Role of Underwater Substructure Inspections in Bridge Management

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INTRODUCTION

In the past, the condition of underwater substructures was largely ignored. Some attention was directed to elements at the water line but most bridges had never received an underwater inspection prior to the early 1990's. During the 1980's, several bridge collapses occurred which were traceable to underwater deficiencies. These failures have led to revisions in the National Bridge Inspection Standards (NBIS) so that bridge owners are mandated to conduct underwater inspections at five-year intervals unless conditions warrant a shorter interval. Since most states started these regular inspections around 1990, it is only now that the third of these statewide inspections are beginning. As such, the current condition of underwater substructures is well documented. However, data is still quite sparse for determining the rate of deterioration. Thus, in a discussion of bridge management systems, underwater elements continue to be the neglected stepchild. The purpose of this paper is to discuss the role of underwater bridge inspections as it relates to bridge management issues.

There are two distinct aspects to underwater bridge inspections, both requiring different types of expertise. Material degradation issues require expertise in materials science and structural engineering, while scour is more related to hydraulics and geotechnical engineering. For either case, there are three levels of inspection that might be required. Level I is a visual, tactile inspection which usually consists of a "swim by" overview with minimal cleaning to remove marine growth. It is detailed enough to detect obvious major damage or deterioration and it is usually conducted over the total exterior surface of each underwater element with limited probing of the substructure and streambed. The results of a Level I inspection provide a general overview and indicate whether a Level II or III inspection may be necessary.

A level II inspection is a detailed inspection, which requires that portions of the structure be cleaned of marine growth. It is intended to detect and identify damaged and deteriorated areas that may be hidden by surface growth. This inspection is more detailed and often measurements of damage are taken. The Level II inspection usually includes only a small portion of the substructure (around 10 percent) and is restricted to the more critical areas.

A Level III inspection is a highly detailed inspection where extensive repair or possible replacement is contemplated. The purpose of this type of inspection is to detect hidden or interior damage and loss in cross-sectional area. Included are extensive cleaning, detailed measurements and selected nondestructive and partially destructive techniques such as ultrasonic, coring, or hardness tests.

WHAT IS THE COMMON INSPECTION PROCESS?

A typical inspection team consists of three members: diver, tender and communications operator. In some cases a field supervisor or professional engineer is also present. The diver conducts the actual inspection. The diver typically has commercial diving training as well as bridge inspection training. Usually, commercial diving equipment is used. A hardhat diving helmet is connected by air hose to an air compressor at the surface. Two-way communication is maintained at all times through a communication line. A volume tank provides a reservoir of air and is connected with a pneumo tube that enables the diver to measure water depths. The diver is equipped with various hand tools for inspection including a light, scraper, knife, calipers, incremental borer used for timber piles, and rule. In general, access to the bents or piers is from a motor launch. For some small streams, the access is from the shore. An outfitted diver and the launch equipment are shown in Figures 1 and 2. The tender's responsibility is to ensure the safety of the diver by maintaining equipment and servicing the diver during the dive. The communications operator records all observations. He also uses drawings and inspection reports to keep the diver oriented to his location.

A hands-on inspection is conducted on each bent or pier from waterline to mudline. For piles, each face is inspected from top to bottom in sequence. Visual inspections are not always possible because of muddy waters, so often the inspection is conducted primarily by feel. In addition to the inspection by hand, a sharply pointed

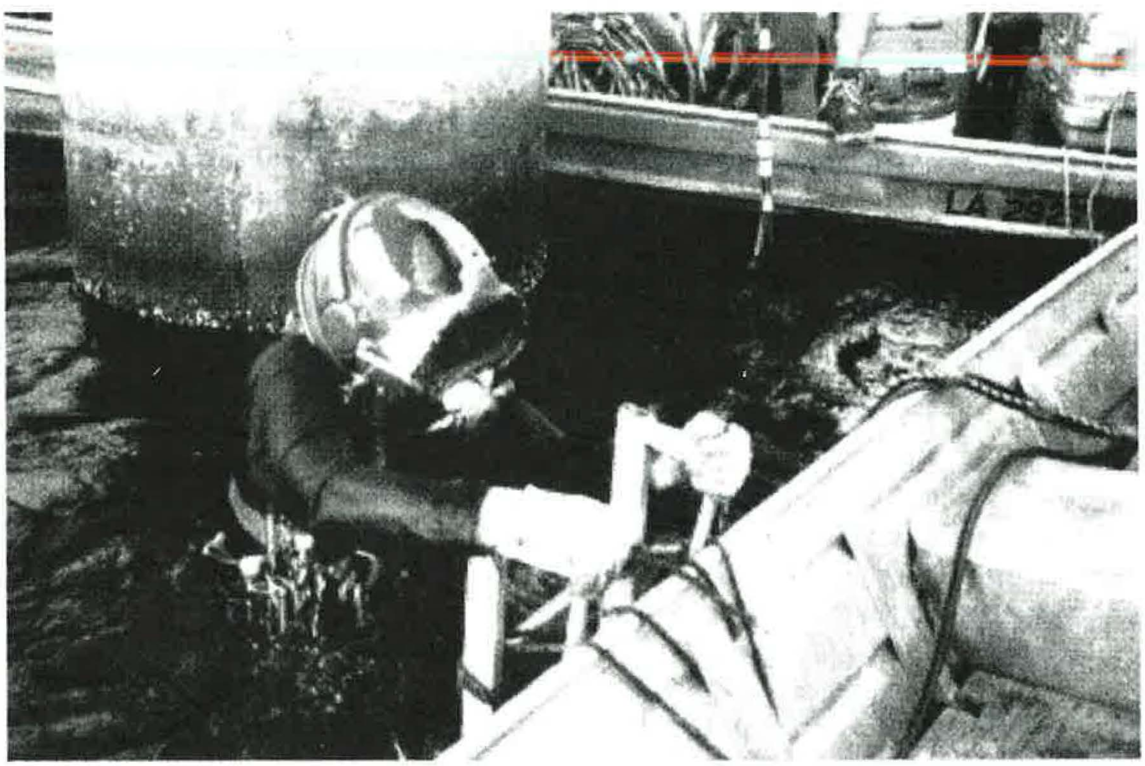

Figure 1: Underwater dive inspector.

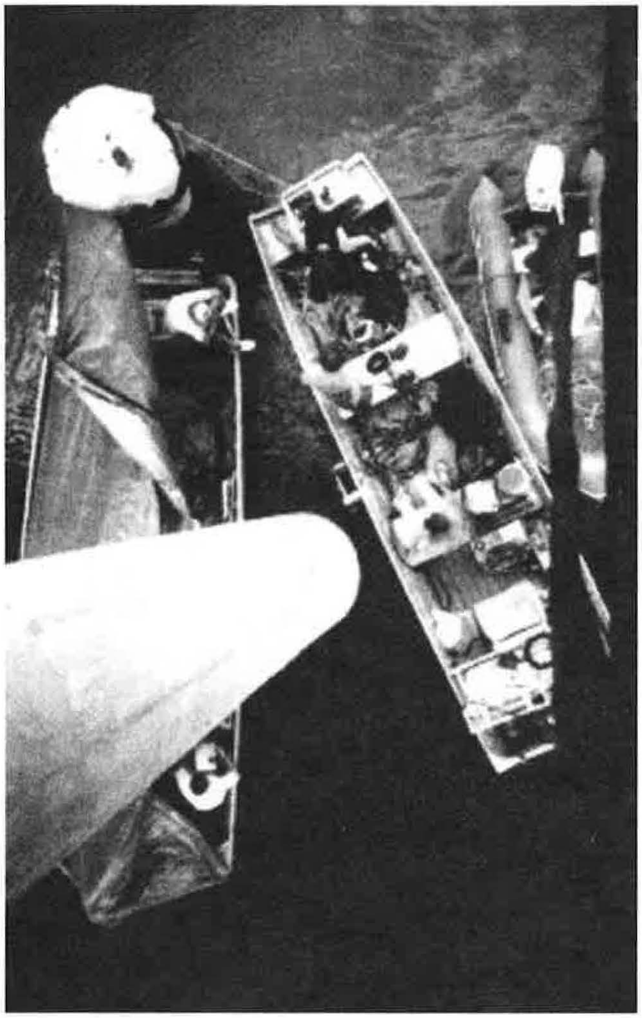

Figure 2: Underwater inspection launch equipment.

probe is used to detect cracks. Dimensions are taken on all damaged sections found. Calipers are used to measure the flange thickness of steel piles and hammer soundings are taken for concrete and timber piles. Suspect timber piles are also cored with an incremental borer. For piers, the surface is inspected in five-foot (1.6 m) wide vertical sections successively moving around the perimeter of the pier.

In addition to the structural inspection, a bottom inspection is conducted to uncover evidence of scour. Depth elevations are taken at each pile of each bent. For piers, depths are taken at equal intervals around the perimeter. Depth readings are also taken at 10-foot (3 m) intervals out from the bent or pier to establish whether scour has occurred. Usually, readings are taken over three intervals, but the actual number depends on the bridge configuration. If evidence of scour is found, then additional depth measurements are taken to clearly define the extent of the scouring. While scour is the main focus of the waterway inspection, other aspects are also considered, such as waterway obstructions, debris, bank erosion, and condition of revetments.

HOW RELIABLE ARE UNDERWATER INSPECTIONS?

Underwater inspections are clearly not as reliable as above water inspections. This difference results from the hostile environment associated with underwater inspections. The first problem is visibility. For many cases, visibility is nearly zero which means that the diver conducts the inspection primarily by feel. Upon finding a suspicious zone, he may be able to see a little by putting his facemask directly onto the surface being inspected. With low visibility, a strong light source is of little help since the light is reflected off the silt suspended in the water. Even with good visibility (2–3 ft or up to 1 m is considered good), the diver's view of the structure is limited. He is thus forced to view the structure in small increments and cannot get an overview of the problem areas. A photo of a damaged steel pile taken in very good visibility conditions is shown in Figure 3. Even under these conditions, the view is somewhat limited.

The second problem is marine growth. While this is not a problem for every structure, in many cases the substructure is covered with marine growth. In some cases this growth is a type of seaweed while in others, solid crustacean material. In either case, the marine growth may hide damage to the substructure. The cleaning of marine growth can be quite time consuming and expensive and is usually done only on a limited basis. The most typical procedure is to spot clean small areas in regions likely to have damage. This approach is somewhat hit-or-miss and thus places limits on the effectiveness of the underwater inspection.

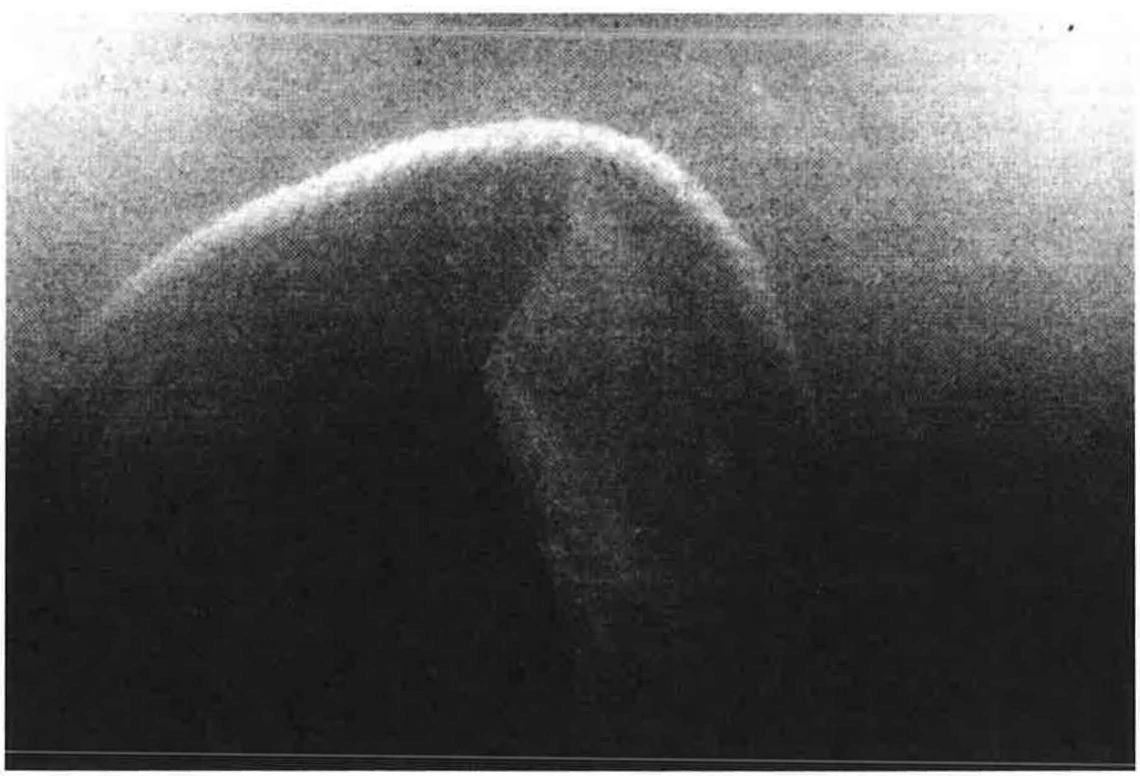

Figure 3: Photo of a damaged steel pile taken in good visibility conditions.

The third problem limiting the effectiveness of underwater inspections is communication. Speaking in legal terms, underwater inspection data is hearsay. The diver is verbally reporting damage to the communications operator as he conducts the inspection. The communications operator is recording the data as the inspection progresses. While there is two-way communication with the diver, it is easy for something to be lost in the translation. After surfacing, the diver usually reviews the notes taken. However, he may be looking at data taken an hour or more earlier about which his memory may already be fading.

The fourth problem is a subtle one of orientation and perspective. An above water inspector can usually stand back and get an overview of the structure. He can relate the proportions and sizes of members and elements. Underwater inspectors do not generally have this luxury. For example, a tilt in a pile above water might be easily observed while the same tilt below the water would not be noticed. Knowing to conduct additional investigation because "something doesn't look right" is much more difficult in underwater inspections.

The fifth problem relates to the detection of hidden damage. Significant portions of underwater substructures are relatively massive. For footings, pier walls, large columns and piles, interior damage is difficult to detect under ideal conditions. Underwater, these difficulties are magnified. Nondestructive testing methods are not as effective underwater and much more difficult (if not impossible) to execute. Even such a simple method as taking a hammer sounding is quite difficult underwater.

A sixth problem relates specifically to scour. Scour occurs during rapid water movement. As the flow returns to normal, particle matter settles out and may backfill the scour hole. Once backfilled, the scour hole is difficult to detect by diver inspections. A rod may be used to probe the soil, but depending on the material, it may or may not be effective in detecting scour. Thus, scour measurements may sometimes be misleading. This issue has been addressed to some extent by defining scour critical bridges. These bridges are then analyzed in detail for their scour potential.

The final problem is dealing with water current. When the flow rate exceeds 2 knots, divers have difficulty maintaining their position. At 3 knots, physical restraints are usually required. Above that rate, inspections cannot be conducted without some type of protection for the diver.

As a result of the obstacles facing underwater inspectors, the accuracy of the inspections could be significantly less than a corresponding above water inspection. This aspect must be an important consideration in developing bridge management systems including underwater substructures.

CAN UNDERWATER INSPECTION REPORTS BE USED FOR BRIDGE MANAGEMENT SYSTEMS?

Current condition ratings for underwater substructures are somewhat limited. The US National Bridge Inventory (NBI) rating scale rates the entire bridge substructure as opposed to individual bents or elements. The scale ranges from 9 for perfect condition to 0 for a collapsed structure. The PONTIS bridge management system uses a condition state rating for commonly recognized elements. The commonly recognized elements may have 3, 4 or 5 condition states depending on the element with the low number being the best condition. Again, this system rates the entire bridge substructure as opposed to individual bents. As a consequence, there is relatively little data as to serviceability, structural strength, structural safety, scour, or remaining service life at the bent or pier level.

Underwater bridge inspections in several southeastern states have been based on an individual bent rating system. This rating is similar to the NBI rating scale except that ratings seven through nine have been combined into a single rating. The result is a seven-point scale with seven designating good condition and one designating imminent collapse. The zero rating was not used since no closed bridges were inspected. This rating system allows for an analysis of substructure deterioration, which could form the basis for bridge management of substructures.

Structural data from Louisiana bridge inspections illustrate the usefulness of such ratings. The bent ratings are grouped into five year age groups and the average is plotted in Figure 4. The regression of the underwater condition rating generally has a strong linear trend ($R^2 = 0.8257$). Yet, there exists at least two well defined plateaus at approximately 20 and 40 years. To further analyze this data, the ratings were separated by material type. A plot of the condition rating versus age for each material type is shown in Figure 5. A linear least-squares regression curve is also shown for each material type.

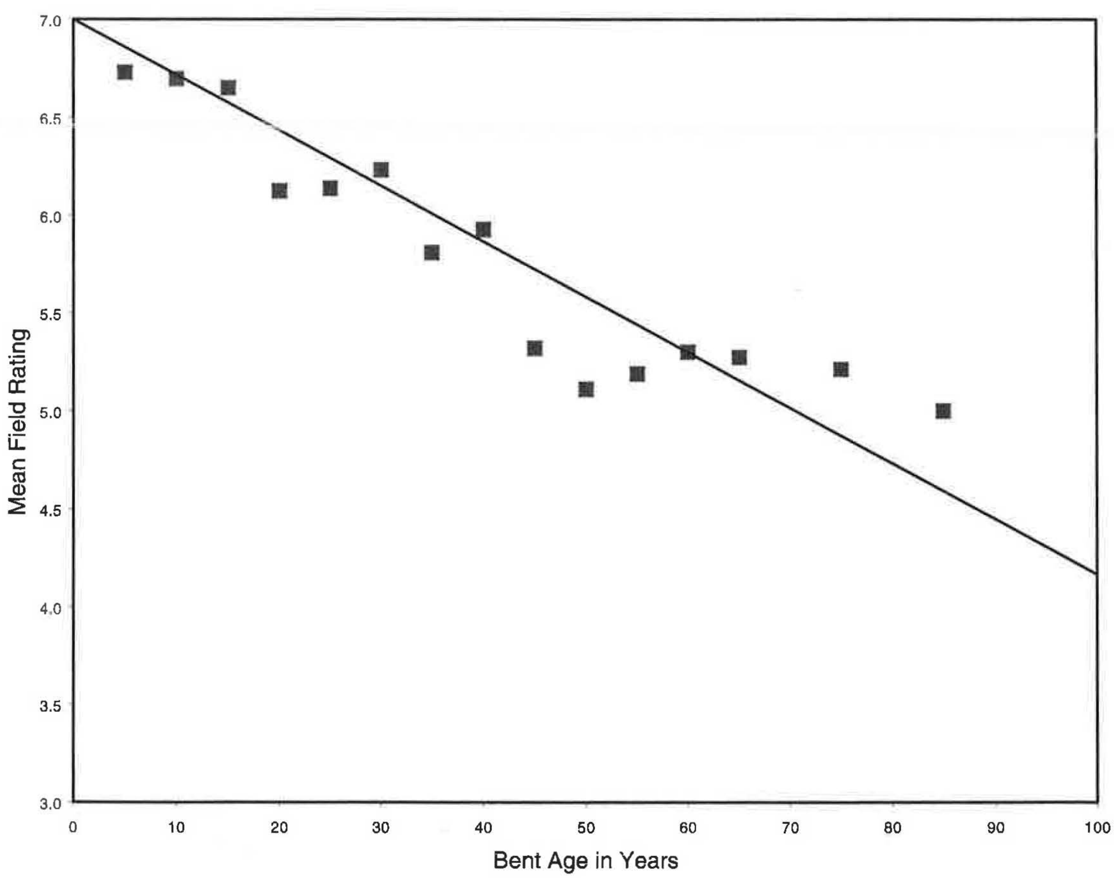

Figure 4: Mean field rating vs. bent age.

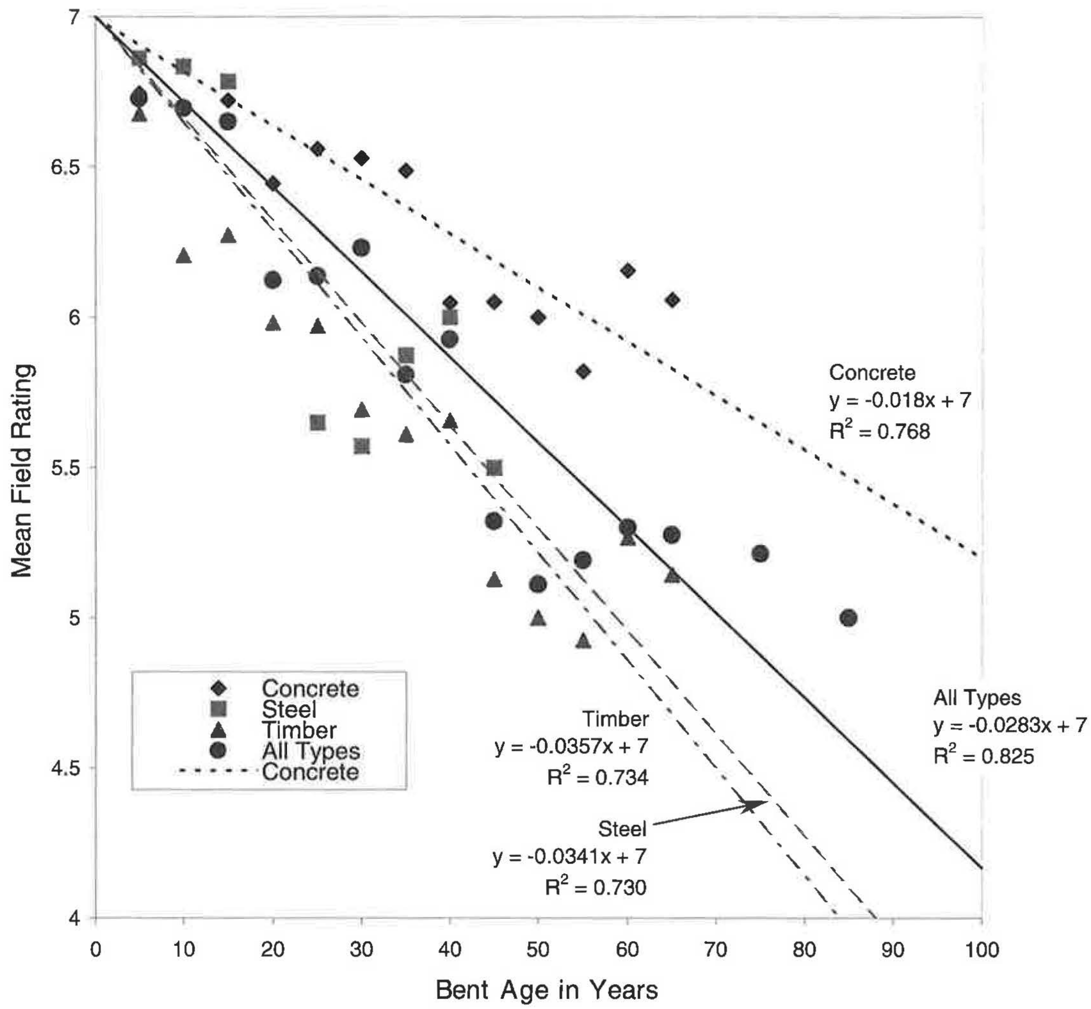

Figure 5: Mean field rating vs. bent age by bent material.

The slopes (m) of these best fit lines characterize deterioration rates. While the steel and timber substructures have similar deterioration rates (m = 0.0341 and 0.0367), the deterioration rate for concrete is significantly less (m = 0.0180). This data provides a basis for substructure deterioration models that can be incorporated into bridge management systems.

SUMMARY AND CONCLUSIONS

Issues related to underwater bridge substructures and bridge management are discussed in this paper. Since underwater inspections are relatively new, a historical record of deterioration patterns is lacking. However, data is now becoming available to provide methods for modeling deterioration. It has also been noted that underwater inspections are conducted in extreme conditions that may limit the accuracy of the results. Bridge management systems should reflect the differences between superstructure and underwater substructure inspections.