm water, a diver will become chilled after prolonged exposure. An exposure suit is usually necessary to protect and insulate the diver.

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. In water above 55 degrees Fahrenheit, a wetsuit will typically provide adequate thermal protection. Wet suits are constructed of neoprene and are intended to be tight-fitting. The wet suit allows a thin layer of water between the suit and the diver's skin, which, when warmed by body heat, acts as insulation to keep the diver warm. Wet suits are available in various thicknesses, usually ranging from 1 to 7 mm. A wetsuit's efficacy depends on suit thickness, fit, water temperature, water transfer, and the dive depth.

A dry suit constructed for diving is an effective suit in cold water. Dry suits are also used in contaminated water dives. The suits can be constructed of crushed neoprene, nylon, or vulcanized rubber. Socks or boots are integral to the suit; hoods may be integral 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 be inflated from a low-pressure air supply; they also have a one-way valve to release air from the suit. For additional thermal protection, the diver may choose to wear additional layers of insulation, such as thermal underwear, wool, or synthetic clothing below the suit. The dry suit normally requires the diver to wear additional weight since the volume of air in the suit increases buoyancy.

4.2 MODES OF DIVING

4.2.1 General

Two primary methods of diving are used to inspect bridges: commercial self-contained underwater breathing apparatus (SCUBA) and surface-supplied air (SSA). Both methods of diving should be performed by qualified personnel and have a dive supervisor in charge of the diving operations. Choosing the method of diving for each inspection site should only be performed by an experienced dive supervisor accounting for several factors, including depth, structure type, environmental conditions, team member experience, potential hazards, traffic, and access requirements. In some cases, the inspection method may need to be changed once the inspection team arrives on-site if observed conditions differ from planned conditions. When choosing commercial SCUBA or SSA diving for an underwater inspection, the safety of the inspection team or the public should take precedence.

In some cases where the structure is located over a shallow waterway, wading is an acceptable method of underwater inspection. The allowable water depth at a structure for a wade depends on State DOT regulations, environmental and structure conditions, and the judgement of the dive supervisor on-site. During a wading inspection, all appropriate and applicable dive safety procedures should be followed. Since wading inspections are not the typical method of underwater inspection and serve the same purpose as a diving inspection, they are not covered in detail in this manual.

4.2.2 Commercial SCUBA

Commercial SCUBA refers to a diving technique where the diver carries a high-pressure air tank with a pressure regulator on their back that is connected by a hose to a demand regulator in the diver's mouth. The main advantage of commercial SCUBA is mobility and reduced surface support equipment. Most commercial SCUBA systems can attach a through-water wireless or hard wire communication system, which can enhance safety, efficiency, and data collection. An example of a commercial SCUBA setup is shown in Figure 54.

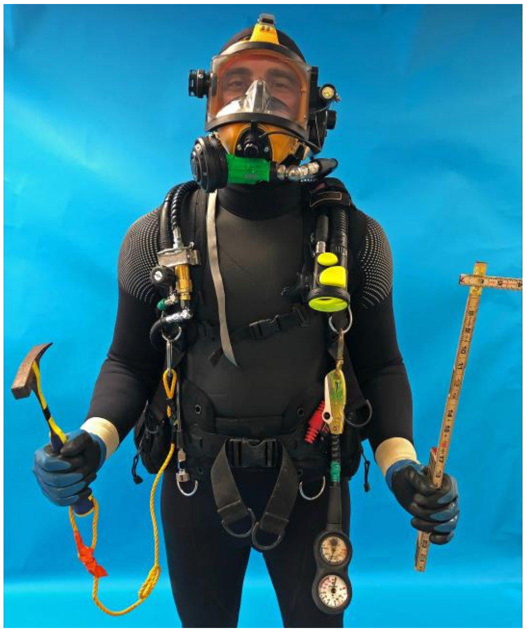


Figure 54. Photo. Example of commercial SCUBA setup. (Source FHWA).

4.2.3 Surface-Supplied Diving

SSA diving operations provide enhanced safety and extended in-water time because the air is provided from a supply on the surface along with a hard wire communication system that is incorporated into a diving umbilical. A pneumofathometer is also included in the umbilical to monitor the depth of the diver. Hoses for hot water suits or cables for video cameras can also be integrated into the umbilical. Air is provided to the diver through the umbilical by either a low-pressure compressor or a bank of high-volume tanks. The diver wears a mask or protective helmet that includes the second-stage regulator and communication equipment. Refer to Figure 55 for an example of a diver dressed for SSA diving.

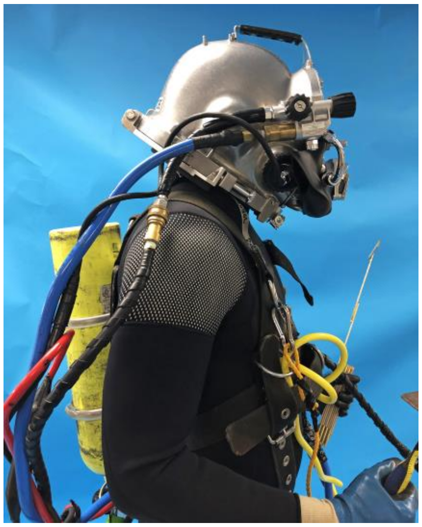


Figure 55 Photo. Example of diver dress for SSA. (Source FHWA).

4.3 INSPECTION TOOLS

4.3.1 General

Underwater inspectors frequently utilize tools when inspecting a bridge. The cleaning of structural elements and NDT sometimes require specialized tools in addition to more common inspection tools. Power tools and hand tools are both used in underwater inspections.

The choice of power tools and hand tools for an inspection depends on the environment, cost, mobilization, and personnel performing the inspection. In most cases, cleaning portions of a structure for a Level II inspection can typically be completed using hand tools. However, if the marine growth is severe, difficult to remove, or if a large surface area needs to be cleaned, power tools may be more efficient. For NDT, power tools are often used to complete the testing on the structure.

4.3.2 Tools

Hand tools are common in all underwater inspections. Almost any standard hand tool can be used underwater. However, due to the harsh environment that an underwater inspector works in, special care should be taken with these tools. Hand tools allow the underwater inspector to retain good mobility and are usually cheap to replace if broken or lost. Hand tools commonly used in underwater inspections include scrapers, awls, hammers, axes, hand saws, wire brushes, and pry bars.

Power tools used in underwater inspections can be pneumatic, hydraulic, or electric. In addition, gas-powered pressure washers are commonly used for inspections that require a lot of cleaning. All these tools are typically expensive, large, and heavy. They take more time to set up and are not as maneuverable as hand tools.

Pneumatic tools use compressed air to power the tool head. The depths the tools can operate in are limited, and they create bubbles that can reduce visibility. Hydraulic tools use pressurized hydraulic fluid to power the tool head, so care should be taken to avoid any spill that could lead to environmental damage. Hydraulic tools and lines are often very heavy and powerful, which can make them difficult to control underwater. Electric tools specifically designed for underwater use can be powered by an attached battery or electric cord from the surface.

4.4 UNDERWATER IMAGING

4.4.1 Photography and Video

Documenting inspection findings is a critical part of any underwater inspection. Having photos or videos of the structure and any defects can provide an easy way to visualize the structure layout and the severity of deficiencies. There are many products available for underwater photography and video that allow the documentation of underwater defects.

Standard cameras can be used in waterproof housing. Typically created out of clear-acrylic plastic, these housings allow for the camera to be operated underwater without water damaging the camera itself. Some digital cameras are specifically designed for underwater photography. The camera itself is resistant to water intrusion up to a specified depth. Many times, these cameras have a dedicated mode for underwater photography. They also often have attached flashes that can be used underwater. An example of an underwater camera commonly used for bridge inspections is shown in Figure 56.

Figure 56. Photo. Camera with underwater housing. (Source FHWA).

Typically, underwater inspections are performed in areas where water visibility is poor. In these cases, getting as close as possible to the subject minimizes the amount of water the photo is taken through. External lights and a clear water box can be used to further increase the visibility where needed. Distances and measurements in photos that are taken underwater can appear different than they are. For this reason, underwater photos taken during the inspection typically include a scale or ruler next to the subject to provide a point of reference. Creating a photo log of all the images taken during an underwater inspection is a critical part of the inspection process. A photo log should include the photo's subject, location, any relevant notes, and the photo number on the camera.

Because light is gradually filtered out by water, almost all photos will need to be taken using artificial light. Suspended particles in the water can drastically reduce the amount of light reaching the subject of the photograph. Thus, artificial light needs to be bright enough to penetrate through the water to reach the subject. This light can be provided by a flash attached to the camera or by a flashlight held by or mounted on the diver. External lights controlled by the diver should be arranged in a way that sheds sufficient light on the subject but does not "washout" the photo by overexposing the subject. Often, it will take several attempts to obtain a desirable outcome in the photo. Modern digital cameras can store thousands of photos and allow for immediate review of photos taken. This technology makes it much easier to obtain high-quality underwater photos.

Underwater videography equipment is sometimes used in underwater inspections. Underwater videos can often be taken using underwater cameras or regular cameras sealed in waterproof housing. During SSA dives, video from a camera controlled by or mounted to a diver's helmet can be routed back through the umbilical to support personnel. This allows topside crew to monitor the diver's progress and provide feedback during the inspection. The video feed can also be recorded to use for the inspection reporting phase. In some cases, the videos can provide on-screen text and a clock. If connected to the diver communication system, the video can also contain narration by the diver and topside personnel.

Many waterways have extremely limited visibility. In these cases, a camera and lights alone are usually not enough to obtain an acceptable photograph. Thus, a clear water box should be used. A clear water box consists of a box made of clear acrylic plastic and filled with clean water. There are often handles, fill caps, and camera and light mounting brackets attached to the box. When the box is pressed up against the subject, it displaces the turbid water and allows a photo to be taken through the clear water in the box. There is usually a scale attached to the opposite side of the box from the camera to allow for a reference of the subject's dimensions. The lighting will have to be adjusted when using a clear water box, as the acrylic sides will reflect the light in different directions. Since the box is filled with water, it is close being to neutrally buoyant. However, because of their size, clear water boxes can be hard to move around in the water, especially with a strong current. In addition, the weight of the water in the box makes it very heavy when carrying it around on shore.

ROVs are underwater video platforms that are self-propelled (Figure 57). Typically powered by batteries or an electric line from the surface, ROVs can be equipped with testing equipment or manipulators to aid in the inspection. Since they are tethered to the surface, the operator can see real-time video footage from the ROV and control its movements. ROVs are often used in very deep inspections and places that are inaccessible or too hazardous for divers to operate in. However, an ROV is limited by the length of its tether, which also poses an entanglement risk. It is often difficult to determine the exact location and orientation of an ROV in the water. In waterways with strong currents or turbid water, it is usually impractical to use an ROV.

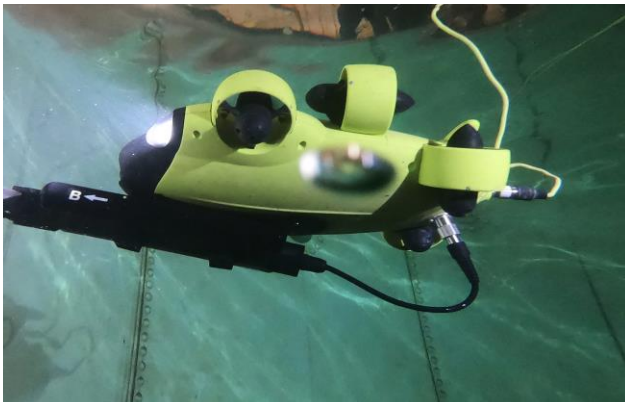


Figure 57. Photo. ROV used to inspect underwater structure. (Source FHWA).

4.4.2 Underwater Imaging

Underwater acoustic imaging is used in the bridge inspection industry to supplement underwater inspections. Available equipment can provide 2D or 3D images of the bridge piers and channel bottom in the bridge's vicinity. The use of acoustic imaging can aid in the planning of diving operations by identifying areas of damage, scour, or debris prior to the diver entering the water. In addition to aiding the inspection, imaging can enhance diver safety by identifying entanglement hazards and areas of undermining that will require a penetration dive prior to the diver entering the water.

Acoustic imaging systems can provide imagery of below-water structures and the channel bottom in low-visibility conditions where underwater cameras are unable to capture quality images. Even in mostly clear water, the range of underwater cameras is limited, especially when attempting to document the extent of debris fields, scour holes, exposed footing height, and areas of undermining. Acoustic imaging equipment can operate at ranges beyond 300 feet and in turbid water. A significant detriment to collecting acoustic images is air suspended in the water. Air has a significantly slower speed of sound than water; therefore, when sound waves hit an air bubble, the soundwave is bounced back to the transducer as a return. If the air bubble is between the transducer and the surface that is being imaged, the returns will be of the air bubble rather than of the structure. When a large amount of air bubbles is close to the transducer or receiver, or between the transducer/receiver and surface being imaged, it may not be feasible to collect complete images.

Acoustic imaging systems operate similarly to sonar depth sounders but at higher frequencies, resulting in significantly greater definition and clarity. Acoustic imaging systems transmit sound waves via transducers. The sound waves strike an object, and part of the sound is reflected towards the source. A receiver records the portion of the soundwave that returns to the source. Based on the speed of sound, which can be calculated accurately based on the water temperature, salinity, and depth, the distance that the sound wave traveled from the transducer to the object to the receiver can be accurately plotted. 2D imaging systems typically use a single sound wave and are referred to as single-beam sonar. 3D imaging systems typically transmit and receive hundreds or thousands of sound waves simultaneously and are referred to as multi-neam sonar. Different acoustic imaging systems utilize transducers of different shapes and sizes that ultimately determine the "footprint" of the sound wave that is emitted. As the soundwave travels further from the transducer, its size increases linearly; therefore, higher resolution imagery is captured closer to the transducer, and the resolution decreases as the sound wave travels further from the transducer.

Acoustic imaging can be especially useful during emergency bridge evaluations. Vessel impacts, extensive scour, high flow velocities, and large debris deposits have the potential to make a bridge unstable or result in dangerous diving conditions. Acoustic imaging can provide an overall assessment of the submerged portions of a structure in each of these situations. Figure 58 is a combined acoustic image of a concrete column bent after being struck by a barge. Acoustic imaging was used to identify possible safety hazards prior to conducting the underwater inspection.

Figure 58. Graphic. Acoustic image of bridge after vessel impact. (Source FHWA).

4.5 DIVE PLATFORMS

4.5.1 General

Underwater inspection dives are typically conducted from the shore or from a boat. In both cases, the dive platform should allow for enough space to safely conduct diving operations, retain communications with a diver, allow for the recovery of a stricken diver, and allow for quick evacuation of a diver in case of a diving emergency. In addition, the dive platform chosen should provide clear visibility to water traffic and avoid trespassing on private property. In all cases where any water traffic might be present, the international code alpha flag should be clearly displayed. Since many recreational boaters do not recognize the meaning of the alpha flag, the red and white sport diver flag should also be flown.

4.5.2 Shore Diving

For structures in small waterways, a dive conducted from shore may be appropriate. There should be a clear staging area on the shore away from traffic that allows for the setup and monitoring of a dive. There also should be easy access to the water for the diver from this area. The staging area should allow support personnel to stay in communication with the diver during the entire dive while providing a view of the dive area to watch for any potential hazards. Both commercial SCUBA and SSA dive can be conducted from shore. Shore diving is not appropriate in areas with motorized boat traffic.

4.5.3 Boat Diving

On larger waterways, diving from a boat is generally preferred. It allows the support team to always stay in close contact with the diver and provides greater visibility for vessel traffic. Dive boats come in many different sizes and types. The boat used as a dive platform is chosen based on water depth, available access points, mode of diving, number of personnel, and environmental conditions. It may be desirable to use a boat with an engine when possible. Federal, State, and local boating requirements should always be followed when operating a watercraft. In general, many States require additional safety training and certification for boat operators. For more information on boating requirements, visit the U.S. Coast Guards website.

CHAPTER 5. UNDERWATER INSPECTION TECHNIQUES

5.1 PREPARATION

An underwater inspection plan (Section 5.1.2) should be prepared in advance and tailored to the type of inspection (initial, routine, special, etc.) to guide the on-site team. It should include detailed information about site conditions, elements to be inspected, equipment requirements, and other special considerations. Additionally, a job hazard analysis (JHA) should be performed using information from the inspection plan based on the anticipated site conditions at the scheduled inspection time. Refer to Appendix A. Job Hazard Analysis (JHA), Example for a JHA example.

The team leader typically prepares the underwater inspection plan and performs the JHA. Therefore, the team leader should be familiar with the OSHA 29 CFR Part 1910, Subpart T - Commercial Diving Operations Standard, which governs the safety of all underwater bridge inspections nationwide. Additionally, local and State regulations should be reviewed and considered, with the most restrictive regulations adhered to for diving operations.

5.1.1 Site Reconnaissance and Data Collection

Before preparing the underwater inspection plan, the team leader should review the bridge file and perform a virtual or physical site reconnaissance. The information gathered should include the following items:

- As-built and repair/rehabilitation plans, if available
- Previous inspection reports and underwater inspection plan
- Scour plan of action if available
- Hydrologic information about historical and anticipated flow rates and elevations
- Site access requirements
- Water depth, velocity, and turbidity
- Debris or other in-water hazards
- Special site conditions (contamination, boat traffic, marine life, etc.)
- Anticipated diving systems
- Local information sources
- Stakeholders who need to be notified

Previous inspection reports can provide useful information for the inspectors to assess previously documented defects and estimate deterioration rates. Channel sounding information available in the historical reports and original construction drawings can help when assessing scour conditions at the site.

Waterway hydrological data may be obtained from online satellite photography and the USGS or USACE websites when planning the inspection. National Oceanic and Atmospheric Administration (NOAA) tide charts can be referenced for coastal waterways. Also, State agencies and local representatives can provide helpful information about historical flooding or seasonal water flows.

5.1.2 Underwater Inspection Plan

The inspection team leader should prepare an underwater inspection plan for each bridge using information collected from existing data and the site reconnaissance. The plan should include all the information needed to execute a complete inspection. The underwater inspection plan should include the following information:

- Location of the bridge
- Substructures to be inspected, with plans
- Anticipated water depth
- Anticipated water velocity
- Diving systems needed
- Inspection equipment needed
- Additional equipment needed for Level 3 testing (if any)
- Access location
- Scope of the inspection
- Marine growth anticipated (if any)
- Amount of cleaning needed (if any)
- Scour countermeasures present (if any)
- Sounding or channel profile requirements (from owner scope of services)
- Inspection method and frequency
- Required qualifications of inspection personnel (Section 2.1.3)
- Special contracting procedures before the inspection
- Notifications
- Scheduling considerations
- Risk factors and emergency procedures (Section 5.1.3)

In some instances, bridge owners or the governing agency may have additional documents that supplement the NBIS requirements specific to their region. These documents include region-specific bridge inspection manuals or the scope of services. When applicable, these items should be referenced in the underwater inspection plan.

5.1.3 Job Hazard Analysis

A JHA is an integral part of the planning process. The purpose of the JHA is to:

1. Identify potential hazards
2. Evaluate their effect on diving operations
3. Prepare a plan to mitigate their impact

The results of the JHA help the team leader determine the size and qualifications of the inspection team. More complex and hazardous diving operations typically need more experienced staff and increased equipment resources. Therefore, selecting a team with qualifications that align with the diving conditions, equipment, and type of structure inspected is an important element of a successful inspection. An example of a completed JHA form is shown in Appendix A. Some items that a JHA typically evaluates for an underwater inspection include:

- Water velocity
- Water depth

- Altitude
- Water temperature
- Underwater visibility (Figure 59)
- Water quality
- Ice hazards
- Floating or submerged debris
- Marine operations and vessel traffic
- Diver access locations
- Adjacent water control structures
- Aquatic vegetation and wildlife
- Construction operations
- Medical evacuation procedures
- Directions to closest operational decompression chamber
- Directions to closest clinic and hospital

A JHA is specific to the site conditions at each bridge and is usually completed before each inspection. However, a single JHA may be appropriate if multiple bridges with similar conditions and bridge types are evaluated within a given timeframe. The JHA is a planning tool that anticipates site conditions based on available information and helps prepare the team to execute inspections safely. When the team arrives on-site, the JHA should be reviewed with the entire team to ensure site conditions are unchanged and the original plan remains valid. Minor JHA adjustments are commonly needed due to site conditions such as flow velocity or visibility changes caused by a recent storm.

Figure 59. Photo. Example of hazardous diving conditions due to poor underwater visibility. (Source FHWA).

5.2 INSPECTION

The underwater inspection plan describes the inspection process and identifies all the inspection elements. The plan may need adjustments when the team arrives on-site based on conditions.

Typically, these adjustments are minor and do not have a significant impact. An inspection schedule or plan may require a complete revision in rare situations, such as severe weather conditions.

The dive team performing an underwater inspection should have voice communication with the surface to facilitate notetaking and enhance diver safety. The inspector may utilize a snorkel and mask to complete the inspection if the inspection occurs in very shallow water free of entrapment hazards. When using a snorkel, the diver will relay inspection findings upon surfacing. Commercially available communication systems exist for both commercial SCUBA and SSA diving systems. Real-time communication between divers and the supervisor on the surface can enhance diver safety and inspection data collection. All diving operations with conditions that could entrap a diver or where the diver does not have free access to the surface (within a submerged culvert or beneath a waterline footing) should be conducted using SSA equipment with a continuous supply of breathing gas and communication to the surface. Additional information on SCUBA and SSA can be found in Section 4.2.

Bridge access should be addressed in the underwater inspection plan. Many small structures can be accessed from shore, while a boat may be warranted for larger structures. If site conditions do not allow a boat to be launched from shore or a boat ramp, it may be necessary to use special equipment, such as a crane, to lower either the boat or divers into the water. Additionally, the safest method of diver deployment and retrieval should be evaluated at each site. Consideration should also be given to the retrieval of an unconscious diver in the event of an emergency.

When a boat is used to perform an inspection, the appropriate boat size is typically dictated by the equipment and team size. All boats have a United States Coast Guard (USCG) data plate attached to the hull, providing the maximum allowable load (33 CFR 164.35). The maximum load includes the weight of all personnel and equipment and helps inform the team leader of the adequate boat size. Other factors that may influence the size of the boat used could be the presence of commercial vessels, deck space needed for additional equipment, stability required for high flow or swell conditions, or other considerations.

Bridge substructures in rivers with flowing water can create significant turbulence around the substructure, which can cause boat damage if it impacts the substructure. Appropriately sized fenders and bumpers attached to the boat can minimize damage during the inspection. Additionally, the boat should be anchored securely or tied to the structure before diving operations, as shown in Figure 60. If the boat is tied to the substructure, two lines should be used to secure the boat, with one line slightly longer than the other. A secondary line provides a higher level of safety if the primary line is parted by abrasion during the dive allowing the supervisor to recover the diver without the boat drifting away.

Figure 60. Photo. Dive vessel tied to bridge pier for underwater bridge inspection. (Source FHWA).

Debris lodged on the substructure should be removed before the inspection, if possible. If the debris cannot be removed, the divers may not be able to access obscured areas. Additional time may be needed on-site to allow the divers to remove the debris or work around it. Refer to Figure 61 for an example of construction debris blocking pier access.

Care should be given to planning the safest method and best location for diver deployment and retrieval. For example, in high flow conditions, diver retrieval should be planned for a downstream location to enable the diver to easily exit the waterway at the end of an inspection or if a dive is aborted. Likewise, boat positioning should allow divers to be quickly and easily deployed and recovered in the safest manner possible.

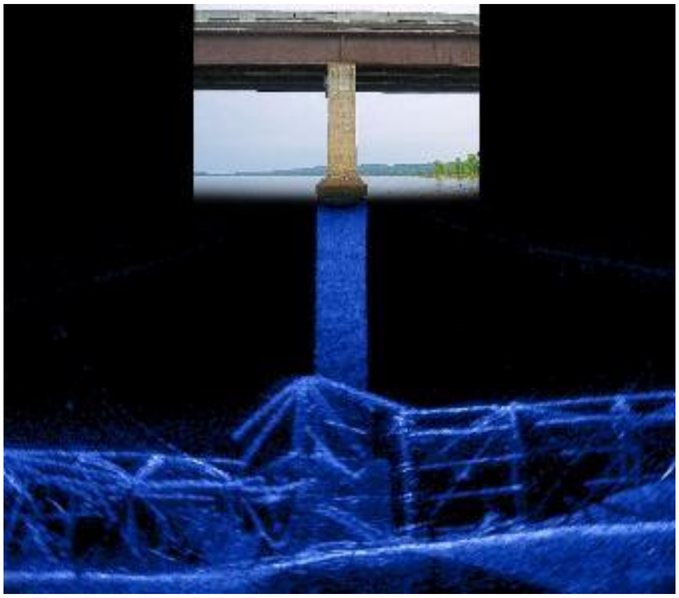


Figure 61. Graphic. Combined acoustic image with abandoned structure restricting diver access. (Source FHWA).

The typical minimum inspection equipment carried with a diver should include a cleaning device, a measuring tool, and a light. Typically, an axe or scraper can be used for cleaning most surfaces. Folding rulers are the preferred measuring device for most inspectors. However, a scale could be etched into the handle of a cleaning device and used as a measuring tool. Most underwater bridge inspections are performed in low visibility conditions, resulting in the diver not being able to see the marks on a ruler or tool; therefore, the divers should be prepared to take measurements tactilely. Tactile measurements can be accomplished by knowing the dimensions of the tools and equipment they carry and the lengths of various body parts like fingers, hands, and arms. In extremely low visibility conditions, defect dimensions may have to be approximated. The diver should be as accurate as possible for the given conditions, and the report should include an explanation of the limitations.

Additional tools, outside of standard inspection tools typically carried by divers, are often needed to investigate and document defects properly. Supplemental tools include cameras, more accurate measuring devices, specialized instruments, and NDT equipment. These tools should be outlined in the underwater inspection plan and located on-site when applicable. These additional tools can be sent to the divers from the team members on the boat when practical. In many instances, the diver may need to come to the surface to retrieve tools from the boat. Also, pneumatic or hydraulic tools may be needed to clean heavy marine growth or remove debris.

As discussed, many underwater bridge inspections occur in limited visibility situations. When there is little to no visibility, underwater inspections are performed using tactile techniques instead of visual inspection. This technique involves the divers moving their hands and arms in a sweeping motion to cover the structure's surface area. Using tactile techniques can be further complicated in high water flow, where rigging lines could be needed to provide access to all surfaces. The diver may have to hold onto a rigging line while performing a sweeping motion with the other arm. If an SSA system is used for diving operations, the diver may be able to use the diver's umbilical to assist in moving around the pier.

A key role in the inspection process is to investigate and document scour and any undermining of substructures and assess scour countermeasures if present. A detailed discussion of bridge scour and scour countermeasures is presented in Chapter 7. Inspection Reports and Component Ratings.

5.2.1 Piers and Abutments

Piers and abutments are typically inspected from the channel bottom up, with the diver first assessing scour conditions before moving up the vertical surfaces. It is typically diver preference whether the inspection begins at a substructure's upstream or downstream side. If a boat is used for the inspection, the anchor point on the substructure unit and the boat orientation may dictate where the diver begins the inspection. However, if the water flow is high, it is generally easier for the diver to descend on the downstream nose where an eddy normally exists to mitigate flow velocity. The diver generally wants to be more heavily weighted to allow an easier descent in fast-flowing water and greater buoyancy control. As previously discussed, rigging lines may be needed to allow the diver to work against the current to inspect all vertical surfaces.

The inspection pattern should be systematic to better facilitate a thorough inspection. Many divers prefer to inspect one face of a substructure at a time, generally working in a back-and-forth pattern moving up from the channel bottom to the water surface with the upstream or downstream nose inspected at each turn. Refer to Figure 62 for an illustration of the typical pattern for inspecting a pier or abutment. If a footing or seal is exposed, the diver should inspect the lowest component first before moving up to the next.

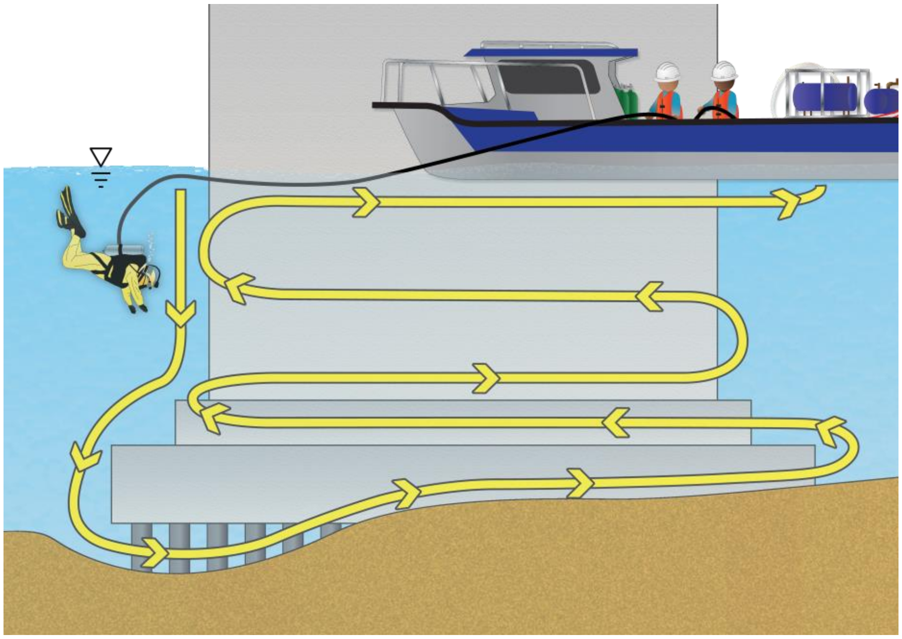


Figure 62. Illustration. Inspection pattern for pier wall with footing and seal.

It is important to accurately document seal and footing exposure and compare it to past inspection results. If undermining is present, the diver should take measurements to provide the undermined area's volume that may be needed for a countermeasure design or structural analysis. This can safely be accomplished using probe rods, especially if the structure/material above the undermined area could be unstable.

Timber debris may be present around piers or abutments in rivers flowing through wooded areas. Timber debris typically becomes lodged on the upstream nose of a pier wall and may be embedded in the channel bottom or suspended in the water column. Floating or suspended timber debris can be unstable, and divers should use caution working around it and generally avoid penetrating beneath it.

Construction debris can be present on the channel bottom, or remnants of the construction forming materials may remain attached to concrete surfaces. These can snag the diver's umbilical and impair the ability of the diver and topside crew to locate and retrieve the diver. Therefore, a floating umbilical is generally more desirable when underwater bridge inspections as it is less likely to snag on debris. Figure 63 is a combined acoustic image and an above-water photograph showing large debris leaning against a pier footing, illustrating entrapment hazards commonly encountered by divers.

Figure 63. Graphic. Combined acoustic image of pier with debris lodged against footing. (Source FHWA).

5.2.2 Piles

Pile bents can be inspected by a two-diver team using commercial SCUBA because it allows the divers to freely move up and down piles without regard to umbilical management. However, the two divers can only be untended when a line of sight with each other can be maintained throughout the inspection. Conditions may warrant the use of SSA equipment or line-tended SCUBA be used for inspection. If this is the case, divers should be aware of how they move between piles to prevent fouling.

In good visibility, a diver may be able to inspect all sides of a pile while descending or ascending an individual pile, freely moving from pile to pile while on the bottom (Figure 64). However, in poor visibility where adjacent piles are not visible, the diver may need to descend one side of a pile inspecting two quadrants and then ascend the opposite side while inspecting the remaining two quadrants, moving between piles on the surface. Site conditions, equipment, and bent configuration typically determine the best approach.

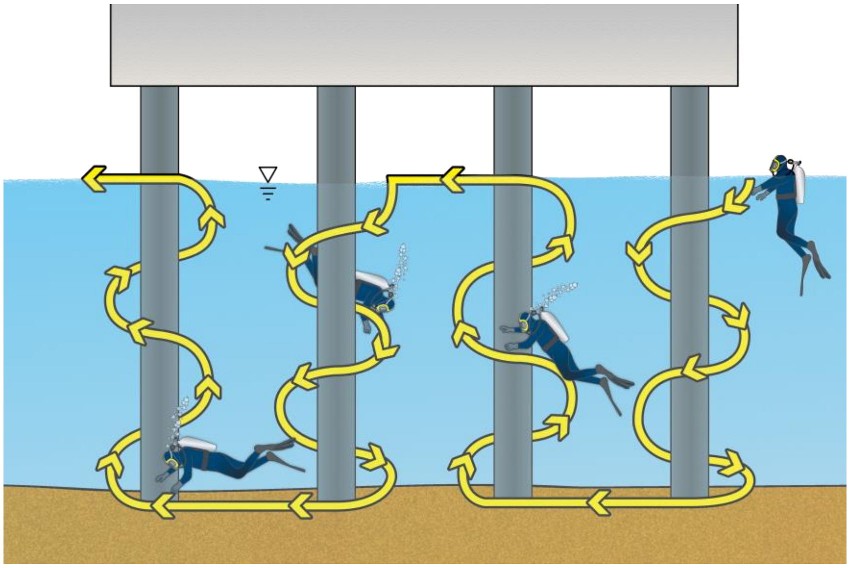


Figure 64. Illustration. Inspection pattern of pile bent in good visibility.

5.2.3 Waterline Footings

Waterline footings present unique challenges for diving operations. They consist of a footing at the water surface supported by multiple piles or drilled shafts extending into the channel bottom. Smaller waterline footings can have as few as five piles supporting them, while large footings can have 50 or more. Refer to the combined acoustic image in Figure 65 of a column bent with two pile-supported waterline footings.

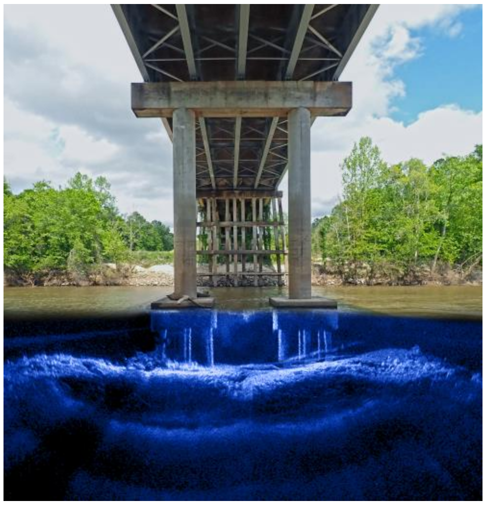


Figure 65. Graphic. Acoustic scan of a waterline footing supported by piles. (Source FHWA).

Waterline footings are considered penetration dives because the diver does not have free access to the surface when underneath them, and SSA equipment should be used for diving operations. Additionally, it is quite easy for a diver to become disoriented under the footing when inside the pile cluster.

A planned approach to inspecting the piles is necessary for umbilical management and inspection accuracy. Figure 66 illustrates an inspection pattern used to inspect piles below the footing.

Effective communication between the diving supervisor and the divers is needed to ensure proper diver orientation is maintained, and notes are recorded on the correct piles.

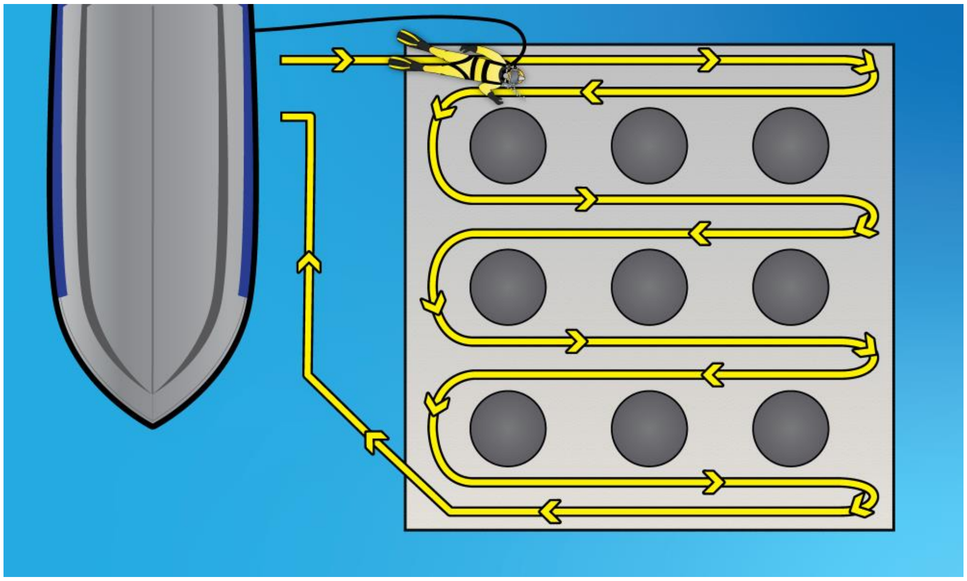


Figure 66. Illustration. Inspection pattern under a waterline footing with SSA.

5.2.4 Drilled Shafts and Large Circular Piers

Drilled shafts are deep foundations drilled into the channel bottom. Refer to the example in Figure 67. Typically, a steel casing is used to form the shaft from below the channel bottom to the design top of the shaft. The steel casing typically ends just below the channel bottom during construction. Over time, scour can expose the shaft below the casing termination point, presenting a rough surface distinctly different from the smooth surface created by the formwork. Drilled shafts can be as small as a few feet in diameter to more than 15 feet in diameter.

Figure 67. Graphic. Combined acoustic image of a drilled shaft bent configuration. (Source FHWA).

Drilled shafts, or similarly circular piers, present a challenge to divers because it is easy to get disoriented on the shaft without corners to use as a reference. The shaft formwork sometimes leaves seams on the shaft, which can help with determining orientation. A typical method to maintain orientation is to drop a downline on one side of the shaft with a heavy weight on the end. In good visibility conditions, the downline provides a visual reference for the diver to ensure they have circled the entire shaft. In poor visibility, the diver may have to go up and down the shaft multiple times, inspecting one specific quadrant at a time. Again, staying oriented is particularly important to ensure the entire shaft is inspected. The diver's position can also be monitored by topside personnel using their bubbles if no flow is present, or the diver can use the direction of flow to stay oriented when flow is present. However, a cluster of drilled shafts can cause the flow direction to become turbulent and vary, so additional precautions should be taken.

5.2.5 Cells, Cofferdams, and Bulkheads

The inspection procedure for cells, cofferdams, and bulkheads is similar to that for piers. These types of structures can be constructed of timber, steel, or concrete. The inspector should also note the size, location, and condition of any scour countermeasures placed at the base of these units and document scour conditions. See Figure 68 for a typical sheet pile bulkhead inspection pattern.

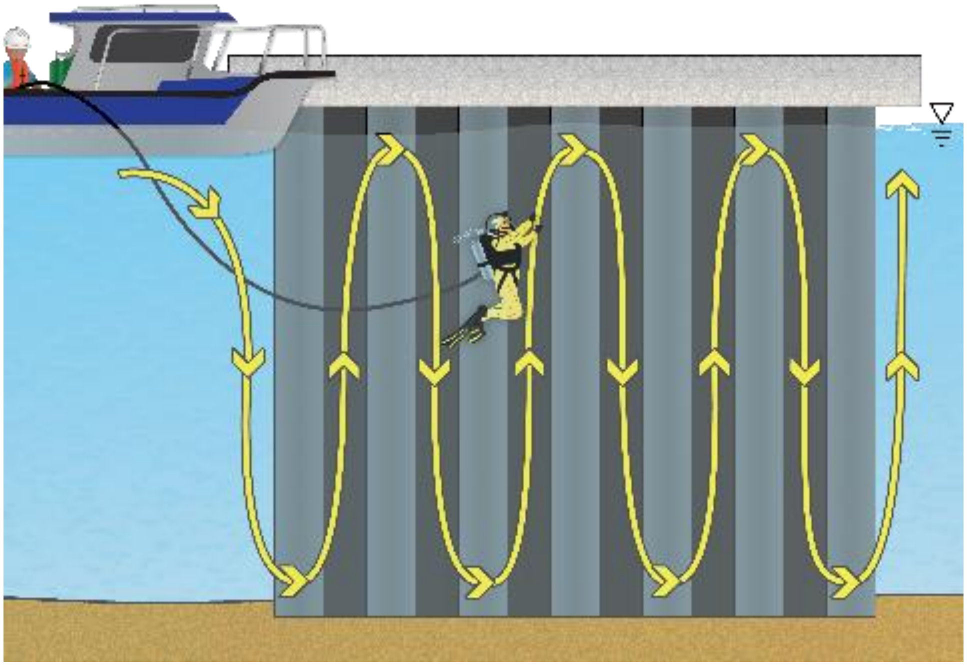


Figure 68. Illustration. Inspection pattern of steel sheet pile bulkhead.

5.3 SPECIAL TESTING, LEVEL 3 INSPECTION

Special testing techniques, referred to as Level 3 inspections, may be needed to gather additional information when the Level 1 and Level 2 inspections are inadequate. Additionally, in-depth inspections for repair design or load rating may require data that the more robust Level 3 inspection can only collect. Devices used for Level 3 inspections typically rely on sensitive instrumentation that may require calibration before use. The user should refer to the manufacturer’s guidance for proper use and calibration procedures.

5.3.1 Steel

During an underwater inspection, corrosion is the most common mode of deterioration encountered when inspecting steel members. Corrosion can generally be first identified through Level 1 and Level 2 inspections. However, a Level 3 inspection is often needed to properly document the full extent of deterioration. Special testing techniques can also be used to determine if the steel has protection against corrosion or to locate cracks in welds or other defects.

5.3.1.1 Ultrasonic Thickness Measuring Device

Inspectors should measure the remaining thickness of corroded members to assess deterioration and compare it to historical readings. The load rater and designers also use the remaining thickness when preparing repair plans. Rulers and calipers, which are part of the standard inspector's equipment, cannot measure the remaining web thickness of steel H-piles, the remaining thickness of steel sheet piles, or the wall thickness of pipe piles accurately.

Underwater ultrasonic thickness measuring devices are designed to measure steel thickness quickly and accurately. The device sends a sound wave through the steel member to its back face, where the sound wave is reflected 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 placed on one side of the member. The steel thickness is then populated on a digital display. The display is typically secured to the diver, who communicates the thickness readings to topside personnel. Some devices utilize a topside display with the transducer connected by a long cable.

When using an ultrasonic thickness measuring device underwater, the steel member must have a clean surface to gather accurate readings. The diver should scrape marine growth off the surface of the steel, where thickness measurements will be collected, as shown in Figure 69. Additionally, rust scale and any loose protective coating should be removed using a wire brush or another abrasive tool. It may be difficult to obtain an accurate measurement if the steel is very rough or badly pitted. If the inspector is unable to collect accurate measurements using an ultrasonic thickness gauge, a pit gauge can be used as an alternative to measure the depth of pitting. While a pit gauge is less precise, it typically is a reliable alternative. There are, however, special transducers that can be used to help overcome this problem.

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

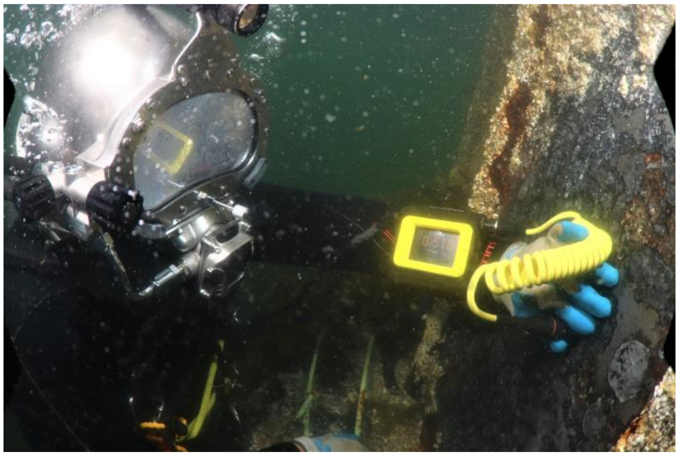


Figure 69. Photo. Diver measuring steel thickness with an underwater ultrasonic thickness gauge. (Source FHWA).

5.3.1.2 Cathodic Protection Gun (CP Gun)

There may be instances where steel bridge members, such as steel piles or steel reinforcement, are corroded by a galvanic cell process. As discussed in Section 3.3.2.3, galvanic corrosion is more commonly observed on members exposed to saltwater or brackish water. Substructures in such an environment may have a cathodic protection system installed. If a cathodic protection system is present, a CP gun can be used to determine the effectiveness of the system by measuring the corrosion potential in the steel member (Figure 70).

Figure 70. Photo. Diver using an underwater CP gun to measure electrical current on steel pile. (Source FHWA).

The corrosion potential readings are displayed in units of millivolt (mV) as a negative value. Readings will generally range from -1150 mV to -500 mV, with the higher absolute value indicating the presence of cathodic protection and the lower absolute value indicating no protection. However, readouts may vary among different CP guns, and the operation manual from the manufacturer should be referenced prior to field use. The operation manual should include a range of corrosion potentials with corresponding interpretations and actions for each range.

When using a CP gun to evaluate the effectiveness of a cathodic protection system, the diver should thoroughly clean the test area to bare steel to facilitate accurate readings. The location of each test site should be noted and referenced to a fixed location.

5.3.1.3 Magnetic Particle Testing (MPT)

Another underwater steel NDT technique is MPT. This technique identifies cracks in welds or defects in steel plates. It is not commonly used in underwater bridge inspection because water flow disrupts the test, and steel substructure elements typically do not have welded connections. The process requires the operator to induce a magnetic field into the steel member on both sides of the suspected defect. Then, a liquid suspension containing a fluorescent dye and ferromagnetic particles is applied. If a flaw is present, the particles flow along the flaw, and the inspector can photograph the particle pattern to document the results. As with the ultrasonic testing system, the testing area should be carefully cleaned to obtain reliable results.

5.3.2 Concrete

Several NDT methods for in-depth inspections can be performed on concrete underwater. However, some modifications to the equipment may be needed if it is not specifically designed for underwater use. All modifications should be consistent with the manufacturer’s procedures and recommendations.

5.3.2.1 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 (Figure 71). The device locates discontinuity and relatively low-strength areas, such as cracks and voids. When taking measurements, the transducers are generally arranged in one of two different positions. The first method is the direct transmission method. For the direct method, the transducers are placed on opposite sides of the member, as shown in Figure 72. This method typically provides the most accurate results.

Figure 71. Photo. Ultrasonic pulse velocity meter with waterproof cables and transducers. (Source FHWA).

The second method is the indirect transmission method, with the transducers on the same side of the member, as shown in Figure 73. This method uses correction factors to interpret the data.

When using this method on concrete piles and columns, measurements should be taken through the member at a minimum of two perpendicular directions at each elevation examined.

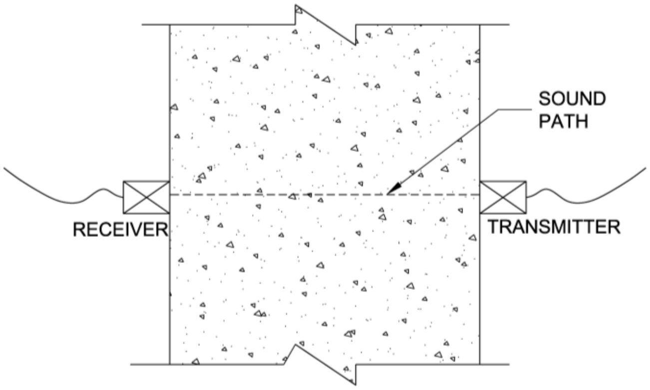


Figure 72. Illustration. Diagram of direct transmission method.

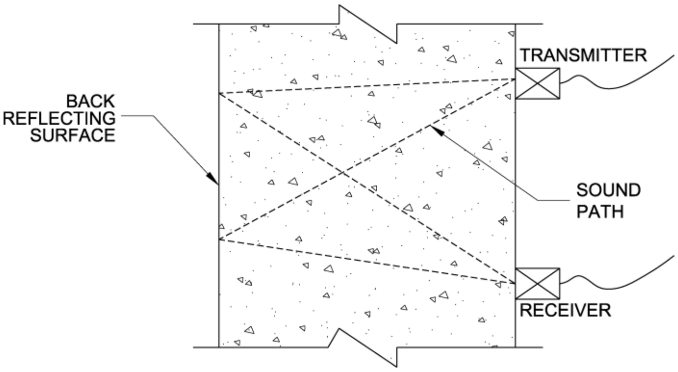


Figure 73. Illustration. Diagram of indirect transmission method.

5.3.2.2 Rebound Hammer

The rebound hammer is a mechanical device used to estimate the compressive strength of in-place concrete based on its surface hardness. The hammer is placed in a waterproof housing, and a special underwater scale is used, as shown in Figure 74.

The diver places the hammer on the concrete surface and presses against the spring-loaded plunger until a mass within the hammer is released, causing an impact. The resulting data is used to estimate the strength of the concrete.

Figure 74. Photo. Rebound hammer in an underwater housing. (Source FHWA).

5.3.2.3 Rebar Locator

The rebar locator, often referred to as the R-meter, can be used to determine the location and depth of clear cover over reinforcing steel in concrete. The device uses a low-frequency magnetic field to locate the steel. However, rebar locators generally need an underwater housing unit for underwater use, as shown in Figure 75. Therefore, this testing method is of limited value in heavily reinforced structures where obtaining depth readings of individual bars is challenging.

Figure 75. Photo. R-meter installed in an underwater housing. (Source FHWA).

5.3.2.4 Coring

Coring is a partially destructive test method and can be used alone or to verify and correlate data from NDT methods. Specially designed hydraulic coring equipment is readily available for underwater use (Figure 76). Cores can be tested in a laboratory. Coring locations should be selected to minimize the chances of hitting internal reinforcing steel. Steel samples can also be taken from cores if needed. Core holes should be patched upon completion.

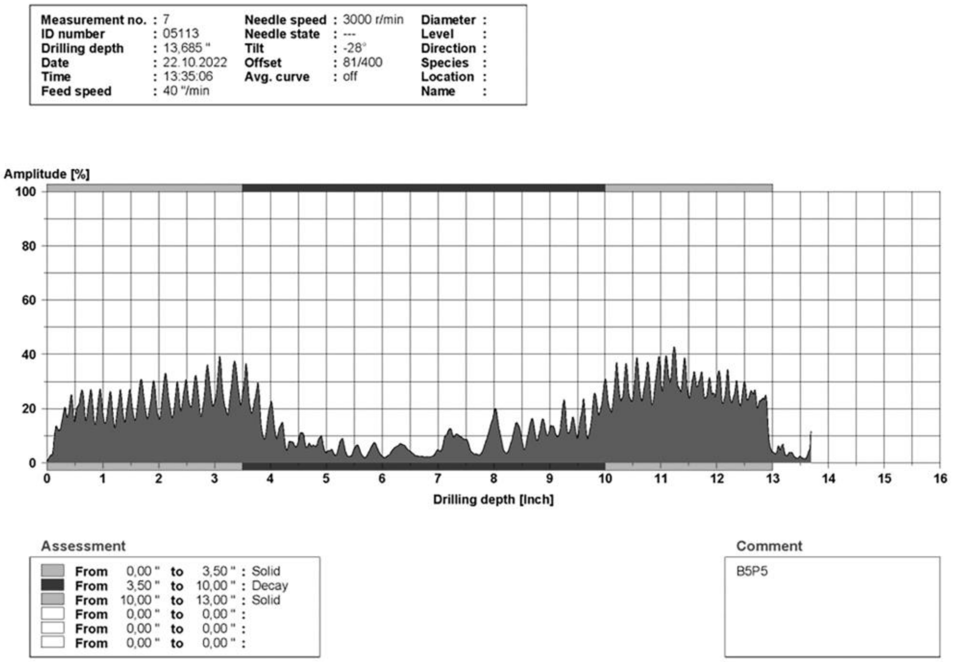
Figure 76. Photo. Diver extracting a concrete core from a bulkhead. (Source FHWA).

5.3.3 Timber

When suspected decay is encountered, it can be verified using advanced inspection methods. Advanced inspection methods are also deployed to determine the moisture content, timber species, or penetration of preservatives. While advanced inspection methods for timber can be nondestructive, destructive testing methods like drilling and probing are more commonly used in the field.

5.3.3.1 Timber Resistance Drill

The most accurate method for testing timber members for internal decay is an underwater timber resistance drill. This device advances a 1mm paddle bit through the member and measures the encountered resistance. A digital chart is created to illustrate the relative resistance of the cross-section. Low resistance readings indicate an area of decay, as illustrated in Figure 77. See the diver using device in Figure 78. The information can be used to develop the remaining timber section of the timber member. The hole created by the timber resistance drill can be plugged with a preservative-soaked toothpick or caulking.



Measurement no. : 7
ID number : 05113
Drilling depth : 13,685 "
Date : 22.10.2022
Time : 13:35:06
Feed speed : 40 "/min

Needle speed : 3000 r/min
Needle state : ---
Tilt : -28°
Offset : 81/400
Avg. curve : off

Diameter :
Level :
Direction :
Species :
Location :
Name :

Assessment

▨ From 0,00 " to 3,50 " : Solid
■ From 3,50 " to 10,00 " : Decay
▨ From 10,00 " to 13,00 " : Solid
□ From 0,00 " to 0,00 " :
□ From 0,00 " to 0,00 " :
□ From 0,00 " to 0,00 " :

Comment

B5P5

Figure 77. Graph. Example of timber resistance drill output illustrating areas of decay.

Figure 78. Photo. Diver using an underwater timber resistance drill. (Source FHWA).

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. Therefore, the inspection should be supplemented with pile perimeter or diameter measurements.

5.3.3.2 Timber Core Samples

The timber species may be needed to complete an accurate load rating on a bridge. If the timber species is unknown, core samples can be extracted from a timber substructure and sent for laboratory testing to identify the species. Core samples can also indicate the depth of preservative penetration into a timber member. Figure 79 shows a diver removing a core sample for laboratory testing and evaluation. The hole remaining after a core is extracted should be plugged with a preservative-treated hardwood dowel.

Figure 79. Photo. Diver extracting a core sample from a timber pile. (Source FHWA).

When collecting core samples to assess the presence of bacterial decay, special care should be taken to avoid transferring bacteria and other destructive organisms to other timber members. Timber boring tools should be cleaned after each core extraction to avoid transferring organisms between members.

5.3.3.3 Timber Pile Wraps

Timber pile wraps are typically used in salt water and brackish environments to eliminate marine borer infestations. See the example in Figure 80 of a timber pile bent with a wrapped pile in the foreground. 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. A sample of wrapped piles should be unwrapped, if necessary, to determine the condition of the structure with certainty.

Figure 80. Photo. Timber pile bent with wrapped piles. (Source FHWA).

CHAPTER 6. SCOUR AND CHANNEL INSPECTIONS

6.1 BACKGROUND

Scour is the result of the erosive action of flowing water, excavating, and carrying away material from the bed and banks of streams and from around the piers and abutments of bridges. Materials scour at different rates. Loose granular soils are rapidly eroded by flowing water, while cohesive or cemented soils are more scour resistant. However, ultimate scour in cohesive or cemented soils can be as deep as scour in sand-bed streams. Under constant flow conditions, scour can reach maximum depth in sand and gravel bed material in hours; cohesive bed material in days; glacial till, sandstones, and shale in months; limestone in years; and dense granite in centuries.

Determining the magnitude of scour is complicated by the cyclic nature of some scour processes. Scour can be deepest near the peak of a flood but hardly visible as floodwaters recede and scour holes refill with sediment. Since most underwater inspections occur during low water periods, the underwater inspector should understand how to identify infilling and evaluate total scour post-flood event.

6.2 BASIC CONCEPTS

The total scour at a bridge is comprised of three primary components:

- Long-term degradation
- Contraction scour
- Local scour

Additionally, the inspector should be aware of and document other types of scour that can occur under specific situations, such as lateral migration of the waterway.

6.2.1 Long-term Degradation

Aggradation and degradation are long-term streambed elevation changes due to natural or human-induced causes within reach of the river on which the bridge is located. Aggradation involves the deposition of material eroded from the channel or watershed upstream of the bridge and, as such, is not a component of total scour. Degradation involves the lowering or scouring of the streambed over relatively long reaches due to a deficit in sediment supply from upstream and contributes to total scour. Things that can cause long-term channel degradation include the following:

- Dams and reservoirs
- Land use changes upstream (increasing runoff)
- Channel straightening (human-made or natural)
- Channel material mining downstream or upstream
- Water diversion into or out of the waterway

6.2.2 Contraction Scour

Contraction scour is a lowering of the streambed across the stream or waterway bed at the bridge due to a restriction of the hydraulic opening. This lowering may be uniform across the bed or non-uniform; the scour depth may be deeper in some parts of the cross-section. Contraction scour results from contraction (or constriction) of the flow, which removes material from the bed across all or most of the channel width. Contraction scour is different from long-term degradation in that contraction scour occurs in the vicinity of the constriction or bridge, may be cyclic, and related to the passing of a flood. See the illustration in Figure 81.

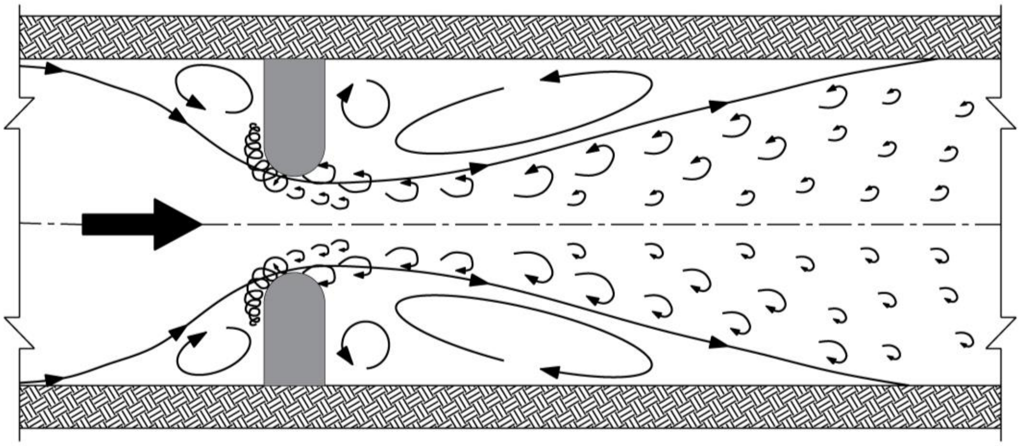


Figure 81. Illustration. Turbulence generated by a narrowing of the channel by bridge abutments or embankment fill.

6.2.3 Local Scour

Local scour involves the removal of material from around piers, abutments, spurs, and embankments. It is caused by an acceleration of flow and resulting vortices generated by obstructions to the flow. Figure 82 illustrates the flow around a column substructure and the resulting vortices.

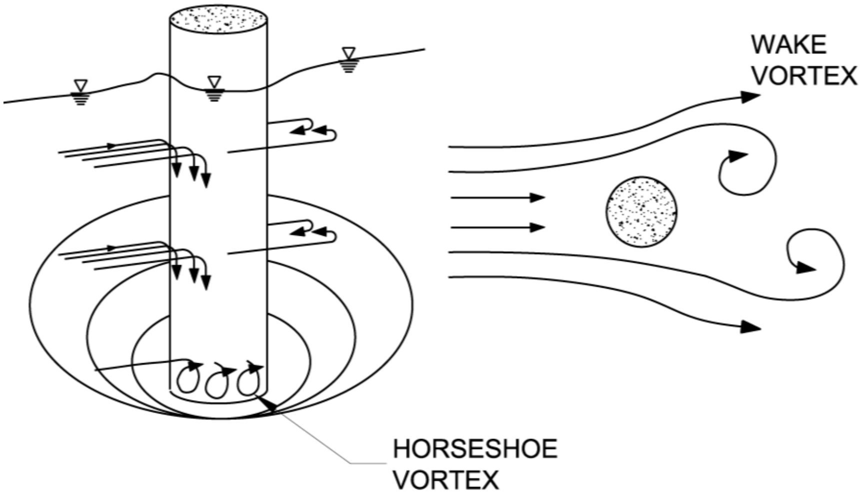


Figure 82. Illustration. Local scour at a cylindrical pier.

Piers located within a waterway are an obstruction to flow, with their geometry and orientation having a direct influence on the depths of local scour. For example, a square-nose pier will have maximum scour depths approximately 20 percent greater than a sharp-nose pier. Substructure alignment relative to flow direction, commonly referred to as the angle of attack, can also affect local scour depths at piers or abutments. When a pier is not aligned with the path of flow, it effectively increases the width of the pier and reduces the capacity of the waterway. Ice and debris buildup can have a similar effect. Additionally, floating timber debris accumulating at a pier on the surface can cause the flow to plunge downward towards the base of the pier, significantly increasing the rate and maximum depth of scour.

Local scour typically presents as a conical depression in the streambed at the upstream nose of a substructure. If local scour is observed, the location and dimensions of the scour hole should be thoroughly documented.

6.2.4 Lateral Migration

Naturally occurring lateral migration of the main channel of a stream or river over time may affect the stability of piers near the waterway. Flood events can accelerate normal migration or, in extreme circumstances, alter the alignment of the entire channel eroding abutments or the approach roadway. Signs of lateral migration, such as concave banks and exposed tree roots, are shown in Figure 83. Lateral migration adds to the total scour at a bridge crossing when present.

Figure 83. Photo. Channel migration threatening stability of bridge pier. (Source FHWA).

6.2.5 Total Scour

Total scour is the cumulative effect of long-term degradation, contraction and local scour, and lateral migration.

6.3 SCOUR CONDITION RATING NBI ITEM B.C.11

6.3.1 General

The underwater inspector will typically assign a scour condition rating, NBI Item B.C.11, to the bridge based on the observed scour conditions. When evaluating this item, the team leader should review the scour vulnerability, NBI Item B.AP.03, to determine the impact of the observed scour on bridge stability.

6.3.2 Scour Vulnerability Rating Values, NBI Item B.AP.03

Scour vulnerability is assigned after a scour appraisal is completed by a multidisciplinary team of hydraulic, geotechnical, and structural engineers. The underwater inspection team cannot change this rating in the NBI. However, when observed scour conditions are not consistent with the scour vulnerability assigned to the bridge, it could indicate that the scour appraisal requires re-evaluation.

The codes in Table 11 are used to assign a scour vulnerability to the bridge. The value assigned guides how the underwater inspection team codes the scour condition rating NBI Item B.C.11.

Table 11. Scour vulnerability coding, SNBI - B.AP.03

Code	**Description**
0	Scour appraisal has not been completed.
A	Scour appraisal completed. Bridge determined to be stable for scour.
B	Scour appraisal completed. Bridge determined to be stable for scour, dependent upon designed, and functioning countermeasures.
C	Scour appraisal completed. Bridge could become unstable for scour. Temporary (not designed) countermeasure installed to mitigate scour. Bridge is scour critical.
D	Scour appraisal completed. Bridge is, or may become, unstable for scour. Bridge is scour critical.
E	Scour appraisal has not been completed. Temporary (not designed) countermeasure installed to mitigate scour.
U	Scour appraisal has not been completed due to unknown foundations.

6.3.3 Scour Condition Rating, NBI Item B.C.11

When the underwater inspection team leader assigns the scour condition rating, they should consider various elements of the original bridge design or scour appraisal. This data can include design scour depth, scour evaluation results, or published POAs for the bridge.

The team leader should report the scour condition that represents the observed or measured scour using one of the codes in Table 12. The entire code description must be satisfied for the code to apply (SNBI, 7.1). A scour condition rating example is shown in Figure 84. The rating in the caption was assigned based on observed scour in the combined acoustic image and the descriptions in Table 12. Consultation with a hydraulics engineer may be necessary to assist in assigning this rating.

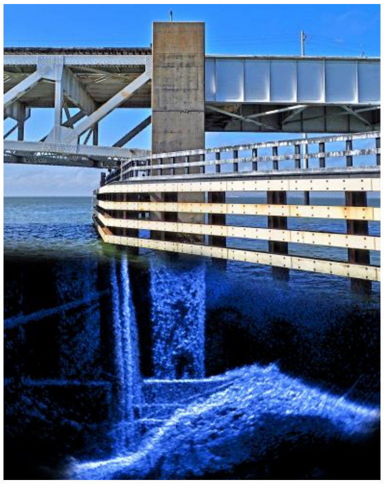


Figure 84. Graphic. Combined acoustic image illustrating scour at bridge pier resulting in vertical seal exposure, item B.C.11 rating code of 5. (Source FHWA).

Table 12. Scour condition rating, SNBI - B.C.11.

Code	**Condition Description**
N	Bridge does not cross over water.
9	No scour.
8	Insignificant scour.
7	Some minor scour.
6	Widespread minor or isolated moderate scour.
5	Moderate scour; strength and stability of the bridge are not affected.
4	Widespread moderate or isolated major scour; strength and/or stability of the bridge is affected.
3	Major scour; strength and/or stability of the bridge is seriously affected. Condition typically necessitates more frequent monitoring, load restrictions, and/or corrective actions.
2	Major scour; strength and/or stability of the bridge is severely compromised. Condition typically necessitates frequent monitoring, significant load restrictions, and/or corrective actions to keep the bridge open.
1	Bridge is closed to traffic due to scour condition. Channel rehabilitation may return the bridge to service.
0	Bridge is closed due to scour condition, and is beyond corrective action. Bridge replacement is needed to restore service.

6.4 CHANNEL COMPONENTS AND CHANNEL PROTECTION DEVICES

6.4.1 General

The channel comprises the banks and streambed that confine the stream. In a broad sense, the channel includes both the main waterway and the floodplain area. Underwater inspections are generally conducted during normal or low flow periods, so the inspection effort generally focuses on the main channel area. However, inspectors should observe the floodplain when possible and document observed conditions if they can adversely impact the bridge crossing or approach roadway. The illustration in Figure 85 shows a common channel configuration and typical terminology used to describe various channel components and protective devices.

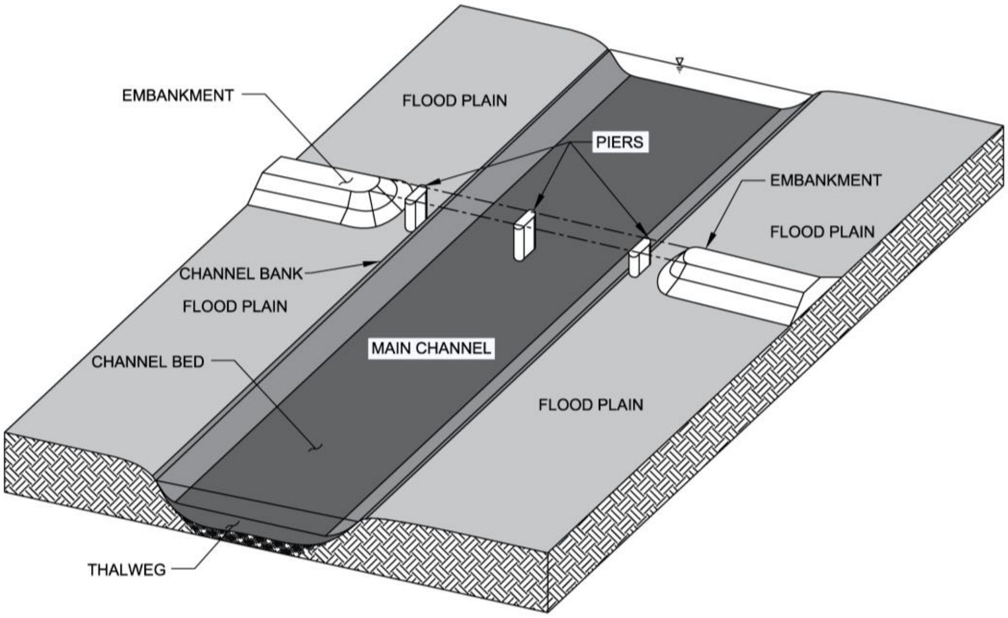


Figure 85. Illustration. Channel components.

6.4.1.1 Bank

The sides of a channel between which the main channel flow is normally confined.

6.4.1.2 Bank Protection or Revetment

An erosion-resistant material placed directly on the bank to protect it from erosion.

6.4.1.3 Bed

Bottom of a channel bounded by banks.

6.4.1.4 Bulkhead

A vertical, or near vertical, wall that supports a bank or an embankment, which can also serve to protect against erosion.

6.4.1.5 Check Dam

A low dam or weir across a channel used to control stage or degradation upstream of its location (Figure 86).

Figure 86. Photo. Check dam downstream of bridge. (Source FHWA).

6.4.1.6 Approach Causeway

Rock or earth embankment carrying a roadway across water approaching a bridge.

6.4.1.7 Spur Dike (groin, spur, jetty)

A structure extending from a bank into a channel designed to encourage sediment deposition along the bank, if permeable, or deflect erosive current away from the streambank, if impermeable (Figure 87).

Figure 87. Photo. Spur dike. (Source FHWA).

6.4.1.8 Flow-control Structure (Baffle)

A structure within or outside a channel that acts as a countermeasure by controlling the direction, depth, or velocity of flowing water (Figure 88).

Figure 88. Photo. Flow control structure (baffle). (Source FHWA).

6.4.1.9 Guide Bank

A dike extending upstream from the approach embankment at either or both sides of a bridge opening to direct the flow through the opening. Some guide banks extend downstream from the bridge (Figure 89).

Figure 89. Photo. Guide bank. (Source FHWA).

6.4.1.10 Levee

An embankment, generally landward of the main channel bank, that confines flow during high-water periods, thus preventing overflow into lowlands.

6.4.1.11 Mattress

A blanket or revetment of materials interwoven or otherwise lashed together and placed to cover an area subjected to scour (Figure 90).

Figure 90. Photo. Mattress installed around bridge pier. (Source FHWA).

6.4.1.12 Riprap

Layer or facing of rock, broken concrete, or similar material dumped or placed to protect a structure or embankment from erosion.

6.4.1.13 Thalweg

The line extending down a channel that follows the lowest elevation of the bed.

6.5 CHANNEL AND CHANNEL PROTECTION RATINGS, NBI ITEMS B.C.09 AND B.C.10

6.5.1 General

The underwater inspector is responsible for documenting the conditions of the channel and channel protective devices at the bridge site by assigning a NBI rating to each of these using the SNBI.

6.5.2 Channel Condition Rating, NBI Item B.C.09

This item is used to provide a condition rating for the channel at the bridge. The channel upstream and downstream should be considered only to the extent that it threatens the bridge and approach roadway. A channel condition rating example is shown in Figure 91. The rating in the caption was assigned based on the observed channel conditions and the descriptions in Table 13. The entire code description must be satisfied for the code to apply (SNBI, Section 7.1). Timber debris impacting the channel should also be considered when assigning the rating.

Figure 91. Photo. Heavy timber debris, Hawaii DOT, B.C.09 rating 3. (Source FHWA).

Table 13. Channel condition rating, SNBI - B.C.09.

Code	**Condition**	**Condition Description**
N	NOT APPLICABLE	Bridge does not cross over water.
9	EXCELLENT	No defects.
8	VERY GOOD	Inherent defects only.
7	GOOD	Some minor defects.
6	SATISFACTORY	Widespread minor or isolated moderate defects.
5	FAIR	Moderate defects; bridge and approach roadway are not threatened.
4	POOR	Widespread moderate or isolated major defects; bridge and/or approach roadway are threatened.
3	SERIOUS	Major defects; bridge or approach roadway is seriously threatened. Condition typically necessitates more frequent monitoring, load restrictions, and/or corrective actions.
2	CRITICAL	Major defects. Bridge or approach roadway is severely threatened. Condition typically necessitates frequent monitoring, significant load restrictions, and/or corrective actions in order to keep the bridge open.
1	IMMINENT FAILURE	Bridge is closed to traffic due to channel condition. Channel rehabilitation may return the bridge to service.
0	FAILED	Bridge is closed due to channel condition and is beyond corrective action. Bridge location or design can no longer accommodate the channel, and bridge replacement is needed to restore service.

6.5.3 Channel Protection Condition Rating, NBI Item B.C.10

Item B.C.10 is used to provide a condition rating for channel protection devices. The condition and effectiveness of channel protection devices installed on banks or in the stream to mitigate channel issues that may impact the bridge should be evaluated. When reporting this item, erosion and scour, damage (unraveling, displacement, separation, and sagging), and material defects (scaling, abrasion, spalling, corrosion, cracking, splitting, and decay) should be considered.

Channel protection devices are considered countermeasures that control, inhibit, delay, or minimize stream instability and scour problems, including river training and armoring countermeasures. River training countermeasures may include spurs, weirs, guide banks, drop structures, and check dams.

A channel protection condition rating example is shown in Figure 92. The rating in the caption was assigned based on the observed embankment protection conditions and the descriptions in Table 14. The entire code description must be satisfied for the code to apply (SNBI, Section 7.1).

Figure 92. Photo. Displaced riprap with erosion, South Carolina DOT, B.C.10 rating 4. (Source FHWA).

Table 14. Channel protection condition ratings, SNBI - B.C.10.

Code	Condition	Condition Description
N	NOT APPLICABLE	Bridge does not cross over water or channel protection devices do not exist.
9	EXCELLENT	Isolated inherent defects.
8	VERY GOOD	Some inherent defects.
7	GOOD	Some minor defects.
6	SATISFACTORY	Widespread minor or isolated moderate defects.
5	FAIR	Some moderate defects; performance of the channel protection is not affected.
4	POOR	Widespread moderate or isolated major defects; performance of channel protection is affected.
3	SERIOUS	Major defects; performance of channel protection is seriously affected. Condition typically necessitates more frequent monitoring or corrective actions.
2	CRITICAL	Major defects; channel protection is severely compromised. Condition typically necessitates more frequent monitoring or corrective actions.
1	IMMINENT FAILURE	Channel protection has failed, but corrective action could restore it to working condition.
0	FAILED	Channel protection is beyond repair and must be replaced.

6.6 CHANNEL AND SCOUR INSPECTION METHODS

The underwater inspector documents the channel condition and channel protection around each substructure unit and measures the extent of scour. These observations are incorporated into the report and form the basis of the ratings discussed in previous sections.

6.6.1 Above-Water Visual Inspection

The inspection team should perform an overall evaluation of all visible channel and channel protection elements at the beginning of each inspection. Information gathered during this initial assessment may prove useful in fine-tuning the diving inspection approach. For example, if timber debris is blocking access to a portion of the bridge, the inspection plan can be modified to mitigate the associated hazard, as illustrated in Figure 93. The river reach in the immediate vicinity of the bridge should be evaluated. Typically, two bridge lengths upstream and one bridge length downstream is an adequate distance. The goal is to extend the inspection far enough to document conditions that could impact the bridge and approach roadway.

Figure 93. Photo. Timber debris lodged upstream of a bridge pier documented during channel above-water inspection. (Source FHWA).

6.6.2 Diver Inspection

Divers can assess overall scour relatively quickly when visibility below water is good. Measurements should be taken at key locations to quantify scour depths and assess any countermeasures that are installed. Figure 94 illustrates where depth measurements are typically taken around the perimeter of a bridge pier footing. When footings are exposed due to scour, the depth to the top of the footing should also be collected to verify the elevation of the footing.

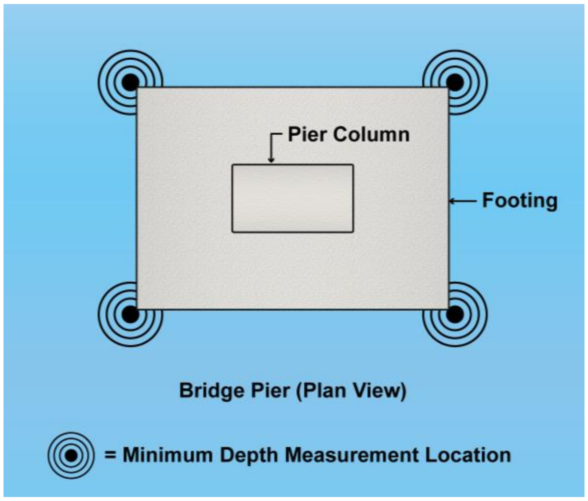


Figure 94. Illustration. Plan view of pier footing illustrating locations of scour depth measurements.

The diver should also probe around the substructure to locate infilling if present. If material has been removed from beneath a substructure unit and undermining is found, the diver should document the volume of the undermined area by measuring the height, width, and penetration under the undermined element. Figure 95 shows a diver collecting penetration measurements of an undermined culvert. This volume is important for possible repair design and to monitor undermining over time, if appropriate. Undermining of a spread footing is more significant than undermining of a pile-supported footing; thus, verifying the foundation type with as-built plans is important when they are available.

Figure 95. Photo. Diver probing undermined culvert to collect penetration depths. (Source FHWA).

6.6.3 Channel Cross-Sections

As discussed in Section 1.3.4, channel cross-sections are typically taken during each underwater inspection cycle. The cross-section is taken along the upstream fascia. Collection of cross-section data can be accomplished in most cases from the bridge deck using a weighted measuring tape, or lead line, with measurements taken at regular intervals (Figure 96). The interval for each measurement depends on how long the bridge is and how varied the channel profile is. Enough data should be gathered to accurately reflect the channel bottom profile and document the location where each measurement is taken so that it can be repeated during subsequent inspection cycles.

Figure 96. Photo. Inspector collecting soundings with an engineer tape from the bridge deck. (Source FHWA).

Most bridge owners gather channel profile information on more than just the upstream fascia to monitor changes more accurately. It is common to take cross-sections both upstream and downstream at set distances from each bridge fascia. Typically, the maximum distance upstream for channel profile information is one bridge length. Bridge owners should establish standards that meet their needs and guide their inspection teams.

Other methods are used when channel profile data cannot be collected using a weighted measuring tape from the bridge deck. These include diver-recorded measurements and depth measurements taken from a boat using a digital fathometer. When these methods are used, depths across the channel along parallel lines at set offsets to the bridge fascia should be recorded and measurements at standard panel points on the bridge (or at set span fractions, quarter points, eighth points, etc.) should be taken. All measurements should be tied to a known elevation on the bridge, that is unlikely to change, so the soundings can be repeated during future inspections. See Figure 97, showing a drawing with sounding data along the fascias and the corresponding channel profiles.

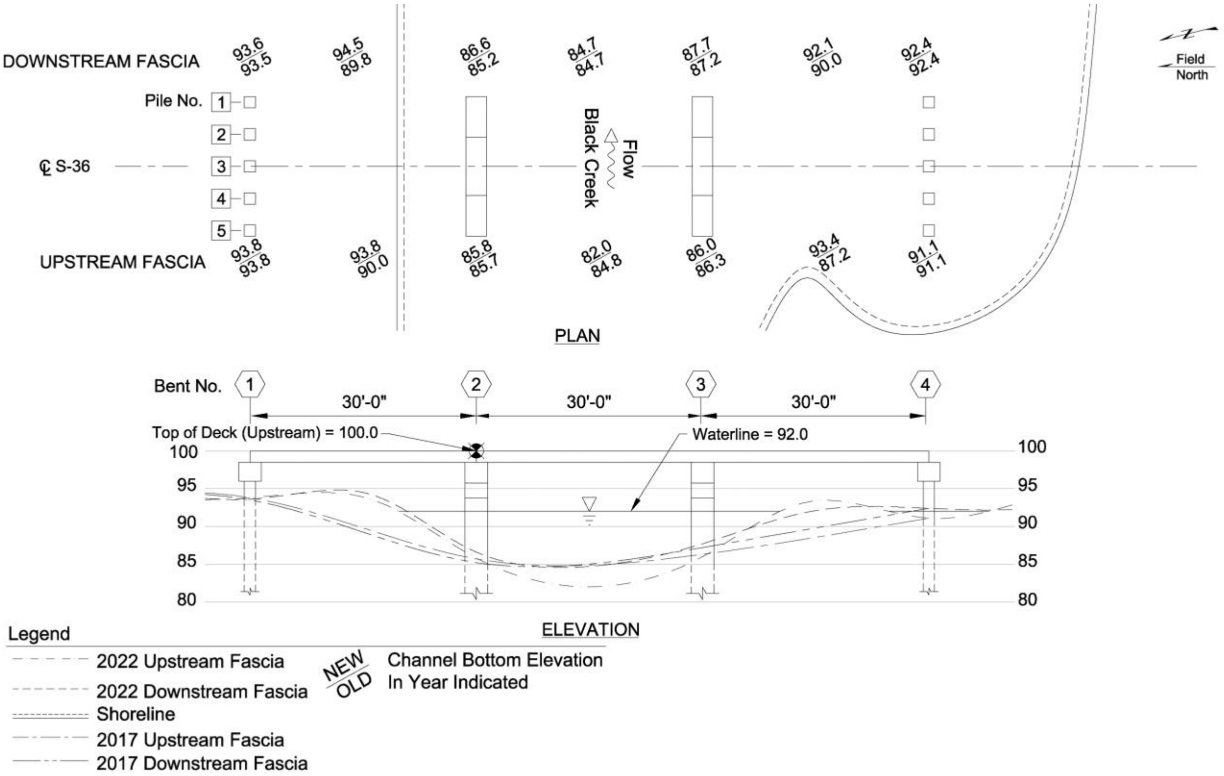


Figure 97. Illustration. Drawing illustrating current and previous channel bottom elevations along the upstream and downstream bridge fascias for scour analysis.

6.7 GEOPHYSICAL INSPECTION

6.7.1 General

After a flood, the stream velocity decreases, resulting in suspended sediment being redeposited into existing scour holes. This deposition 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. In addition to simple hand probing tools, geophysical tools can be used to measure scour after infilling occurs. Geophysical tools include ground penetrating radar and tuned transducer or low-frequency sonar. Each of these methods has advantages and limitations that are described below.

6.7.2 Ground Penetrating Radar

Ground penetrating radar (GPR) can be used to obtain high-resolution, continuous subsurface profiles on land or in relatively shallow water (less than 25 feet). The GPR transmits electromagnetic pulses into the subsurface material and measures the two-way travel time between different channel bottom materials, which is graphically displayed to show infilling.

GPR systems include a transmitter/receiver and an antenna. The transmitter and receiver can be mounted in a small boat, and the antenna deployed over the side of the boat contacting the water surface, as shown in Figure 98.

Figure 98. Photo. GPR antenna being lowered to the water surface. (Source FHWA).

Figure 99 shows a cross-section generated by a GPR signal upstream of a bridge pier. A scour hole located at the pier is approximately seven 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 three feet to the first interface and six feet to the second interface. Thus, the total depth of the scour hole, at least at one time, was about 16 feet deep, not seven feet as soundings would have indicated.

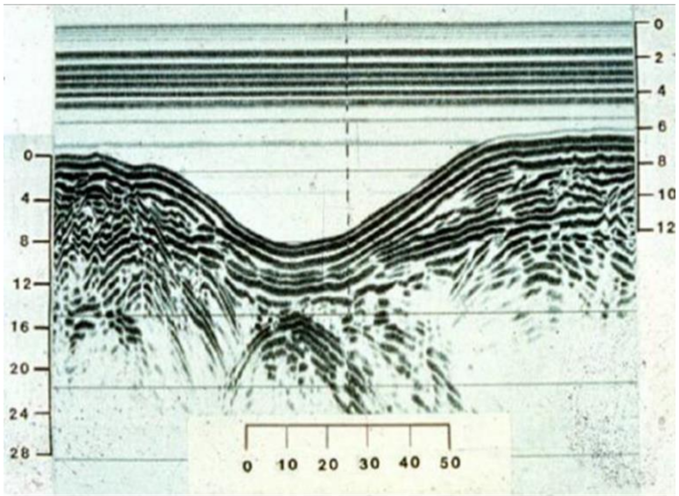


Figure 99. Graphic. GPR record.

6.7.3 Tuned Transducer

The tuned transducer, or low-frequency sonar, is a seismic system that operates through the transmission and reception of acoustic waves. The low-frequency sonar system consists of a transmitter, a receiver, a transducer towed alongside the boat, and a graphic recorder. The transmitter produces a sound wave that is directed toward the channel bottom by the transducer. A portion of the sound wave is reflected to the transducer by the channel bottom surface, and a portion of that signal penetrates the sub-bottom material. Various layers of sub-bottom material also reflect portions of the signal when there is a change in acoustic impedance between the two layers. Figure 100 is the output from a tuned transducer at the same location represented in Figure 99, illustrating the difference in the output of the two systems.

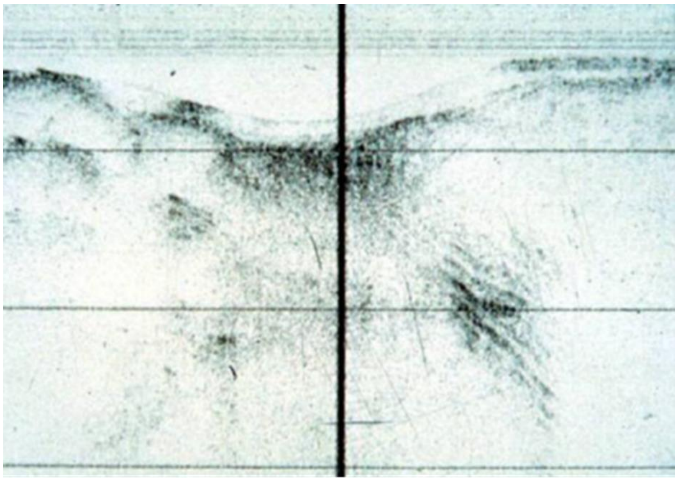


Figure 100. Graphic. Typical tuned transducer output.

6.8 IMAGING TECHNOLOGY

Acoustic imaging technology helps to identify diving hazards before divers enter the water. It also identifies large deficiencies and documents the amount of scour that may extend large distances away from bridge piers. Acoustic imaging can also be deployed during flood conditions when diving conditions are most hazardous and scour is most severe.

6.8.1 2D Imaging

2D images in bridge inspection are collected utilizing a single beam sonar. The sonar head, consisting of a transducer and receiver, is mounted in a stationary location. Once mounted, the sonar head rotates, collecting data at numerous iterations through the rotation to construct a visual representation of the structure and channel bottom below the water. The below-water image is frequently combined with an above-water picture to create a photomontage of the bridge pier above and below water. Figure 101 shows a bridge inspection team preparing to scan the submerged portion of a bridge pier.

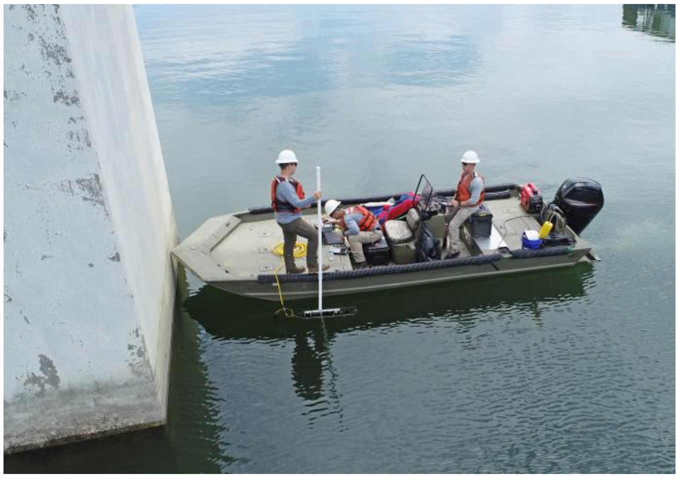


Figure 101. Photo. Inspection team collecting 2D acoustic imaging of a bridge pier as part of underwater bridge inspection. (Source FHWA).

2D imaging is useful for documenting the height of footing exposure, seal exposure, and depth of local scour holes around bridge piers (Figure 102). Additionally, it is helpful in identifying the location and extent of debris and other potential diving hazards (Figure 103). Identified features and defect measurements can be obtained from commercially available software to collect and process the sonar data, creating a to-scale image of the below-water portions of the bridge pier and channel bottom. Note that the further away an object is from the sonar head, the lower the resolution, and the less detail can be displayed.

During data collection of 2D imaging, the sonar head should remain stationary, as any movements can create inaccurate images. Typically, movement can be mitigated by rigidly attaching the sonar head to a vessel, bridge pier access equipment, or another stationary object throughout the duration of a single scan. However, when wave action is created by wind or high currents, it becomes difficult to maintain the sonar head in a stationary position to accurately record data. Additionally, air bubbles near the sonar head during high flow also deteriorate the quality of the collected images.

Figure 102. Graphic. 2D image of scour on a bridge pier. (Source FHWA).

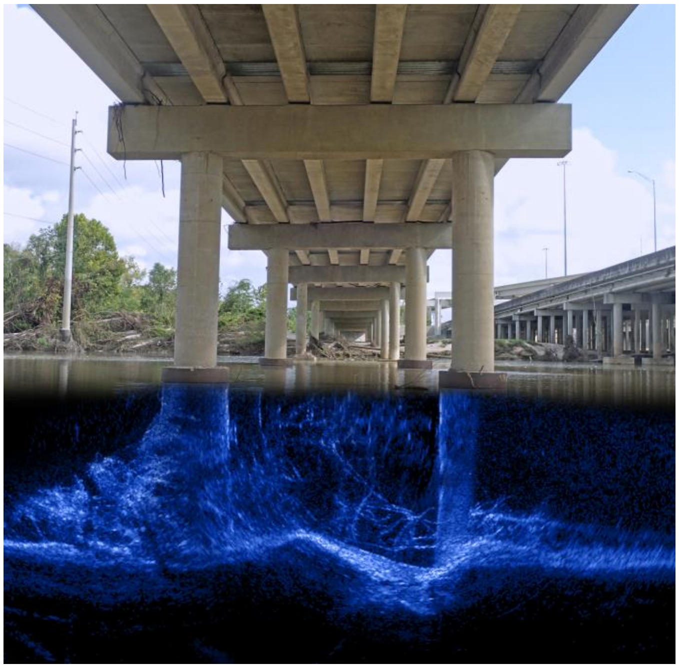


Figure 103. Graphic. Combined acoustic image revealing timber debris below water. (Source FHWA).

6.8.2 3D Imaging

Multi-beam sonar, or 3D imaging, is used to build a point cloud of below-water environments. Within the bridge inspection industry, it is used for hydrographic surveys of channels in the vicinity of a bridge, to create a 3D model of bridge piers and surrounding channel surface, and identify scour or debris in the bridge pier area.

The multi-beam sonar system consists of a sonar head, an inertial reference unit, and two GPS antennae. The system is typically mounted to a vessel, with data collection occurring while the vessel is underway, as shown in Figure 104. Depending on the multi-beam sonar system, a few hundred to several thousand data points are collected multiple times per second to build a point cloud of geo-referenced points. Since this system collects data while the vessel is in motion, it can collect accurate data when there is wave action and higher water velocity; however, air bubbles created near the sonar head can still significantly distort the data.

Figure 104. Photo. Inspection vessel outfitted with a 3D scan system. (Source FHWA).

Every data point collected is georeferenced with an X, Y, and Z coordinate, providing highly accurate data on footing exposure, seal exposure, and volume of scour holes around bridge piers. Figure 105 shows a clearly defined scour depression at the upstream (right) side of the pier wall. Scour depressions can sometimes extend several hundred feet off a bridge pier, making 3D sonar data collection more feasible and effective than 2D sonar.

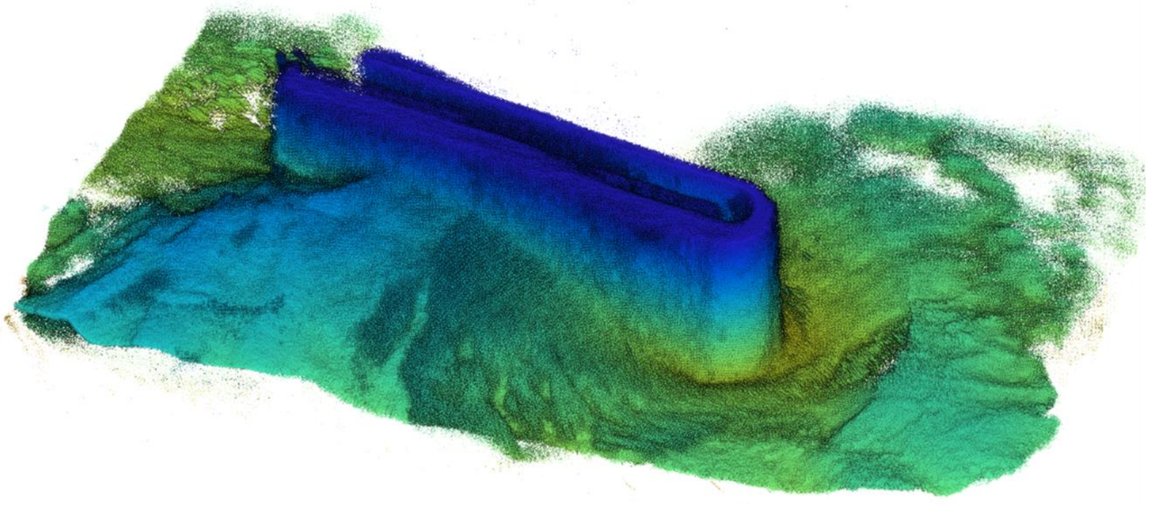


Figure 105. Graphic. 3D sonar of scour hole around the pier. (Source FHWA).

CHAPTER 7. INSPECTION REPORTS AND COMPONENT RATINGS

7.1 INTRODUCTION

7.1.1 General

The underwater bridge inspector provides information about bridge and channel conditions below the normal high waterline. This information is combined with above-water data and used by the bridge owner to manage future structure maintenance, rehabilitation, and replacement planning and budgeting. The bridge owner typically submits condition information of all bridges within its area of responsibility to its State. The individual States then report all bridge condition information to the FHWA through a yearly report using NBI data. The FHWA subsequently reports to Congress on the condition of the bridges within the United States.

7.1.2 National Bridge Inventory Reporting

The basis for coding and reporting bridge information in the NBI is detailed in the SNBI. As previously discussed, the underwater inspector is responsible for reporting the condition of the following NBI items during the underwater inspection:

B.C.09 Channel Condition Rating
B.C.10 Channel Protection Condition Rating
B.C.11 Scour Condition Rating
B.C.15 Underwater Inspection Condition

Item B.C.15 represents the condition of the underwater portion of a bridge substructure that is typically submerged and inaccessible during a routine inspection. Item B.C.03 represents the condition of the entire substructure; therefore, the underwater inspection condition is incorporated into the B.C.03 rating. The substructure condition can vary greatly between the below- and above-water portions. A bridge substructure may appear to be in good condition based on the routine inspection by topside personnel, but the B.C.03 condition rating may be lowered if the underwater inspection reports deterioration of the pier below the water.

7.1.3 National Bridge Elements (NBE), Bridge Management Elements (MBE), Agency Defined Elements (ADE), and Defects

Bridge element condition ratings are required to be reported to the FHWA for bridges on all National Highway System (NHS) routes (23 CFR 650.315(a)). Reporting is optional for non-NHS route bridges; however, many States report this data on all bridges since maintaining one database is logistically easier. States are required to submit the bridge element data, consisting of the NBE, the underwater elements, provided on the next page (23 CFR 650.315(a)).

Elements that are entirely below ground and not accessible for inspection, such as piles and pile caps/footings, are not intended to be reported unless they become exposed and visible for inspection. Refer to Table 15 for an example of bridge elements reported as part of an underwater inspection.

Table 15. Example of bridge elements reported to FHWA, SNBI - 7.2.

Element	Units	Element Number					
		Steel	PSC	RC	Timber	Masonry	Other
Column	each	202	204	205	206		203
Column Tower (Trestle)	ft	207			208		
Pier Wall	ft			210	212	213	211
Abutment	ft	219		215	216	217	218
Pile Cap/Footing	ft			220			
Pile	each	225	226	227	228		229
Pier Cap	ft	231	233	234	235		236
Culvert	ft	240	245	241	242	244	243

All elements have four defined condition states. The severity of multiple distress paths or deficiencies is defined in the AASHTO MBEI for each condition state, with the general intent of the condition states as follows: Condition State One (CS1) – Good; Condition State Two (CS2) – Fair; Condition State Three (CS3) – Poor; and Condition State Four (CS4) – Severe. Refer to the AASHTO MBEI for element defect and condition state definitions.

7.1.4 Detailed Inspection Reports

NBI and element-level reporting systems are designed to present summaries of inspection data. Additional information gathered during an underwater inspection should be documented in standard inspection forms or formal engineering reports. Reports supply information that evaluates the bridge's current condition and provides the basis for determining future maintenance costs, scheduling, and workforce requirements. Reports should consist of written descriptions with photos and sketches as necessary to identify areas of damage and distress. An inspection report should be clear and complete, including the following information:

- Location, configuration, and orientation of the structure
- Construction and repair history and the performance of those repairs
- Substructure condition for portion inspected
- Detailed defect descriptions; severity, location, quantity, etc.
- Scour condition
- Channel condition
- Channel protection device conditions
- Drawings, photographs, and soundings as required by bridge owner
- Repair recommendations
- Frequency and type of future inspections

The inspection team leader should sign the final inspection report. Some states require the report to be signed and sealed by a registered professional engineer responsible for the inspection team.

7.1.5 Databases

Many agencies have transitioned to maintaining their bridge files electronically in a database rather than storing and preserving hard copies of historical documents. This transition requires the agency to make an electronic record of all previously required information in the bridge file and continue to maintain the database with inspection data from each subsequent inspection in the future. Beyond maintaining bridge files, bridge management systems can perform deterioration modeling to predict future maintenance needs, manage the workflow of repair recommendations through the agency, and maintain inspector certifications, among other capabilities.

Numerous bridge management systems are commercially available, and many bridge owners have customized the graphical user interface to accommodate their specific needs for data collection and report generation. Ultimately, these systems are used to report the required NBI data to the FHWA annually.

7.2 RECORDING INSPECTION NOTES

7.2.1 General

Notes can be recorded on paper or an electronic tablet in the field. Whichever method is used, it should provide the ability to incorporate sketches, record notes, and catalog photographs.

Inspectors should recognize that their notes are part of the permanent bridge record. Therefore, writing should be legible and use proper grammar. A key should be provided for reference if abbreviations are used in the notes. A set of abbreviations commonly used in bridge inspection is provided in the BIRM.

7.2.2 Coordination with Above-Water Inspection Personnel

The underwater inspection team should coordinate their inspection with the routine inspection personnel to ensure complete inspection coverage of the substructure. The inspection limits should be well defined in the scope of services. Inspection limits tied to the waterline are inadequate, as the waterline elevation changes over time. It may be possible to use marine growth for an inspection limit if it is clearly delineated, but it is best to use a known elevation on the bridge that does not change. For instance, identifying the underwater inspection limits on a bridge as “from 20 feet below the top of the concrete barrier at Bent 10 to the channel bottom” provides a constant reference elevation for the underwater inspection team to use each cycle.

7.2.3 Inspection Field Book

A pre-prepared inspection field book is suggested to facilitate an efficient underwater bridge inspection. Standardized forms and checklists encompassing the identified inspection procedures, the underwater inspection plan, bridge plans, and previous inspection reports can be included to ensure all aspects of the inspection are completed. The field book can be tailored for each inspection based on the structure type, expected environmental conditions, and local or agency-specific requirements. An example of an inspection field book is shown in Appendix B. Sample Field Book.

Tablets allow notes to be recorded either by handwriting or typing. Additional pages, photos, and sketches can also be added to electronic field books in real-time, allowing greater flexibility than paper notes. Tablets also allow the inspector to immediately access multiple digital reference manuals and the inspection databases to record and upload the required data immediately. They can also reference and record other forms required for a typical underwater bridge inspection, such as dive logs, safety plans, JHA, and company-specific dive or safety manuals. Disadvantages of electronic field books are durability, reliability, battery issues from extremely high or low temperatures, difficulty recording notes during precipitation events, and difficulty seeing screens in bright natural light. Regardless of whether traditional paper field books or electronic field books are used, there is an inherent risk of data loss when working on or near water. However, another advantage to electronic field books is the ability to backup data in real-time or after completing each inspection. When using electronic field books, a protocol should be in place to backup notes. Data backup options include saving files to an additional device, emailing files from the tablet to another secure location, and uploading files to a cloud-based server using a cellular or Wi-Fi internet connection. Hardwire that downloads data to an external device is another good backup option. A robust data backup plan helps to minimize the risk of data loss in the field.

APPENDIX A. JOB HAZARD ANALYSIS (JHA), EXAMPLE

Bridge ID: 000000000	Date: (mm/dd/yyyy)

Location(s): (Latitude, Longitude)

Potential Hazards

1. Inspector struck by motorist due to heavy traffic on bridge.
2. Slips, trips, and falls due to steep embankment or wet walking surface.
3. Hypothermia, dehydration, or heat exhaustion.
4. Stings, bites, and scratches from wildlife in area.
5. Lost or distressed diver due to swift current overwhelming diver.
6. Trapped diver due to timber/construction debris in waterway.
7. Drowning due to equipment failure, loss of air, or illness.
8. AGE or DCS from ascending too fast or omitted decompression.

Hazard Mitigation and Plan of Action

1. Always wear a reflective vest and be aware of your surroundings when working near a road. If a diver needs to cross the road, they should be escorted by someone wearing a reflective vest. If the shoulder is too narrow to allow safe passage when performing work on a bridge, cones should be placed along the shoulder or curb as a warning to oncoming drivers.
2. Maintain situational awareness while walking on the dive site. This level of awareness includes but is not limited to the deck of any dive boats, embankments, riprap, etc. Surfaces may be wet, slippery, or have awkward angles. Wear hard-toed boots with serviceable soles; hard-toed boots are required unless changing out of dive gear. Do not wear a bailout harness while moving about on the dive boat, and this may result in a fall overboard. Carry bailout harnesses to the dress out location only.
3. Wear the appropriate clothing/gear for the weather conditions. If a diver is very cold or showing signs of hypothermia, bring them out of the water and have them change into dry clothes. If a diver shows signs of overheating, bring them out of the water and have them hydrate. Drink plenty of water throughout the day.
4. Always wear gloves while diving and avoid wildlife. Have a spotter when diving in areas with dangerous wildlife. If bitten/stung by venomous wildlife, call emergency services and transport to the nearest hospital for treatment as necessary. If possible, identify/take a picture of the animal and give it to medical staff.
5. Be aware of your diving capabilities/limitations. If the current flow is too high, abort the dive and wait until conditions allow for safe diving.
6. Hazardous debris is common at bridge sites. Use the ladder to enter the water if the bottom conditions cannot be determined. Avoid swimming through timber debris, especially on SCUBA. Properly manage umbilical throughout dive.
7. Follow setup procedures checklist for all life support equipment and initial each step as it is completed. Monitor LP compressor fuel level, air bank pressures, and diving comms throughout dive. Ensure the diver knows not to ventilate when changing the air source. In the event of loss of air, have the diver go on bail out, abort the dive, determine the cause of air failure, and reassess the air system. The dive can resume only after the problem has been completely resolved and the diver has been briefed. Check the diver's bailout air pressure and replace, if necessary, before going back into the water.
8. Do not hold your breath or cough during ascent and always follow the Navy dive tables. Never remove the dive helmet while in the water. In the event of a diving-related illness, immediately administer first aid and transport to the nearest hospital or decompression chamber for treatment.

Underwater Inspection Team and Guests[1]

Inspection Team Leader: (first name, last name)

Diving Supervisor Name: Signature:	Name: Signature:	Name: Signature:
Name: Signature:	Name: Signature:	Name: Signature:

---

[1] All personnel at the bridge site should print/sign their name acknowledging they attended the safety brief

APPENDIX B. SAMPLE FIELD BOOK

The following is a sample field book for an underwater inspection. Job hazard analysis, dive plan, dive log, as-built plans, previous routine and underwater inspection reports, and field sketch may also be included for a complete field package.

AnyDOT

Underwater Bridge Inspection Field Book

for

Bridge Number: A123

Waterloo County

Route 1A over Waterway River

Item B.L.05 – Latitude: *50.16667*

Item B.L.06 – Longitude: *– 125.16667*

Owner Contact: *Mike Rogers – AnyDOT*
512-555-3211

Emergency: *911*

Nearest Hospital: *1215 Medical Way, Lakeville*
XXX-XXX-XXXX

Nearest Recompression Chamber: *3345 Pressuretown Ave, Watertown*
XXX-XXX-XXXX

Bridge/Job Information

ITEM			Verify
B.ID.01	Bridge Number:	A123	X
B.IE.02	Inspection Begin Date:	7/1/23	
B.IE.03	Inspection End Date:	7/1/23	
B.IE.11	Inspection Note:	Underwater inspection of Piers 4 thru 9	
B.SB.01	Substructure Config.:	P01 – Pier data set	X
B.SB.04	Substructure Type:	P03 – multiple columns	X
B.SB.06	Foundation Type:	P01 – steel H-shape	X
	Direction of Stationing:	North to South	X
Latest Routine Inspection Date:		3/21/23	X

Environmental Conditions

Water Type:	[✓ **Fresh**] Salt Brackish
Tidal:	Yes / [✓ **No**]
Time of Soundings:	Start Time: 10:00 End Time: 10: 24
Maximum Current:	1 fps
Water Surface Conditions:	[✓ Calm] Choppy Other:
Underwater Visibility:	3 ft.
Weather/Air Temperature:	Sunny [✓ Cloudy] Rain Snow / 68° F
Water Temperature:	60° F
High Water Mark:	3 ft. Above current waterline

Inspection Team

Engineer/Team Leader:	James, T.L.
TL# (B.IE.04)	53WFC001
Divers/Inspectors	Waters, A.B.
	Flow, J.M.
	Muddy, C.B.

Inspection Access and Equipment (B.IE.12)

Method of Inspection:	A09 Surface-supplied air diving / [✓ A08 Commercial SCUBA]	
Dive Platform	[✓ A06 Boat]	Shore
Access Location (Boat Ramp Coordinates)	Boat Ramp Name: Spinner Lake Access	NE / NW / SE / [✓ SW] Embankment
Additional Access Information:	N/A	
Additional Equipment Required:	A10 ROV I13 U/W Imaging [✓ I14 Depth Finder]	

Item B.C.09 Channel	Item B.C.10 Channel Projection
Prev / New	Prev / New
8 / 8	8 / 8

[✓ N] / S / E / W Embankment Condition	Is embankment stable? [✓ Y] / N Protection: [✓ Riprap] / Vegetation / None Protection Notes: Riprap extends from the face of the abutment to the midpoint of span 1 Erosion: Y / [✓ N] Location and dimensions:
N / [✓ S] / E / W Embankment Condition	Is embankment stable? [✓ Y] / N Protection: [✓ Riprap] / Vegetation / None Protection Notes: Riprap extends from the face of the abutment to the midpoint of span 9 Erosion: Y / [✓ N] Location and dimensions:
Stream Alignment (Angle of Attack): 10%	Does it affect the structure? No
Channel Bottom Material:	[✓ Sand] Silt Clay Organics Gravel Riprap Other:
Timber Debris:	Location, max diameter, and amount in CY: None
Blockage (%) of Waterway Opening	Horizontal: 0 % Vertical: 0 % Overall: 0 %

Item BC.11 Scour

Prev / New 7 / 7	
Has channel bottom degradation or aggradation occurred?	Y / [✓ N] Notes:
Has the channel changed or meandered over time?	Y / [✓ N] Notes:
Is there local scour present?	[✓ Y] / N Notes: Minor scour up to 24" deep exposing the footings at Piers 7 and 8
Scour comments:	Cutbanks: Y / [✓ N] Location(s) and height: Other scour notes:

Item BC.15

Item Number	Prev / New	Description
Underwater Inspection Condition	6 / 6	Exposed footing at Piers 7 and 8 up to 24" due to scour. Spalls on two piers with exposed rebar and up to 20% loss of section (80% remaining)

SOUNDINGS

Is bridge superelevated? N If so, take a WL Reference at both fascias.

WL Reference Point:	TOD	Waterline is _19.2_ft. (above / [✓ below]) reference point
WL Date/Time:	7/1/23 1500	
Reference Point to TOD:	Elevation 100.0	
Sounding Device:	Sounding pole / digital depth sounder / [✓ weighted tape] (circle one)	

SSU Stationing	Upstream Fascia (N / S / E / [✓ W])		Downstream Fascia (N / S / [✓ E] / W)	
	___WL___to CB	__TOD__ to WL	___WL___ to CB	__TOD__ to WL
3.5	+2.0		+2.0	
4	8.6		8.6	
4.5	11.4		16.3	
5	11.5		17.8	
5.5	13.0		18.5	
6	10.8		20.0	
6.5	13.0		19.2	
7	10.3	19.2	11.6	19.2
7.5	6.5		7.8	
8	5.6		2.6	
8.5	3.1		3.0	
9	4.8		+1.0	
9.5	2.7			
10	+3.0			

WL = Water Line CB = Channel Bottom N = North S = South
D/S = Downstream U/S = Upstream E = East W = West
TOD = Top of Deck

PHOTO LOG

Bridge ID#: __ A123_______________ Date: __7/1/23__

First Photo #: __98__ Last Photo #: __134_

Photo #	Description of Photo	Looking (N/S/E/W)
98	Cover/Bridge ID	
129-130	Upstream Fascia (N / S / E / [✓ W])	S
107-108	Downstream Fascia (N / S / [✓ E] / W)	N
120	View Upstream (On / [✓ Under]) Bridge	W
99-100	View Downstream ([✓ On] / Under) Bridge	E
106	[✓ N] / S / E / W Embankment	N
111	N / [✓ S] / E / W Embankment	S
	N / S / E / W Embankment	
	N / S / E / W Embankment	
109-110	[✓ North] / East Channel Bank	N
121-122	[✓ South] / West Channel Bank	S
112-113	Pier: __4__- __N__ Face	
123-124	Pier: __9__- __S__ Face	
	Pier: ______- _______Face	
125-126	Typ _concrete_Condition Above Waterline @ Pier: _9-5_-_N_ Face	
131-132	Typ _concrete Condition Below Waterline @ Pier: _9-5_-_N_ Face	
133-134	Typ Footing Condition Above Waterline @ Pier: _8-2_-_S_Face	
	Typ _______Condition Below Waterline @ Bent: ____-_____Face	
	Typ _______Condition Above Waterline @ Bent: ____-_____Face	
	Typ _______Condition Below Waterline @ Bent: ____-_____Face	
	Additional Photos (Timber Debris, Cut Banks, Erosion, Etc.)	
127-128	Photos of Pier 8	
101-105, 114-119	Construction of New Bridge	

Typical Conditions

Defect Notes

Location	Description	CS	Photo #
Column	From high water mark to channel bottom, Abrasion, up to 1/8" deep, Aggregate Secure	2	

Pier _4

Footing Exposed? Y/[✓ N]	NW	NE	SW	SE

Defect Notes

Location	Description	CS	Photo #
	No additional defects		

Pier _5

Footing Exposed? Y/[✓ N]	NW	NE	SW	SE

Defect Notes

Location	Description	CS	Photo #
	No additional defects		

Pier _6

Footing Exposed? Y/[✓ N]	NW	NE	SW	SE

Defect Notes

Locaton	Description	CS	Photo #
	No additional defects		

Pier _7

Footing Exposed? [✓ Y]/N	NW 18"	NE 12"	SW 0"	SE 0"

Defect Notes

Location	Description	CS	Photo #
Column #4	NE corner @ column/footing interface, area of poor consolidation 3"High x 10"Wide x 2"Deep	3	
Footing	NE Corner, top of footing, spall, 5"High x 3"Wide x 1.5"Deep	3	

Pier _8

Footing Exposed? [✓ Y]/N	NW 24"	NE 20"	SW 18"	SE 14"

Defect Notes

Location	Description	CS	Photo #
Footing	NE Corner, top of footing, spall, 10"High x 6"Wide x 1.5"Deep	3	
Column #2	S face @ column/footing Interface (2' from SE corner), [3] cover spalls 9"High x 3 ½"Wide (max ½"Deep) w/ exposed rebar (horizontal shear steel in the column) with up to 20% section loss (80% remaining section)	3	127
Column #5	S face, 6" above column/footing interface, spall/delamination 2'High x 3.5'Wide x up to 2"Deep	3	128
Footing	SE corner, 3' below top of footing, spall, 10"High x 6"Wide x ½"Deep	3	
Seal	N face, seal, poor consolidation, 5"High x 3'Wide x 1.5"Deep	NA	

Pier _9

Footing Exposed? Y/[✓ N]	NW	NE	SW	SE

Defect Notes

Location	Description	CS	Photo #
	No additional defects		

APPENDIX C. SAMPLE UNDERWATER BRIDGE INSPECTION ELEMENTS TABLE

The following is an example of the elements, their total quantity, and condition states quantities. This example is meant to demonstrate how element condition states may be reported as part of an Underwater Inspection. The condition state quantities are based on the field book example in Appendix B.

Pier 4

Element Number B.E.01	Defect	Element/Defect Description	Total Quantity B.E.03	Units	Condition State Quantity			
					CS1 B.CS.01	CS2 B.CS.02	CS3 B.CS.03	CS4 B.CS.04
205		Reinforced Concrete Columns	6	EA		6		
	1190	Abrasion/Wear	6	EA		6		

Pier 5

Element Number B.E.01	Defect	Element/Defect Description	Total Quantity B.E.03	Units	Condition State Quantity			
					CS1 B.CS.01	CS2 B.CS.02	CS3 B.CS.03	CS4 B.CS.04
205		Reinforced Concrete Columns	6	EA		6		
	1190	Abrasion/Wear	6	EA		6		

Pier 6

Element Number B.E.01	Defect	Element/Defect Description	Total Quantity B.E.03	Units	Condition State Quantity			
					CS1 B.CS.01	CS2 B.CS.02	CS3 B.CS.03	CS4 B.CS.04
205		Reinforced Concrete Columns	6	EA		6		
	1109	Abrasion/Wear	6	EA		6		

Pier7

Element Number B.E.01	Defect	Element/Defect Description	Total Quantity B.E.03	Units	Condition State Quantity			
					CS1 B.CS.01	CS2 B.CS.02	CS3 B.CS.03	CS4 B.CS.04
205		Reinforced Concrete Columns	6	EA		5	1	
	1109	Abrasion/Wear	6	EA		5	1	
220		Reinforced Concrete Pile Cap/Footing	29	LF		28	1	
	1080	Spalls/Delaminations/Patch Areas	1	LF			1	
	6000	Scour	28	LF		28		

Pier 8

Element Number B.E.01	Defect	Element/Defect Description	Total Quantity B.E.03	Units	Condition State Quantity			
					CS1 B.CS.01	CS2 B.CS.02	CS3 B.CS.03	CS4 B.CS.04
205		Reinforced Concrete Columns	6	EA		4	2	
	1090	Exposed Rebar	1	EA			1	
	1080	Spalls/Delaminations/Patch Areas	1	EA			1	
	1190	Abrasion/Wear	4	EA		4		
220	-	Reinforced Concrete Pile Cap/Footing	70	LF		69	1	
	1080	Spalls/Delaminations/Patch Areas	1	LF			1	
	6000	Scour	69	LF		69		

Pier 9

Element Number B.E.01	Defect	Element/Defect Description	Total Quantity B.E.03	Units	Condition State Quantity			
					CS1 B.CS.01	CS2 B.CS.02	CS3 B.CS.03	CS4 B.CS.04
205		Reinforced Concrete Columns	6	EA		6		
	1190	Abrasion/Wear	6	EA		6		

Summary for Underwater Components for Bridge Number A123

Element Number B.E.01	Defect	Element/Defect Description	Total Quantity B.E.03	Units	Condition State Quantity			
					CS1 B.CS.01	CS2 B.CS.02	CS3 B.CS.03	CS4 B.CS.04
205		Reinforced Concrete Columns	36	EA		33	3	
	1090	Exposed Rebar	1	EA			1	
	1080	Spalls/Delaminations/Patch Areas	1	EA			1	
	1190	Abrasion/Wear	34	EA		33	1	
220		Reinforced Concrete Pile Cap/Footing	99	LF		97	2	
	1080	Spalls/Delaminations/Patch Areas	2	LF			2	
	6000	Scour	97	LF		97		

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