U.S. Department of Transportation
Federal Highway Administration

TECHNICAL ADVISORY

REVISIONS TO THE NATIONAL BRIDGE INSPECTION STANDARDS (NBIS)

T 5140.21
September 16, 1988

Par.

1. PURPOSE. To provide guidance for implementing the changes contained in the 1988 revision of the NBIS.

2. BACKGROUND

   a. Title 23, Code of Federal Regulations, Part 650, Subpart C sets forth the NBIS for bridges on all public roads. Section 650.3 defines bridges, specifies inspection procedures and frequencies, and indicates minimum qualifications for personnel. Reporting,inventory, load posting and inspection record keeping requirements are also stated.

   b. The Federal Highway Administration (FHWA) published a Notice of Proposed Rule Making (NPRM) in the April 7, 1987, Federal Register to revise the NBIS. The proposal was a result of continued analysis of the National Bridge Inventory (NBI) data, advances in training and bridge inspection techniques, the need to intensify bridge inspection efforts on certain bridges, bridge elements which pose a higher than normal potential for collapse should they fail, and the need for improved record keeping and positive management procedures to identify, inspect and evaluate the critical elements of some bridges. Sixty-one commenters responded to the NPRM and, where appropriate, comments were addressed in the regulation. The Final Rule was published in the Federal Register on August 26, 1988.

3. TYPES OF INSPECTION. The terminology used in this Technical Advisory to describe types of inspection corresponds to terminology proposed by the American Association of State Highway and Transportation Officials (AASHTO) for inclusion in its Manual for Maintenance Inspection of Bridges. Attachment 1 of this Technical Advisory gives AASHTO's descriptions for the following inspection types:

   a. Inventory Inspection

b. Routine Inspection

c. Damage Inspection

d. In-Depth Inspection

e. Interim Inspection

4. SUMMARY OF NBIS REVISIONS

a. Varying the Frequency of Routine Inspection. States must determine the types or groups of bridges that require a routine inspection at intervals less than the basic 2-year interval and establish appropriate frequency and depth of inspection policies for them. States may adopt inspection intervals that are longer than the basic 2-year interval for certain types or groups of bridges where it is determined that a 2-year interval is not required. Prior FHWA approval is required for inspection intervals exceeding 2 years.

b. Special Inspection Requirements. States must identify bridges with fracture critical members and designate them in their NBI files. The States must also establish appropriate inspection procedures for these members and specify inspection intervals. Similar requirements are established for bridges that need underwater inspection and for bridges with special features which, by their nature or experience, need special monitoring and evaluation.

c. Inspector Certification. An alternate procedure is added for certifying bridge inspection team leaders as meeting required levels of competence.

d. Reporting Requirements. Changes in the status of a bridge due to replacement, rehabilitation or load restrictions must continue to be added to the NBI file within 90 days for bridges under State jurisdiction. For bridges under local jurisdictions, the reporting period is increased to 180 days.

5. IMPLEMENTATION GUIDELINES

a. Varying the Frequency of Routine Inspection. The intent of this NBIS revision is to maintain a 2-year interval as the normal inspection frequency for routine inspection. However, the revised rule includes provisions for adjusting the frequency of routine inspection for certain types or groups of bridges to better conform with their inspection needs. States must identify bridges which require monitoring at intervals less than 2 years and increase the inspection frequency for these bridges as needed to assure adequate monitoring. States have the option either to continue inspecting the remaining bridges at least once every 2 years or to develop an alternative inspection program which specifies bridges that may be inspected at intervals longer than 2 years. While the NBIS does not specify a maximum interval between routine inspections, intervals should not exceed 4 years. Criteria used for selecting bridges that will have inspection intervals exceeding 2 years must be approved by the FHWA.

(1) The following list is intended as a guide for identifying classes of bridges that, in general, would not be considered for routine inspection at intervals longer than 2 years. This list is also appropriate for identifying bridges that are candidates for routine inspection at intervals more frequent than every 2 years.

(a) Bridges with any condition rating of 5 or less.

(b) Bridges that have inventory ratings less than the State's legal load.

(c) Structures with spans greater than 100' in length.

(d) Structures without load path redundancy.

(e) Structures that are very susceptible to vehicular damage, e.g., structures with vertical over or underclearances less than 14'-0", narrow thru or pony trusses.

(f) Uncommon or unusual designs or designs where there is little performance history, such as segmental, cable stayed, etc.

(2) A new or newly rehabilitated bridge should not be considered for inspection intervals longer than 2 years until it has received an inventory inspection and an in-depth inspection 1 or 2 years later. No bridge should be considered for inspection intervals longer than 2 years unless the bridge has received an in-depth inspection and this inspection revealed no major deficiencies.

(3) The interval established for routine inspections should be evaluated and, if necessary, adjusted after each inspection.

(4) Regardless of the frequency selected for routine inspection, individual bridge members may require differing types and frequency of inspection (e.g., fracture critical members, distressed members and underwater members). The requirements for these special inspections are discussed under paragraph 5b. In addition, any structure that has been subjected to an earthquake, a major flood, or any other potentially damaging event should immediately receive a damage inspection.

(5) Proposed inspection programs that call for routine inspection at intervals longer than 2 years must be approved by the FHWA Regional Administrator inconsultation with the Washington Headquarters office. The State's criteria for determining frequency of inspection exceeding 2 years must envelop the criteria of all jurisdictions within the State, i.e., the FHWA will not separately approve a jurisdiction's criteria that allows longer intervals between inspections than the State's criteria allows.

(6) Local governments within the State that want to increase the 2-year inspection interval must submit their programs for FHWA approval through the State. This requirement is necessary since the State is responsible for maintaining and ensuring the adequacy of NBI data on all bridges within its borders that are subject to the NBIS. Federal agencies should submit their proposals for increasing the 2-year inspection interval through the States to the FHWA Washington Headquarters. The FHWA will send approvals of acceptable Federal agency proposals directly to the Federal agencies and copies will be distributed through normal FHWA channels to affected States.

(7) Submissions to the FHWA for increased inspection intervals must contain the following information as a minimum.

(a) The criteria used in establishing the interval between inspections. The criteria developed for establishing the interval between inspections, if greater than 2 years, shall include the following:

1 Structure type and description.

2 Structure age.

3 Structure load rating.

4 Structure condition and appraisal ratings.

5Volume of traffic carried.

6 ADTT.

7 Major maintenance or structural repairs performed within the last 2 years.

8 An assessment of the frequency and degree of overload that is anticipated on the structure.

(b) A discussion of failure experience, maintenance history, and latest inspection findings for the group of structures identified.

(c) The proposed inspection interval.

b. Special Inspection Requirements. The 1988 NBIS revisions expand the inspection and reporting requirements for bridges with fracture critical members, underwater inspection requirements or other special inspection requirements. The inspection requirement for these features must be designated on individual inspection and inventory records and compiled in master lists. Provisions for recording this information have been made in the 1988 edition of the Recording and Coding Guide for the Structure Inventory and Appraisal of the Nation's Bridges.

(1) The purpose of the master lists is to promote better inspection program management of nonroutine inspections. The lists are intended as a tool for planning, scheduling and monitoring these inspections. Master lists should be prepared based on inspection findings beginning with the current inspection cycle. The lists should be fully compiled within 2 years (one complete inspection cycle) from the effective date of the regulation and maintained current thereafter. Master lists should be prepared for:

(a) Bridges that have fracture critical members.

(b) Bridges that require underwater inspection.

(c) Other bridges that, because of location, strategic importance or special design features, warrant special attention.

(2) For each listed bridge, the following information should be included as a minimum.

(a) Type and location of the bridge.

(b) Type and frequency of required inspection.

(c) The location of the members to be inspected.

(d) Inspection procedures to be used.

(e) Dates of previous inspections.

(f) Special equipment required.

(g) The findings of the last inspection.

(h) Follow-up actions taken on findings of the last inspection.

(3) FHWA division offices should review the lists for completeness and appropriate follow-up on inspection findings in the course of their NBIS compliance reviews.

c. Underwater Inspections

(1) Underwater members must be inspected to the extent necessary to determine structural

safety with certainty. In addition to structure elements, underwater inspections must include the stream bed. In wadable water, underwater inspections can usually be accomplished visually or tactually from above the water surface; however, inspections in deep water will generally require diving or other appropriate techniques to determine underwater conditions. The underwater inspection requirements of Title 23 Code of Federal Regulations Section 650.303 pertain to inspections that require diving or other special methods or equipment. Theattached Transportation Research Board Circular Number 330, Underwater Bridge Inspection Programs, together with references, outlines the state-of-the-art of underwater inspections. This circular also provides guidance for establishing underwater inspection programs and prioritizing these inspections. Three levels of underwater inspections are described in the circular:

LEVEL I - a "swim-by" overview, with minimal cleaning to remove marine growth.

LEVEL II - limited measurements of damaged or deteriorated areas that may be hidden by surface biofouling. Marine growth is cleaned from a sample of underwater members in 10 inch wide bands at designated levels to enable close inspection.

LEVEL III - highly detailed inspections utilizing nondestructive tests such as ultrasound or minimally destructive tests such as coring of wood or concrete and insitu hardness tests.

(2) The appropriate level and frequency of underwater inspection will depend on such factors as age, construction material, type of design (e.g., spread footings, piling, etc.), stream bed material, presence of corrosive pollution, depth and velocity of flood flows, maintenance history and numerous other factors. The following guidelines are applicable to most inspections.

(a) Routine Underwater Inspection. A LEVEL I inspection should be made on 100 percent of the underwater portion of the structure to determine any obvious problems. A LEVEL II inspection should be made on at least 10 percent of underwater units selected at random to verify the LEVEL I inspection. The channel bottom and sides should be inspected for scour.

In alluvial channels, cross-sections of the channel bottom should be taken and compared with as-built plans or previously taken cross-sections to detect lateral channelmovement or deepening. Bottom probes in the vicinity of piers and abutments should be made if loose sediments are present to determine probable scour depths. In streams carrying large amounts of sediment, reliable scour depth measurements may not be possible at low flow due to scour hole backfilling. Where depth measurements are essential in these types of streams, they should be made during a high runoff event.

(b) In-Depth Inspection. An in-depth inspection of underwater members should be made if their condition is not conclusive based on the above routine inspection. In-depth inspections may include more extensive Level II inspection to determine section losses and Level III inspection to determine the internal soundness of members. The detail of the inspection must be sufficient to establish the integrity of the members.

(3) Qualifications of Diver-Inspectors. The individual in overall charge of the State bridge inspection program is responsible for defining the necessary qualifications of divers for each bridge where diving is required.

(a) Divers performing underwater inspections and evaluations should be fully qualified by training and experience in evaluating the types of degenerative underwater structural and bed conditions that can exist at given bridge locations. Depending upon bridge complexity, substructure and superstructure interaction or other relevant site conditions, a diver fully qualified to be a bridge inspector team leader will be needed for some bridges. For others, a diver fully trained and experienced in inspection and evaluation of substructure and bed conditions will meet inspection and safety needs.

(b) Inspections made by divers not fully qualified as bridge inspectors or bridge inspection team leaders should be limited to bridge situations where simple measurements, verbal descriptions,underwater photography, etc. can provide conclusive evidence of underwater conditions to an on-site fully qualified bridge inspection team leader.

(4) Engineering Evaluation. Underwater inspections should be followed by an engineering evaluation of the structure's vulnerability to scour damage and the need for countermeasures. Scour evaluations should be conducted by an interdisciplinary team comprised of structural, hydraulic and geotechnical engineers. These evaluations may vary from quick to detailed depending on inspection findings, channel characteristics, depth and velocity of flood flows, foundation depths and other factors. Guidelines for evaluating scour vulnerability and designing scour countermeasures are included in the Attachment to FHWA Technical Advisory 5140.20, dated September 16, 1988, titled Scour at Bridges.

(5) Inspection Frequency. As required by the 1988 revisions, underwater inspections must be performed at least every 5 years. However, a 5-year interval is appropriate only where underwater units are in sound condition and there is no evidence of channel instability that might endanger the bridge. Where deterioration is evident but repairs are not yet essential, or where the water environment is highly deleterious to structural members, more frequent inspections are recommended. Where channel stability is a concern, scour should be monitored during and after high runoff events until scour countermeasures can be installed. Similarly, the performance of newly installed scour counter-measures should be checked soon after the first high runoff event.

d. Certification of Bridge Inspectors

(1) The 1988 revision adds a fourth alternative to the previous options for qualifying bridge inspection team leaders by allowing Level III or IV Bridge Safety Inspection certification under the National Society of Professional Engineer's National Certification of Engineering Technologies (NICET) program. The alternatives now are (a) registration as a professional engineer, (b) eligibility for registration as a professional engineer, (c) completion of a comprehensive course in bridge inspection and a minimum of 5 years of bridge inspection experience, or (d) NICET Certification. States may choose any level of minimum requirements for bridge inspection team leaders provided that the requirements meet at least one of the above NBIS alternatives.

(2) Level III Certification requires that the individual have performed at least 5 years of documented bridge inspection work. The individual must have at least one written recommendation from a person familiar with his or her work and must pass a written test covering bridge inspection and evaluation. In accordance with NICET, an individual who attains Level III Certification is qualified to do independent technician work with little or no supervision on jobs covered by standard and complete plans, specifications, or instruction.

(3) The NICET Level IV Certification requires that the individual have at least 10 years of bridge inspection experience. The individual must be able to document that he or she has performed in senior positions on several bridge inspection assignments. All experience must be verified, preferably by a professional engineer. The individual must also pass a written test demonstrating his or her knowledge of bridge inspection and evaluation. The certification also requires a written recommendation as to one's character and integrity from a professional engineer or engineer personally familiar with the individual. An inspector certified at Level IV, according to NICET, is capable of independent technician work, including delegated responsibilities and duties for which an engineering precedent exists.

(4) Specific requirements of bridge inspection certification are contained in the NICET publication entitled Program Detail Manual for Certification in the Field of Transportation Engineering Technology - Subfield of Bridge Safety Inspection. To obtain this document

contact the National Institute for Certification in Engineering Technologies, 1420 King Street, Alexandria, Virginia 22314, phone (703) 684-2835.

(5) Instead of registered professional engineer team leaders, some States are able to accomplish most needed work with highly trained, experienced technicians. However, some bridges require a great deal of specialized experience and knowledge which can only be provided by an experienced bridge engineer. This is especially true for evaluation of the safe load capacity of bridges which may have any uncommon feature of design or may have deteriorated to the point that specialized analysis is appropriate. Because bridge inspection team leaders must, in their day-to-day inspections, make judgments as to the integrity, safety, and load carrying capacity of both individual elements and the collective elements of individual bridges acting as a unit, it is essential that team leaders be well trained and experienced in bridge performance and inspection techniques. The FHWA encourages State and local bridge owners to provide additional training for NICET Level III certified inspectors as well as continuing training for all inspectors and team leaders.

(6) The qualifications of bridge inspection personnel should be in the bridge owners file. This applies not only to State highway agency inspectors but to all personnel inspecting bridges within the State's boundaries. The name and title of all inspectors involved in a bridge inspection should appear on the inspection report.

e. Prompt Updating of Bridge Inventory Files When Load Posting Signs are Placed at Specific Bridges

(1) Many States have had difficulty obtaining updates to NBI records from local governments and Federal bridge owners within the time constraints imposed by the NBIS. The 1988 revisions extend the reporting time for updating NBI data for locally owned and inspected bridges to 180 days while retaining the existing 90-day limit for State inspected bridges. This extension is intended to provide a more realistic time frame for States to obtain NBI information from local agencies and enter it into the inventory. This reporting requirement for updating the NBI applies to load posting of bridges, adding records for new bridges and updating records of existing bridges that have been modified.

(2) The FHWA strongly encourages States to develop formal procedures for the prompt communication of inventory, inspection and load posting information to and from local bridge owners. The procedures should preferably include written follow-up on load posting notifications made by the State, and prescribe a time frame in which local bridge owners must submit data to the State pertaining to inspection, load posting and newly constructed bridges.

Thomas O. Willett, Director
Office of Engineering

Attachments

DESCRIPTION OF INSPECTION TYPES

Proposed for Inclusion in the American Association of State Highway and Transportation Officials' Manual for Maintenance Inspection of Bridges

Inventory Inspections

An Inventory Inspection is the first inspection of a bridge as it becomes a part of the bridge inventory but the elements of an Inventory Inspection may also apply when there has been a change in the configuration of the structure (e.g., widenings, lengthenings, supplemental bents, etc.). The Inventory Inspection is a fully documented investigation performed by persons meeting the required qualifications for inspection personnel and it must be accompanied by an analytical determination of load capacity. The purpose of this inspection is twofold. First, it should be used to determine all Structure Inventory and Appraisal (SI&A) data required by the Federal Highway Administration and all other relevant information not required by the National Bridge Inspection Standards (NBIS) but of the type normally collected and managed by the owner agency. The second important aspect of the

Inventory Inspection is the determination of baseline structural conditions and the identification and listing of any existing problems or locations in the structure that may have potential problems. Aided by a prior detailed review of plans, it is during this inspection that any fracture critical members (or details) are noted for subsequent focus and that assessments are made of other conditions that may later warrant special attention.

If the bridge subjected to an Inventory Inspection is anything other than a newly constructed structure, it may be necessary to include some or all of the elements of an In-Depth Inspection.

Routine Inspections

This is a regularly scheduled, intermediate level inspection consisting of sufficient observations and/or measurements to determine the physical and functional condition of the bridge, to identify any developing problems and/or change from "Inventory" or previously recorded conditions and to ensure that the structure continues to satisfy present service requirements.

The Routine Inspection must fully satisfy the requirements of the National Bridge Inspection Standards with respect to maximum inspection frequency, updating of Structure Inventory and Appraisal data and the qualifications of the inspection personnel. These inspections are generally conducted from deck, ground and/or water levels, and from permanent work platforms and walkways, if such are present. Special equipment (e.g., underbridge inspection equipment, rigging or staging) is necessary for a Routine Inspection, in circumstances where its use provides the only practical means of access to areas of the structure that are being monitored.

The results of a Routine Inspection are to be fully documented with appropriate photographs and a written report that includes any recommendations for maintenance or repair and for scheduling of follow-up In-Depth Inspections, if necessary. Load capacity evaluations will be provided to the extent that changed structural conditions would affect any previously recorded ratings.

Damage Inspections

This is an unscheduled inspection to assess structural damage resulting from environmental or man-inflicted causes. The scope of inspection must be sufficient to determine the need for emergency load restrictions or closure of the bridge to traffic and to assess the level of effort necessary to affect a repair. The amount of effort expended on this type of inspection will vary significantly depending upon the extent of the damage. If major damage has occurred, inspectors must evaluate fractured members, section loss, make measurements for misalignment of members and check for any loss of foundation support. A capability to make on-site calculations to established emergency load restrictions may be necessary. This inspection may be supplemented by a timely In-Depth Inspection as described below to document more fully the extent of damage and the urgency and magnitude of repairs. Proper documentation, verification of field measurements and calculations and perhaps a more refined analysis to establish or adjust interim load restrictions are required follow-up procedures. A particular awareness of the potential for litigation must be exercised in the documentation of Damage Inspections.

In-Depth Inspections

An In-Depth Inspection is a close-up, hands-on inspection of one or more members above or below the water level to detect any deficiencies not readily visible using Routine Inspection procedures. Traffic control and special equipment (e.g., underbridge inspection equipment, staging and workboats) should be provided as necessary to obtain access. Personnel with special skills such as divers and riggers may be required. When appropriate or necessary to fully ascertain the existence of or the extent of any deficiency(ies), nondestructive tests and/or other physical and chemical tests may need to be performed.

The inspection may include a load rating to assess the residual capacity of the member or members, depending on the extent of the deterioration or damage.

This type of inspection can be scheduled supplement to a Routine Inspection, though generally at a longer interval, or it may be a follow-up for Damage or Inventory Inspections.

On small bridges, the In-Depth Inspection, if warranted, should include all critical elements of the structure but for large and complex structures, these inspections may be scheduled separately for defined segments of the bridge or for designated groups of elements, connections or details that can be efficiently addressed by the same or similar inspection techniques. If the latter option is chosen, each defined bridge segment and/or each designated group of elements, connections or details will be clearly identified as a matter of record and each will be assigned a frequency for re-inspection. To an even greater extent than is necessary for Inventory and Routine Inspections, the activities, procedures and findings of In-Depth Inspections must be completely and carefully documented.

Interim Inspections

This is an inspection scheduled at the discretion of the individual in responsible charge of bridge inspection activities. An Interim Inspection is used to monitor a particular known or suspected deficiency (e.g., foundation settlement or scour, member condition, the public's use of a load-posted bridge, etc.) and can be performed by any qualified person familiar with the bridge and available to accommodate the assigned frequency of investigation. Unless in satisfaction of the NBIS qualification requirements for inspection personnel, the individual performing an Interim Inspection must be carefully instructed regarding thenature of the known deficiency and its functional relationship to satisfactory bridge performance. In this circumstance, guidelines and procedures on what to observe and/or measure must be provided and a timely process to interpret the field results must be in place.

The determination of an appropriate Interim Inspection frequency should consider the severity of the known deficiency.

TRANSPORTATION Number 330, March 1988

RESEARCH ISSN 0097-8515

CIRCULAR

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UNDERWATER BRIDGE INSPECTION PROGRAMS

The Transportation Research Board is a unit of the National Research Council, which services as an independent advisory to the federal government on scientific and technical questions of national importance. The Research Council, jointly administered by the National Academy of Sciences, the National Academy of Enigineering, and the Institute of Medicine, brings the resources of the entire scientific and technical community to bear on national problems through its volunteer advisory committees.

modes
1 highway transportation
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subject areas
25 structures design and performance
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SUMMARY OF A WORKSHOP PREPARED BY DANIEL D. MCGEEHAN AND LYNN H. SAMUEL, PHD

ABSTRACT

The Transportation Research Board workshop on Underwater Inspection programs revealed surprising agreement among the representatives of Federal and State agencies and underwater inspection professionals. The importance of complying with the federal inspection standards to examine all bridges in water at least every 5 years was emphasized. Advantages of effective underwater inspection programs

include cost effectiveness, liability protection, and identification of factors contributing to bridge deterioration. Establishing a program requires an accurate inventory of bridges with underwater elements, a baseline inspection of all structures, and a prioritizing system for the bridge inspection sequence. Careful documentation of all findings is mandatory. The inspection can be performed by in-house dive teams or contracted to architectural andengineering or diving firms. Since each method has advantages and disadvantages, some agencies combine the approaches to capitalize on the benefits of each. The hazards of using untrained or inexperienced divers for underwater inspection work was stressed. Bridge inspection programs have already illustrated some important factors in bridge deterioration including age, construction materials, environment, accidental damage, and traffic load. More information is needed to predict the optimal frequency and extent of inspections. This is one of several important research areas. Others include technological advances in testing and documentation methods, and dissemination of state-of-the-art technology to agencies responsible for highway safety.

INTRODUCTION

This circular contains the summary of a workshop sponsored by the Committee on Structures Maintenance, A3C06, held at the Transportation Research Board (TRB) offices in Washington D.C., March 17, 1986. The objectives of the meeting were to identify issues related to the establishment and continuation of underwater inspection programs and to determine needed areas of research. To accomplish these objectives, individuals from Federal and State agencies responsible for ensuring the safe performance of bridges on public roads met with professionals in the underwater inspection field to discuss current methods for and problems relating to the evaluation of underwater structures.

The meeting was initiated because of concerns expressed by state highway officials about designing effective underwater inspection programs. State and local governments are ultimately responsible for the safety of their bridges and are accountable to the public and the Federal Government for bridge failures. Current Federal inspection standards encourage flexibility in evaluating individual structures, but require underwater inspection of all bridges at least every 5 years and recommend the assessment of structures in corrosive water at 2-year intervals (Manual for Maintenance Inspection of Bridges, Section 2.5, AASHTO, 1983). Although the Federal requirements do not set specific guidelines for performing these inspections, the availability of Federal funding can be jeopardized if survey and inspection programs are inadequate.

A report prepared in 1981 for the TRB through the National Cooperative Highway Research Program indicated that the states used different approaches in the inspection of their bridge structures (Underwater Inspection and Repair of Bridge Substructures, NCHRP 88, 1981). Only 15 states claimed to routinely inspect their bridges below the water-line. Of these, several states inspected only "major" bridges. The 35 other state agencies indicated that they inspected their bridges infrequently, usually for specific problems. Many of the inspections were conducted visually from the surface at low water, or by sounding, rather than through direct assessment by a diver. The collapse of the Chickasawbogue Bridge on U.S. 43 in Mobile, Alabama, in April, 1985, prompted a National Transportation Safety Board (NTSB) hearing that underscored State agencies, general noncompliance with the National Bridge Inspection Standards (NBIS) regarding underwater bridge inspection. Compliance with Federal regulations is even lower for small, inconspicuous bridges. However, the NTSB hearing clearly indicated that no matter how inconspicuous it might be, the bridge that collapses is significant.

Underwater inspection programs have been hindered in the past by numerous misconceptions. Contrary to previous beliefs, (1) surface inspections are not adequate for predicting underwater conditions, (2) many bridge substructures are inaccessible at low water by wading, (3) bridges do not have a guaranteed engineering life span, (4) and underwater inspections should control, not increase, costs. For adequate assessment, a number of bridges clearly require diving, and states are now moving toward more comprehensive underwater inspection programs. Increased enforcement of Federal requirements, prompted by several bridge failures, have been only partly responsible for this trend. The specter of State liability in a liability- conscious society with the dissolution of sovereign immunity has been another instrumental factor in some States. Public concern, improvement of technology for underwater inspections, and the availability of computerized data bases have also played a role. Furthermore, the nation's highways, are aging and requiring more maintenance, with the average bridge having been built in 1948 and the interstate highway system now being 20 to 25 years old. In addition to the legal commitments for states to conduct regular underwater inspections to ensure public safety, there are some practical incentives to develop efficient underwaterinspection programs. Comprehensive programs that have been in effect for 5 to 10 years have demonstrated significant savings by avoiding closings, preventing collapse, and reducing the costs of repairs.

The objective of inspection and preventive maintenance is to protect investments by detecting weaknesses prior to imminent failure while the less expensive rehabilitative measures are still feasible. Repair of an existing structure is almost always less expensive than total replacement. Supportive maintenance may include concrete jacketing of columns or piles in bents, riprap replacement, reinforcement of concrete footings, and, in wooden bridges, replacement of cross members. Accurate information about the condition of bridges coupled with predicted bridge wear and maintenance requirements enable long-term plans for the allotment of financial resources. Supplemental inspections are necessary under several special circumstances: following damage from floods or boat collisions, before alterations or reconstruction of the superstructure or substructure, and for preacceptance evaluation of contracted construction work.

This circular concentrates on establishing an underwater inspection program, in-house and contract inspections, underwater inspector training, factors contributing to bridge deterioration, inspection cycles and scope, and areas of needed research. A bibliography has been included to demonstrate the many facets of an underwater program.

ESTABLISHING THE PROGRAM

The first step in establishing an underwater inspection program is to obtain an accurate inventory of bridges with elements in water too deep to allow visual evaluation during periods of low flow. The condition of substructures in water of greater depths cannot be adequately evaluated from the surface. The inventory is most conveniently stored on a computer, and should include information such as the age of the structure, the bridge construction materials (wood, concrete, steel), the number and type of elements in the water (piles, retaining walls), water conditions (salt, heavy current, corrosive pollution),maintenance history and modifications, and an estimate of the traffic volume. Although some of this information may not be available from the outset, it should be acquired as soon as possible because it is important for evaluating bridge conditions; for planning diving schedules, inspection techniques, and underwater maintenance; and for prioritizing bridges in the inspection sequence. In addition, this information should be a part of the general bridge inventory, so that underwater conditions are included in the records of the overall condition of each bridge over water.

State highway departments may be responsible for many bridges that cannot all be inspected concurrently, so the sequence of inspections depends on a system of priorities. Prioritizing reflects the relative level of concern over the safety of a bridge and is based on factors such as age, construction history, maintenance history, significance of failure, and deficiencies noted on previous inspections. Upon the initiation of a bridge inspection program, bridges with high priority should be inspected in the first year and all bridges within 5 years.

A baseline assessment should be obtained for all structures in the inventory to include inspection of all underwater elements in each structure. Although random sampling may be necessary due to financial constraints, this approach erroneously assumes that all bridge elements are homogeneous and gives inaccurate baseline information. For example, piers of the same bridge may have different bottom conditions, depths, currents, or accidental damage. In addition, there may be variations in material quality in piles that would go undetected if only sample bents were inspected.

Underwater inspections are classified into three levels defined by the extent of the survey conducted and measurements obtained. A baseline inspection is most efficiently and economically performed with Level I techniques. Level I inspections consist of a "swim-by" overview, with minimal cleaning to remove marine growth. The inspections rely on visual or tactile examination of the exterior of the underwater structure. Attention should be concentrated at the mud line, mean low water, one or more intermediate depths, and areas of damage. The amount and type of debris associated with thestructure should be noted. The Level I inspection is useful to determine adherence to construction plans or to detect obvious damage. Upon completion of a Level I assessment, problems that have been identified can be further evaluated with a Level II inspection.

Level II inspections are more detailed, and are directed towards obtaining limited measurements of damaged or deteriorated areas that may be hidden by surface biofouling. Marine growth is cleaned from the structure to enable close inspection. Cleaning is time consuming and therefore is usually restricted to sample areas of the entire structure. Cleaned areas generally consist of minimum 10-inch wide bands at designated levels. Simple instruments, such as calipers, rulers, and graduated picks, are used for Level II measurements, although a limited number of more precise measurements using ultrasonic devices may be obtained. Level II inspections are usually necessary to assess wood or steel structures, and to evaluate problems detected on a Level I inspection. Several Level II measurements taken randomly can be used to verify the results of a Level I inspection.

Level III inspections are highly detailed, utilizing nondestructive testing techniques (such as ultrasound) or even minimally destructive sampling procedures (such as the coring of wood or concrete and in situ hardness testing). The purpose of a Level III inspection is to detect hidden damage or loss in cross-sectional area and to assess material heterogeneity.

Careful documentation of inspection findings is mandatory. The documented findings are used for planning appropriate inspection cycles, evaluating the amount of deterioration that has occurred between inspections, and determining maintenance requirements. A complete data base is also useful for liability protection. Sites of significant findings must be carefully identified to enable divers to return to the same location for further assessment. Documentation can take the form of detailed written reports, sketches, and measurements. Photographs or underwater video are often used to document areas of damage. Underwater photography techniques are advancing rapidly and are now capable of producing good pictures in the turbid water characteristic of bridge inspections. Standardization of the overall reporting procedure is important to limit subjectivity and to facilitate comparisons with subsequent inspections todetermine deterioration rates and contributing factors. Consistency among reports assists in bridge prioritization and administrative recognition of conditions requiring repair. Inspection findings should be promptly incorporated into the general inventory.

IN-HOUSE INSPECTION AND CONTRACT INSPECTION

Agencies have three basic options in conducting underwater inspections: to establish in-house inspection capability, to contract the work to a private contractor, or to use both in-house and contracted dive teams. Each method has its advantages and disadvantages.

The in-house system is similar to the arrangements for surface inspections of bridges in most highway departments, with trained inspectors being responsible for most field assessments and department engineers for engineering decisions. The capabilities of in-house underwater inspection teams vary with their level of training and equipment. An in-house dive team offers the advantage of low cost, especially for the assessment of numerous small, widely scattered bridges. In-house teams can be mobilized quickly for priority or emergency assessment before a contract can be negotiated. The agency retains control and flexibility by using its own employees. In-house dive teams can be useful in quality control work by performing preacceptance inspections for contracted construction or maintenance. They can also perform other underwater tasks beneficial to the agency; for example, archaeological survey work, maintenance of ferries and department watercraft, underwater search and recovery for the agency, and light maintenance work, particularly that of an emergency nature. Disadvantages of using in-house divers largely result from the increased responsibility of the agency when using its own employees. The agency must assume liability for the employees' safety, which necessitates having a supervisor knowledgeable in underwater procedures, conditions, and hazards. Diver training and equipment must be maintained at a level adequate for the working conditions.

The contractor options available for underwater inspection are quite diverse. Basically, an architectural and engineering (AE) firm may be used, or a diving firm. AE firms involved inunderwater inspection variously offer engineer divers or engineer supervision of trained divers functioning as technicians, such as engineer-directed inspections using diver-to-surface video. An AE firm without diving capabilities may subcontract a diving firm. Detailed engineering assessments of structures are provided by AE firms, which can be useful where construction and repair are found necessary. However, the AE capability for assessments may duplicate expertise already present in highway departments and is more costly than hiring a diving firm to work with the agency staff. Diving firms hired for underwater inspections either report directly to agency engineers or employ their own engineering consultants. In the selection of diving companies, experience in underwater inspection is more significant than salvage or construction credentials. Contracted inspections offer several advantages. The contractor assumes the responsibility for the diving employees. Generally, contractors are better suited through equipment and training for diving under hazardous conditions. They also provide an objective assessment of the structure in the event of a challenge to inspection findings.

The pitfalls of contracting underwater inspections can be largely avoided by having available an agency representative knowledgeable in underwater inspection techniques and conditions. This person should play an instrumental role in contractor selection and negotiations. The requirements and expectations of the agency must be carefully defined before undertaking negotiations for underwater inspection contracts. This requires preliminary information about the inspection conditions. Without adequate preassessment, the inspection may fall short of expected goals. Some flexibility should be included in the inspection contract. Contract renegotiation may be difficult if the inspection findings are unexpected and require a change in plan.

Several states are using a combination of in-house and contractor approaches with considerable success and efficiency. By contracting inspections of large, difficult, or hazardous structures, they are able to reduce the training and equipment required by their divers and decrease their liability. An in-house team with limited capabilities can be maintained at low cost and can provide quality control of contracted work and inexpensive inspections of structures under nonhazardous working conditions.

UNDERWATER INSPECTOR TRAINING

A common error in establishing an in-house dive team is recruitment of minimally trained personnel who have limited diving experience, restricted to recreational settings. The diving conditions for underwater inspections (poor visibility, underwater obstacles, and unpredictable currents) are very different from those for sport diving. Diving techniques are also different. Commercial divers use heavy weights for negative, not neutral buoyancy, depth sounding instead of gauge determined depth, and line tending and safety divers rather than buddy diving. Most inexperienced divers spend too much effort adapting to the diving conditions to do an effective inspection, but divers trained for these conditions can perform good inspections safely. The workshop summarized here was intended to concentrate heavily on training for underwater inspectors. However, the training director of the National Oceanic and Atmospheric Administration (NOAA), a federal agency active in diver training and the safety of commercial and research diving, who was scheduled to participate, did not attend.

Unfortunately, many organizations use employees with other duties as part-time divers. Part-time divers may not maintain the familiarity with diving that is requisite for effectiveness in a dark-water environment. Furthermore, this arrangement for using part-time divers causes the diving program to be constantly competing for personnel. Continuity is achieved by using a core of full-time personnel supplemented by part-time employees. Usually organizations are reluctant to spend funds to train part-time personnel; however, full-time employees can be trained and, in turn, can train and supervise a part-time staff.

Commercial dive training and experience are the most desirable preparation for the conditions of underwater inspection. Minimal requirements for underwater inspectors should consist of diving certification through a nationally recognized training agency, physical fitness to dive attested to by a physician knowledgeable in underwater medicine, experience in dark-water diving, and recent diving activity. It is essential that the diving activities be overseen by an experienced divemaster. NOAA regulations offer guidelines for diver qualification. Although engineer divers are considereddesirable by the directors of some programs, diving competence is the foremost requirement for any underwater inspector.

FACTORS IN BRIDGE DETERIORATION

Preliminary comparisons of bridges included in underwater inspection programs have clearly identified some factors as contributors to the deterioration of bridges. Each bridge inspection should carefully consider these factors, and they should be weighed in prioritizing bridges for inspection. Among the most significant considerations are age, material used in construction, marine environment, accidental damage from boat collisions or floods, traffic load, and extremes of temperature and weather.

Age usually is the dominant factor in engineering predictions of service level. However, the aging of a structure is in part determined by, and can be accelerated by, a combination of the other factors mentioned. Age alone has been a poor predictor of bridge failure, but may become more significant as the highway system becomes older.

The major bridge construction materials are concrete, wood, and steel. These are prone to different types of failure and therefore require different inspection strategies. Wooden structures contain a great number of substructure components, including numerous piles and cross members, that require considerable time for inspection. The life of wooden structures depends heavily on the environment. Those in salt water are prone to attack by marine borers, that can cause rapid deterioration. For this reason, wooden bridges are difficult to assess without corings. Bolt replacement at the cross members is a common maintenance requirement, but undercutting is rare with driven wooden piles. The durability of steel structures is also heavily dependent on the water conditions. An assessment of these structures is incomplete without thickness measurements using calipers or ultrasonic methods. Steel bridges are particularly sensitive to corrosive water. Concrete bridges are susceptible to spalling and scour. Because of the possibility of scour patterns with uneven undercutting on one or more sides, the entire circumference of the footing must be examined. Adequate concrete cover over the metal reinforcing is necessary to slowcorrosion, although there is some evidence that water may penetrate to the metal under certain conditions. In addition, immersed concrete is believed to deteriorate due to ions present in the water. Stress cracks can be an important indicator of load damage, and cracks can also result from settling of the structure, improper handling and overdriving of the precast piles, and corrosion and swelling of the rebars. Freeze-thaw cycles can cause cracking and surface spalling of concrete. The length, location, and frequency of cracks should be noted on inspections, and an attempt should be made to identify the cause.

The aquatic environment has significant effects on bridges in addition to those mentioned above. Heavy currents are especially destructive. Rapid tidal currents lead to surface spalling and necking (severe spalling of a pile at the waterline with considerable loss of cross-sectional area). Bottom currents cause scour around the piles. The scour most often occurs around midchannel piles, but not always. Floods cause damage from rapidly moving water as well as from the impact of the large debris carried by the flood waters. The accumulation of debris at bridges focuses the flow of water, thus increasing the potential for scour. Damage, including scour of bridge piers, fracture of piles, and undercutting and collapse of retaining walls, can dramatically appear after moderate to major floods in inland waterways. Usually the extent of the damage is not evident from the surface. Floods are the leading cause of bridge collapse in the United States. Similar damage results from coastal storms and hurricanes. Bridges in salt water are subject to greater corrosion than those in fresh water, and to damage from heavy tidal influences and marine organisms. If there is prolific marine growth, such as may occur in the semitropical environments of Florida and Hawaii, the accumulation may even contribute to the deadweight of the structure. Polluted water, most likely to be found in inland waterways associated with heavy industry, is particularly destructive.

Traffic load is a significant contributor to bridge wear, with overloading being the second most common cause of bridge failure. This type of damage is usually seen on secondary roads where small design loads are used. Stress cracks seen in concrete piles or the splintering of wooden piles are signs of overloading.

EXTENT AND FREQUENCY OF INSPECTIONS

The appropriate frequency and extent of underwater inspections have been difficult to estimate. Although the federal inspection requirements were designed with flexibility to allow states to tailor programs for individual structures and conditions, too little data are available to indicate the pattern of deterioration of underwater structures. The information required for individualizing inspection programs becomes more apparent as inspection data are accumulated. Two or three inspection cycles will yield excellent prognostic data on bridge deterioration. The best approach at present is to obtain a baseline evaluation of all bridges, noting any damage. Those structures found with deterioration not yet requiring repair should be monitored closely, at intervals shorter than five years. The initial Level I inspection may be followed by a Level II inspection to evaluate problem areas.

An optimal baseline study will assess all underwater elements. A sampling approach may be considered in subsequent inspections, but the goal is an evaluation of the entire structure. Random sampling risks inadequate assessment. It also forces a difficult choice between continuously examining the same sample to monitor deterioration, or sampling different elements in successive inspections in order to eventually inspect the entire bridge. If sampling of piles is necessary due to financial constraints, the flexibility to examine more piles if a problem is detected should be included in the inspection plan.

To incorporate a new bridge into the inspection program, the initial assessment should be a preacceptance inspection following construction. This inspection, before marine growth has occurred, identifies construction related damage to the bridge piles, assesses adherence to construction plans, and provides a baseline for future inspections. Suggestions for a long-range inspection plan should be obtained from the design engineer, based on the structure's design and environment.

Most underwater inspections will be performed separately from surface assessments. Since the underwater inspectors have a good vantage point for examining the underside of the bridge deck and its junction with the supporting structures, these are included in an underwater inspection in some programs. Theintegration of information from surface and underwater inspections is an important final step in assessment of a bridge. There are advantages to separating the funding for surface and underwater programs because of the increased cost and time involved in underwater programs, and the different inspection personnel, procedures, and equipment required. Despite the convenience of considering the superstructure and substructure separately, they function as a unit. Final repair and maintenance plans must be based on combined evaluation of the surface and underwater components.

RESEARCH TOPICS

Underwater inspection has progressed dramatically in the last 5 years, but research is still needed in some areas. Patterns of deterioration of bridges, and therefore the frequency and minimal extent of inspections, remain obscure. As data accumulate, more accurate predictions of bridge deterioration and service life may be possible. Current federal inspection standards are based on theories of engineering judgment and risk. With more information, required inspection frequencies will become evident, and the inspection requirements may be revised. The understanding of bridge deterioration that comes from inspection programs will be valuable for maintenance planning as well as for the selection of structures and materials for use in bridge design and construction.

Technological research is also needed. Ultrasonic testing methods applicable to underwater inspections, remote controlled vehicles to be used where the use of human divers is difficult or impossible, methods of cleaning marine growth from substructures, and a number of nondestructive and minimally destructive testing procedures are currently in various stages of development. Improvements are continuously being made in underwater photography and video, general diving equipment, and underwater communications. Ultimately, sidescan sonar-type equipment may be developed for evaluating bridge substructures. Computer assisted drafting and design (CADD) systems may be employed to yield important information about bridge conditions.

It should be noted that underwater inspection is more advanced in the private and commercial sector than in many publicagencies. In this regard, dissemination of current methods and technology is one of the most urgently needed steps towards effective underwater bridge inspection for safe highways.

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Contributions to the preparation of this document should be acknowledged. Daniel D. McGeehan organized and chaired the workshop session; Lynn H. Samuel composed the initial draft and incorporated reviewer's comments. The workshop attendees participated in the meeting and contributed valuable comments and criticisms during the review of the manuscript.

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