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UNDERWATER BRIDGE INSPECTION PROGRAMS

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A Summary of a Workshop Prepared by
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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 five 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 and engineering 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 five years and recommend the assessment of structures in corrosive water at two-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 under-
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

TABLE 2 SITES WITH MERGING-RELATED ACCIDENTS

Site No.	Climbing Lane Length and AADT	Vertical Alignment	Horizontal Alignment	Sight Distance	Passing Ahead	Accidents[a] Total and Rate	Merging-Related
1	0.13 mi	Up 8.5%	Tight curve	Restricted	Very	20	1
	3,400	No crest			Restricted	1,612[b]	#1[c]
2	0.73 mi	Up 6.0%	No curves	Excellent	Restricted	10	1
	9,725	No crest				282[b]	#2[c]
3	0.81 mi	Up 5.0%	After a curve	Good	Average	12	1
	9,725	Crest				364[b]	#3[c]
4	0.16 mi	Up 5.9%	Slight curve	Good	Restricted	17	5
	11,000	No crest				466[b]	#4–8[c]
5	0.22 mi	Up >5%	In middle of	Restricted	Restricted	6	1
	2,200	No crest	tight curve			747[b]	#9[c]
6	0.28 mi	Up >5%	In curve	Restricted	Very	4	2
	2,200	No crest			Restricted	498[b]	#10–11[c]

a - Accidents within ±0.10 mile of end of merging taper, 1980-84.

b - Accidents per 10^8 vehicle miles.

c - Numbers refer to accidents described in text.

Source: California Department of Transportation photolog, site plans, correspondence, TASAS, and (6).

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The first sentence in the last paragraph in column 1 should read as follows:

For car speeds of 38 mph, truck speeds of 22 mph, and speeds of other slow vehicles of 26 mph, the following results are obtained.

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The paper by Lacy and Pannee (pp. 99–106) was sponsored by the Committee on Engineering Fabrics.

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Portions of the original publication were printed in an incorrect sequence. A revised photocopy of the circular is available on request from the Business Office, Transportation Research Board, 2101 Constitution Avenue, N.W., Washington, D.C. 20418 (telephone 202-334-3218).

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The data in Table 2 are incorrect. The following table should be used in place of Table 2:

Speed (mph)	Speed (km/h)	Stopping Sight Distance (ft)	Stopping Sight Distance (m)
30	48	200	61
40	64	325	99
50	80	475	145
60	97	650	198
70	113	850	259

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In reference 1, the date for "Accident Facts," published by the National Safety Council, should be 1986.

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 five 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 the structure 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 water 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 underwater inspection 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, entire structure. Cleaned areas generally consist of minimum ten 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 to determine 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 in underwater 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 considered desirable 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 slow corrosion, 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 inpections 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. The integration 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 five 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 judgement 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 public agencies. 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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