

SUMMARY REPORT

**PRIORITIZING BRIDGE STRUCTURES
FOR UNDER WATER INSPECTION**

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16. Abstract <p>In the last decade, there has been increasing national concern about the adequacy of underwater inspection of bridge substructures. A number of factors have contributed to this concern, in particular the collapse of several major spans, some of which led to loss of life. Substructure failures have been the cause of bridge collapses and the subject of at least five National Transportation Safety Board (NTSB) highway bridge investigations. In at least four instances, deficiencies in the substructure could have been identified by underwater inspection.</p> <p>During this project, 425 bridges in Virginia were identified as requiring underwater inspection. It was concluded that assessments of the type and extent of damage to structures below the waterline prior to inspection are highly inaccurate. Prioritizing bridges for inspections must be based on an established history of underwater inspections.</p> <p>Trends in the deterioration of underwater structures indicate several factors to be considered in developing a priority system for an underwater inspection program. These trends are described, and time intervals for the inspection of bridges with a previous inspection history are suggested.</p>			
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(The opinions, findings, and conclusions expressed in this report are those of the authors and not necessarily those of the sponsoring agencies.)

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ABSTRACT

In the last decade, there has been increasing national concern about the adequacy of underwater inspection of bridge substructures. A number of factors have contributed to this concern, in particular the collapse of several major spans, some of which led to loss of life. Substructure failures have been the cause of bridge collapses and the subject of at least five National Transportation Safety Board (NTSB) highway bridge investigations. In at least four instances, deficiencies in the substructure could have been identified by underwater inspection.

During this project, 425 bridges in Virginia were identified as requiring underwater inspection. It was concluded that assessments of the type and extent of damage to structures below the waterline prior to inspection are highly inaccurate. Prioritizing bridges for inspections must be based on an established history of underwater inspections.

Trends in the deterioration of underwater structures indicate several factors to be considered in developing a priority system for an underwater inspection program. These trends are described, and time intervals for the inspection of bridges with a previous inspection history are suggested.

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INTRODUCTION

In recent years, there has been increasing national concern about the adequacy of underwater inspection of bridge substructures. A number of factors have contributed to this concern, in particular the collapse of several major spans, some of which led to loss of life. Substructure failures were determined to be the cause of bridge collapses in the last five National Transportation Safety Board (NTSB) highway bridge investigations. In at least four instances, deficiencies in the substructure might have been identified by underwater inspection (Jackson and Weber, 1990); consequently, the Federal Highway Administration (FHWA) has emphasized the importance of underwater bridge inspections, and the states have responded by improving their underwater inspection methods.

FHWA policies state that “underwater members must be inspected to the extent necessary to determine structural safety with certainty.” Current federal inspection standards require underwater inspection of all bridges over water at least every five years; bridges with submerged metal substructures must be inspected every two years.

Underwater inspections are customarily classified into three levels, which are defined by the extent of the survey conducted and the measurements obtained. Level I inspections consist of a “swim-by” overview, with minimal cleaning to remove marine growth. These inspections are based on visual or tactile assessment of the exterior of the underwater structure. Level II inspections are more detailed and focus on obtaining limited measurements of damaged or deteriorated areas. Marine growth is cleaned from the structure, usually from sample areas, and simple instruments including calipers, rulers, and graduated picks are used. A limited number of more precise measurements using ultrasonic devices may be obtained. Level II inspections are usually required to assess wood or metal structures and to evaluate problems detected during a Level I inspection. Sample Level II measurements can be used to verify the

results of a Level I inspection. Level III inspections are intense, in-depth evaluations utilizing nondestructive testing techniques (for example, ultrasound) or even minimally destructive sampling procedures (for example coring of wood or concrete and in situ hardness testing). The objective of a Level III inspection is to detect hidden damage or loss in cross-sectional area and to identify material heterogeneity.

Although federal standards encourage flexibility in the evaluation of individual structures, FHWA guidelines for underwater inspection of bridges suggest a Level I inspection on 100 percent of the substructure, a Level II inspection on at least 10 percent of the underwater units, and a scour inspection for each bridge subject to scour (FHWA, 1988). In-depth inspections including more extensive Level II and Level III inspection of some areas are necessary if the integrity of the structure can not be ascertained on the basis of the initial evaluation.

PURPOSE AND SCOPE OF THE STUDY

When the number of bridges exceeds the number that can be evaluated with available staff, a system for prioritizing bridge inspections is necessary. This should be based on conditions known to contribute to bridge deterioration. In addition, more frequent inspections than the FHWA-recommended five-year interval may be required for bridges subject to more rapid deterioration. In this study, factors were identified that can adversely affect the condition of bridge structures below the waterline and thus should be considered in inspection scheduling.

BRIDGE PRIORITIZING METHODS

The methodology of the study included four steps:

- the establishment of a computerized inventory of bridges requiring underwater inspection
- survey and inspection of all bridges in the inventory
- analysis of the data to determine whether factors contributing to deterioration can be identified.

Establishment of the Inventory

Each district supplied a list of bridges and the information available from the bridge inventory: route number, structure number, name of waterway, county, and age. Districts were requested to indicate bridges of particular concern for immediate evaluation. All districts responded with their needs for underwater inspection.

Information on water depth, number of elements in the water, construction material, foundation type (piles, footings), and water salinity (fresh, brackish, salt) were added from on-site observations. The extent and types of deterioration of the substructure, the substructure condition rating, the presence of scour, and the recent and projected inspection dates were added to the inventory following the underwater assessment.

Inspections

Agency and contract divers completed the underwater inspection of 425 bridges during the study.

All substructure elements of each bridge on the inventory were inspected. A Level I inspection was completed on 100 percent of the submerged substructures of all bridges. Each substructural element including piers, piles, abutments, fender systems, and dolphins were examined from the waterline to the mudline. Cracks, spalling, scour around the footings and in the surrounding streambed, accumulation of debris, and the effectiveness of previous rehabilitation work were specifically noted. Inspections were primarily tactile because of limited visibility.

A Level II or III sampling was performed (1) on all wooden elements and (2) when damage was detected on other elements. Level II inspections included measurements of pile diameter and damaged areas, scour profiles, and localized cleaning of marine growth. If scour was suspected based on exposure of footings or the bottom profile around the substructure elements, multiple-depth readings were taken around the pile, and the exposure of the foundation was quantified. The majority of the bridges were in fresh or mildly brackish water with minimal marine growth that did not interfere with inspection of the underwater members. When marine growth interfered with an inspector's access to the substructure, it was scraped away in limited areas with dive knives and hand-held scrapers.

The Level III inspections consisted of manual core samples obtained by divers on exposed wooden foundation pilings and wooden substructures and piers. Dowels treated with creosote were driven into the boring sites after the

sample was obtained. Boring samples were analyzed by the Division of Forestry for borer infestation.

Documentation

A condition rating scale for underwater substructures was devised based on FHWA bridge and culvert inspection guidelines (see Appendix). New bridges fewer than 6 months old with no problems detected on initial inspection received a 9. Bridge substructures with undercut footings or abutments were rated 4 or less depending on other findings. If a large amount of debris was found that could not be removed by the inspection team, the bridge was downgraded to a 6 even if in relatively good condition because of the potentially deleterious effect of the debris.

A final report of inspection findings for each bridge was prepared in the office generally within two weeks of the inspection. If a problem needing immediate attention (condition rating of 4 or less) was detected, the District Bridge Engineer and the Assistant Bridge Engineer in the Central Office were notified within 24 hours. The final report usually included a substructure cross sectional diagram with inspection findings indicated, a diagram of a typical bent, photographs of the substructure and any damage detected, description of inspection conditions, mode of access, substructure rating, and recommendations.

Data Analysis

The information obtained during the inspections was analyzed to identify correlations between construction and environmental factors and the damage and condition ratings for each bridge. Characteristics of the bridges that were analyzed included age, foundation, number of elements, and bridge material. Environmental factors analyzed were salinity and water depth. For the purpose of analysis, damage was divided into a number of categories: scour, spalling, wood rot, cracking, and corrosion.

INSPECTION CONDITION RESULTS

Physical Characteristics

A total of 425 structures were inspected. Four of these structures are bridge culverts, 5 are wharfs or ferry docks maintained by VDOT, and the remaining 416 are bridges.

The substructures of most of the bridges in the inventory (87 percent) are constructed of concrete; the second most common bridge material is timber (8 percent). Wooden substructures are located only in the Suffolk, Richmond, and Fredericksburg districts. A few bridges are combinations of concrete, steel, and wood; there are 7-steel jacketed bridges on the underwater inventory. Virginia has no bridges with exposed steel H-pile substructures.

Bridge foundations were categorized for the inventory as piles or footings. Footings were the most common type of foundation, they are found exclusively on concrete structures. Footings were less commonly located in brackish water, whereas driven piles, although less common than footings, were divided nearly equally between fresh and brackish water.

DAMAGE CATEGORIES

Most of the structures in this comprehensive survey were in fair to good condition. About 80 percent received a rating of 6 or above. Of the bridges that received a rating of 4 or below, scour was usually the primary defect. Seven of the wooden structures in the state had local but severe deterioration. Surprisingly, many of the structures with lower ratings were small and inconspicuous; most had fewer than 10 elements in the water.

Scour

Scour was confined to bridges with spread footings. In most cases, scour was limited to exposure of the footings. Some had shallow scour holes, and only a few were severely undercut. The scoured structures were usually located in shallow, flood-prone fresh water waterways. Several were downstream from a dam. Bridges with tremie concrete footings often had extensive scour.

Spalling

Spalling was seen on over 40 percent of the bridges. The damage was usually greatest at the waterline, although it occurred at the mudline of scoured bridges. All of these structures were exposed to heavy currents or flooding. In some cases, extreme spalling was in part attributable to poor quality concrete and improper placement procedures. Factors contributing to spalling included poor quality concrete, erosion, impact from bedload, and hydrologic stresses such as intermittent floods, strong currents, and water flow ebbs and surges caused by a dam upstream.

Wood Deterioration

Severe wood deterioration that lowered the condition rating to 4 or less was attributable to decay; there was no evidence of teredos, limnoria, or caddis flies. The water surrounding these structures was both fresh and brackish. Most of these low-rated wooden structures were recreational docks and not open to vehicles. Despite the frequency of wood deterioration, piles exposed by scour never showed deterioration. This may be attributable to the relatively short period of time that they were exposed or to the fact that they were continuously submerged following exposure.

DISCUSSION

Prior to the implementation of comprehensive underwater inspection programs, most information on bridge limitations and deterioration was based on investigations of bridge collapses. Recent investigations have highlighted the vulnerability of bridge substructures. Two important issues have emerged in the analysis of these accidents: (1) the significance of environmental conditions in bridge design and maintenance and (2) the development of underwater programs to ensure that vulnerable bridges are inspected and that recommendations resulting from inspections are implemented. It has become evident that no matter how inconspicuous it is, the bridge that fails is significant (McGeehan and Samuel, 1988). The concern generated by these bridge failures has shaped the current federal regulations for bridge inspection.

Periodic underwater inspections evaluate the present condition of the bridge including how the design is performing in the underwater setting. In doing so, the knowledge and tenets of modern engineering are applied in the assessment of structures that were built prior to the information presently available. Substructure deterioration may be subtle, and underwater monitoring may be the only method of detection to avoid catastrophic failure.

In addition to the legal and ethical commitments of the states to conduct regular underwater inspections, there are practical incentives to develop efficient underwater inspection programs. Established programs have realized significant savings by avoiding the closing of bridges, preventing collapses, and reducing the costs of repairs. The objective of an underwater inspection program is to protect the bridge owner's investment by detecting defects prior to its collapse. If rehabilitation is still feasible, it is almost always less expensive than replacement.

This report summarizes a survey of all bridges requiring underwater inspection in Virginia. Many of these structures had never been inspected below

the waterline. Although most of the bridges were in good condition, several had significant damage that had been unnoticed from surface inspections and which required prompt repair. Most of the bridges with substructural deterioration were small, inconspicuous structures that would have been overlooked in a less comprehensive survey.

The size of the underwater inventory was unexpected. The project received the rapid and enthusiastic support of the districts because of concern about the adequacy of inspection of structures in water. Modifications to the bridge inventory resulting from this project were the inclusion of the bridge construction material, the number of submerged elements, the type of foundation, and the requirement for underwater inspection.

Frequency of Inspection

The extent of the underwater inspection and its frequency within a 5-year maximum interval is left to the discretion of the states by FHWA. Within this limit, the frequency of underwater inspections should be based on the findings of previous inspections. A baseline inspection of all structures on the underwater inventory is required to initiate a program. In the VDOT program, a Level I survey of 100 percent of all submerged elements was performed. More intensive inspection (Level II or III) was performed when damage was detected by the Level I inspection. Some programs have elected to do Level I inspections of sample areas of each structure, but this approach risks missing localized damage or deterioration.

If rehabilitation is required, subsequent inspections will depend on the scheduling of the repairs. If repairs are made immediately, they should be inspected promptly. Subsequent inspections will be based on the type of repair. If immediate rehabilitation will be deferred and the damage will be monitored by inspection, the frequency of inspection will be determined by the extent of damage and the condition rating. In water, deterioration is particularly dynamic and requires careful monitoring.

Unscheduled inspections may be required under certain conditions. An underwater inspection is necessary if the load posting will be altered or if construction is planned on either the superstructure or the substructure. Vulnerable bridges should also be re-evaluated after heavy storms or high water conditions.

Pre-acceptance inspections should be performed on every new bridge and during and following every underwater maintenance effort. In the case of new bridges, pre-acceptance inspections provide as-built plans and enable the agency to detect deviations from the design plans. A baseline condition is established as a reference for future inspections. In addition, damage to new bridges

from scour or other causes has occurred during construction (Murillo, 1987, Lamberton et al., 1981). Examples of construction-related damage include metal protrusions from concrete that will eventually corrode, cracking of concrete, splintering of timber piles, and unprotected sites in timber for entrance of borers (Lamberton, 1981). Interval inspections during construction are recommended because damage may be hidden by subsequent work, and marine growth accumulating on the structure may impede inspection. Corrosion that has been found on buried piles was believed to have occurred during construction (Drago, 1987).

Scour is a dynamic process that is dependent on water flow. Some conditions tend to exacerbate scour. These include exposed foundations, abutments protruding into the stream, debris, and the migration of the channel.

Damage and Rehabilitation

Debris is a serious concern around bridge piles. Not only does it interfere with the inspector's assessment of the structure, but accumulated debris can redirect the water flow causing scour around the bridge piers.

Inspection of Bridge Rehabilitation

Several types of underwater maintenance are used by VDOT. The most commonly used measures are concrete pile jacketing and riprap placement for scour protection. Concrete pile jacketing has proved to be an effective method of surface protection of the pile. The timing of the jacketing process is critical and requires careful underwater monitoring. The marine growth must be removed prior to pouring the jackets, or a poor bond will result between the old and the new concrete. One study demonstrated a reduction in strength of the bond of 10 percent in 3 days and 20 to 30 percent in 7 days if the growth is not removed. Therefore VDOT quality assurance inspection monitors the completeness of the initial cleaning and requires pouring of the jackets within 3 days. If pouring is delayed, the piles must be recleaned.

Benefits of Underwater Inspection Programs

Overall, the condition of the nation's bridges as revealed by underwater inspection programs has been good. However, each program has, like Virginia's, reported bridges in need of rehabilitation (Avent, Drago).

CONCLUSIONS

As a result of the data gathered during this study, some correlations can be made between age, material, environmental conditions and bridge condition. In general, older structures should be scheduled for an underwater inspection before newer ones. However, in our study there seemed to be little correlation between age and the condition of the structure. Factors such as quality of concrete, damage during construction, construction methods, storm damage, freeze thaw damage, etc. influence the condition of the structure. These factors are usually too random to be used for accurate predictions. Conditions such as corrosion, scaling, spalling, and cracking can be used to make predictions.

Bridges with spread footings are usually more vulnerable to scour. Our data indicated that scour most often occurs when changes in environmental conditions cause a redirection of the stream current. Construction upstream or downstream that would affect the velocity of or volume of water near a structure could result in scour. The erosion of a river bed could redirect the water flow thereby increasing the potential for scour. To some extent, footings constructed on "solid foundations" had indications of scour as a result of the long-term erosion of the rock foundation. Ice did not appear to cause initial damage to the structures; however, it did exacerbate existing problems. If cracking existed in a concrete structure, freezing and thawing often caused large areas to spall. In some structures, the long-term abrasion of the ice rising and falling with the tide began to wear away portions of the concrete near the waterline ("necking"). In timber piles, freezing appeared to be the cause of splitting, which could expose untreated portions of a pile to predispose it to rotting. Debris around bridge foundations in water is a major problem. In some instances, debris channeled the water flow and appeared to be the cause of scour. Some bridges could not be adequately inspected because debris blocked access to the structure. For bridges previously uninspected, the prioritization would appear to be:

1. concrete structures with spread footings
2. timber structures
3. structures with concrete piles.

In each category, the oldest bridges should be inspected first. Structures with high traffic volume would be of a higher priority than those with lower volume. Interstate should be inspected before primary, and primary before secondary.

Once the basis for an inspection program has been established and all bridges have been inspected, a different prioritization system should be developed.

1. Bridges with high ratings would be placed on a five-year schedule.
2. Bridges with low ratings would be placed on a six-month to one-year schedule until recommended rehabilitation measures have been completed.
3. Recently rehabilitated bridges would be inspected to ensure that specified repairs have been made. These bridges should be placed on a short-term schedule to determine whether repairs were appropriate and whether subsequent damage was caused by the repairs. It is possible that the jacketing of one pier could restrict a channel thereby causing scour at a different location. If the rehabilitated structure rates high, it would then be placed on a five-year or routine schedule.
4. All new construction and rehabilitated structures should be inspected prior to acceptance.

RECOMMENDATIONS FOR IMPLEMENTATION

Recommendation 1.

There are several possible approaches to developing an underwater inspection program. The options include: contracting all inspections to private underwater inspection firms, maintaining a VDOT inspection team, or using the combined efforts of an in-house team with those of outside contractors.

With adequate support, recruitment, funding, equipment, and training, the option to use an in-house team that would be able to use contract efforts for unique situations would appear to be the most efficient and cost-effective.

Resolution:

This recommendation has been implemented as recommended.

Recommendation 2.

Some bridges require special equipment. A hyperbaric chamber would be required at Smith Mountain Lake because of water depth in excess of 100 ft. Long spans, e.g., over the James River, require many months to inspect unless multiple dive teams can be used. Bridges with heavy ship traffic require special vessels to conduct safe operations. Inspections conducted in fast current, in confined enclosed spaces, and in other potentially hazardous situations require

special training and continued updating of skills. Inspections in these situations should be accomplished by the use of private contractors.

Resolution:

This recommendation has been implemented. The department has a program in which selected bridges are advertised for inspection by private contract; this contract is a professional service contract. VDOT has established a committee to review proposals and select contractors.

Recommendation 3.

Bridges to be inspected by private firms should be advertised and awarded as professional services rather than on a low-bid basis.

Resolution:

This recommendation has been resolved; see previous recommendation and resolution.

Recommendation 4.

A safety committee to deal with OSHA and other training and safety issues should be established within VDOT.

Resolution:

A meeting was held to implement this resolution. Members of the committee will include representatives from the Divisions of Employee Safety and Health, Structures and Bridge, and from the Research Council. Members from other agencies were also considered. The formation of this committee was delayed as a result of the early retirement program. Plans to establish the committee are now active.

Recommendation 5.

The VDOT dive manual should be updated to cover all diving operations in which the Department's divers will be involved.

Resolution:

Implementation of this recommendation was delayed when several members of the Diving Safety Committee retired. Plans to update this manual have been discussed with the Structures and Bridge administrator. Implementation of this recommendation is scheduled and will be under the guidance of the Diving Safety Committee once that committee has been reactivated.

Recommendation 6.

A schedule of training for VDOT divers should be developed. This training should be reviewed and updated by the VDOT Diving Safety Committee.

Resolution:

The Structures and Bridge Division has been updating the training of their dive team. Since the Diving Safety Committee has not been reactivated, it has not been involved at this time.

Recommendation 7.

Acceptance inspection should be conducted on all new structures and those which have been rehabilitated prior to acceptance.

Resolution:

This activity is part of the VDOT underwater inspection program.

RECOMMENDED RESEARCH AREAS

This study reported the results of a baseline inspection of all bridges requiring underwater inspection in Virginia. Additional studies will focus on improving inspection methods and expanding the bridge database. Scour inspection has recently emerged as a national concern as a result of several bridge failures. It has been identified as one of the primary causes of bridge collapses. Routine scour inspections are now required by FHWA for all vulnerable bridges. Similar to underwater inspection, methods are not defined for routine, reliable inspection. Studies are currently under way by the research dive team to develop a methodology for routine scour inspection.

A series of interval inspections in the underwater program will provide valuable information on the deterioration of bridges. Building on the information obtained from the baseline survey, interim inspections will guide VDOT in the scheduling and prioritizing of inspections.

Special techniques are needed for Level II and III inspections. The weakest area of underwater assessment of bridges is that concerned with wooden structures. The U.S. Navy has conducted several research projects to evaluate the application of computerized tomography to wooden pile assessment.

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APPENDIX

Bridge and Culvert Inspection Ratings

Rating	Condition	Underwater Conditions
9	New	
8	Good No repairs needed.	No scour, debris, cracking, spalling, etc.
7	Generally good Potential exists for minor maintenance.	Some small accumulations of debris. Minor hairline cracking.
6	Fair Potential exists for major maintenance.	Large trees, extensive debris present. Extensive hairline cracks. Minor spalling. Minor scour.
5	Generally fair Potential exists for minor rehabilitation.	Extensive debris present. Wider cracking. Moderate spalling. Moderate scour around footings.
4	Marginal Potential exists for major rehabilitation.	Extensive debris. Cracking with large spalls. Evidence of rusted reinforcing steel. Heavy scour with some undermining of structure.
3	Poor Need for repair or rehabilitation immediately.	Extensive debris. Severe cracking with large spalls and exposed reinforcing steel. Heavy scour with severe undercutting of sub-structure foundation.
2	Critical The need for repair or rehabilitation is urgent. Facility should be closed until the indicated repair is completed.	Cracking and spalling are significant enough to endanger life. The structural strength of the elements is significantly reduced. Undercutting has reduced the load capacity of the structure.
1	Critical Study should determine the feasibility for repair.	Facility is closed.
0	Critical Facility is closed and is beyond repair.	