STATE-OF-THE-PRACTICE AND STATE-OF-THE-ART IN U.S. BRIDGE INSPECTION

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Abstract

Bridge inspection techniques and technologies have been ever evolving since the National Bridge Inspection Standards (NBIS) were established in the United States more than 30 years ago. As technology has advanced, so have the tools and methods that have become available to a bridge inspector. The emergence of previously unknown problem areas has also fostered this evolution.

This paper presents a discussion of the bridge inspection techniques typically used in the United States for the inspection of bridges as required on a biennial basis, and advanced inspection techniques that are available and used when more difficult problems have been identified or need to be evaluated.

Introduction

All publicly owned highway bridges in the United States that are longer than twenty feet (e.g., bridges and culverts) are required to undergo an inspection at least once every 24 months, according to the requirements of the National Bridge Inspection Standards (NBIS)[4]. The NBIS regulations have been in place for more than 30 years, and have resulted in a high level of performance of the nation's almost 600,000 highway structures. The NBIS defines the types and frequencies of the various inspections that are required, and also details the required training and expertise of bridge inspection personnel.

Visual inspection is the primary method and technique used to perform bridge inspections in the United States. In addition, more advanced tools and Non-Destructive Evaluation (NDE) methods are available, and are typically used when needed. The type, location, accessibility, and condition of a bridge, as well as the type of inspection, are some of the factors that determine what methods and inspection practices are used.

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[4] Special provisions are provided in the NBIS that allow for inspection frequencies that exceed 24 months; however, the vast majority of bridges in the United States undergo inspections as required by the NBIS at least once every 24 months, and many are inspected on a much more frequent basis.

Bridge Inspection Types

There are five basic types of bridge inspections defined in the NBIS: initial, routine, damage, in-depth, and special. The first inspection to be completed on a bridge is the "initial" inspection. The purpose of this inspection is to provide all the required data (termed Structure Inventory and Appraisal data in the NBIS) necessary to establish baseline structural conditions, and to identify and list any existing problems or locations in the structure that may have potential problems in the future.

The most common type of inspection conducted, as a result of the requirements of the NBIS, is the "routine" inspection. The purpose of the "routine" inspection is to determine the physical and functional condition of a bridge on a regularly scheduled basis.

A "damage" inspection is an unscheduled inspection to assess structural damage resulting from unanticipated environmental factors or human actions (e.g., following a flood or earthquake, or after an overheight vehicle hits one or more bridge girders). An "in-depth" inspection is a close-up, hands-on inspection of one or more members above or below the water level to identify deficiencies not readily detectable using routine inspection procedures, or during the inspection of a fracture critical member.

Finally, a "special" inspection is used to monitor a known or suspected deficiency. If bridge members have known problems or deficiencies, they might be inspected on a much more frequent basis than required by the NBIS; an example of this would be for a steel member that has a known fatigue crack in it, so that it can be monitored until a repair can be completed, or the bridge replaced.

Bridge Inspection Tools and Practices

For the purposes of this paper, the term "state-of-the-practice" is used to describe the methods commonly used during routine bridge inspections. Similarly, the term "state-of-the-art" is used to describe the methods available and being used as required or during an in-depth or special inspection.

Safety is enhanced through these inspections and by "rating" bridge components, such as the deck, superstructure, and substructure, and by the use of NDE methods and other advanced technologies. As noted earlier, visual inspection is the primary method used to perform "routine" bridge inspections, and tools for cleaning, probing, sounding, and measuring, along with graphical visual aids, are typically used. On occasion, destructive tests are conducted to evaluate specific areas or materials of concern, or to help identify appropriate rehabilitative work. Type, location, accessibility, and condition of a bridge, as well as type of inspection, are some of the factors that determine what methods of inspection practices are used. When problems are detected, or during the inspection of critical areas, more advanced methods are employed.

Commonly used methods for evaluating concrete elements during “routine” inspections include mechanical sounding to identify areas of delamination and other forms of concrete degradation. Similarly, for the “routine” inspection of steel members, methods include cleaning and scraping, and the use of dye penetrant and magnetic particle testing to identify cracks and areas of significant corrosion. Table 1 lists many of the typical state-of-the-practice tools and techniques used for “routine” bridge inspections.

State-of-the-art methods utilized during “in-depth”, “damage”, and “special” inspections include impact echo, infrared thermography, ground penetrating radar, and strain gauges for concrete structures and elements, and ultrasonic, eddy current, radiography, acoustic emissions, strain gauges, and x-ray technology for steel structures and elements. Table 2 provides examples and brief descriptions of some of the state-of-the-art methods used in bridge inspection in the United States.

Table 3 provides a cross-reference between the type and location of an element in a structure, and typical state-of-the-art and state-of-the practice bridge inspection tools commonly in use.

There are numerous other technologies under development that have the potential to substantially advance the practices used for bridge inspection. Some of these are being developed or are in limited use by other industries, such as the aerospace and nuclear industries. There is no one-size-fits-all approach in the use of NDE and testing tools; each technology is designed for a specific purpose and function. Although these developing technologies have the potential to augment and advance bridge inspection practice, the challenge is to find a way to make them efficient, effective, and practical for field use. The Federal Highway Administration (FHWA), along with industry, academia, and State transportation agencies, continue to investigate and improve the practicality of many of these technologies. As a result of these efforts, a number of systems have recently become available that can assist an inspector in the identification and quantification of such things as reinforced concrete deterioration, steel tendon distress, and the displacement or rotation of critical members in a bridge.

There are also a number of systems that can be used to monitor a bridge to provide real time data and alert the owner to such things as failure of load carrying members; excessive rotation or displacement of an element; overload in a member; growth of a crack; scour around a bridge pier; or occurrence of a significant flood event. The type of information provided is typically very specific and provides data on isolated areas or members of the bridge. The most practical of these systems are being used by owners during “in-depth” or “special” inspections, or are being implemented for long-term monitoring. The effectiveness and costs associated with continuous monitoring systems and testing must be weighed with the benefits gained. Continuous monitoring systems routinely need to be assessed and maintained, and do not eliminate the need for visual inspections since only isolated areas are examined. In some circumstances, it is more effective to increase the inspection frequency, repair or retrofit areas of concern, or replace the structure.

Summary

Although the United States does experience occasional catastrophic collapses of highway bridges, most of these are "event driven" – i.e., due to an extreme, unanticipated event like an earthquake or ship collision. As a result, the overall history and performance of highway bridges in the United States for the past 30+ years has been quite good, in large part due to the high bar set by the National Bridge Inspection Standards.

The standards and tools used for bridge inspection are constantly evolving and improving – the most difficult challenge is therefore making sure that bridge inspectors have sufficient access to these tools, and the knowledge on how to use them effectively.

Table 1. State-of-the-Practice Bridge Inspection Tools
(Reference: "Bridge Inspector's Reference Manual," Publication FHWA-NHI-03-001, Federal Highway Administration, Washington, DC, October 2002)

Tools for cleaning:

- Wire brush – used for removing loose paint and corrosion from steel elements
- Scrapers – used for removing corrosion or growth from element surfaces

Tools for inspection:

- Ice pick – used for surface examination of timber elements
- Increment borer – used for internal examination of timber elements
- Chipping hammer – used for loosening dirt and rust scale, sounding concrete, and checking for sheared or loose fasteners
- Plumb bob – used to measure vertical alignment of a superstructure or substructure element
- Chain drag – used to identify areas of delamination on concrete decks
- Range pole/probe – used for probing scour holes

Tools for visual aid:

- Binoculars – used to preview areas prior to inspection activity and for examination at distances
- Flashlight – used for illuminating dark areas
- Lighted magnifying glass (e.g. five power and 10 power) – used for close examination of cracks and areas prone to cracking
- Inspection mirrors – used for inspection of inaccessible areas (e.g. underside of deck joints)
- Dye penetrant – used for identifying cracks and their lengths

Tools for measuring:

- Pocket tape (6 foot rule) – used to measure defects and element and joint dimensions
- 25 foot and 100 foot tape – used for measuring component dimensions
- Calipers – used for measuring the thickness of an element beyond an exposed edge
- Optical crack gauge – used for precise measurements of crack widths
- Paint film gauge – used for checking paint thickness
- Tilt Meter and protractor – used for determining titling substructures and for measuring the angle of the bearing tilt
- Thermometer – used for measuring ambient air temperature and superstructure temperature
- 4 foot carpenter's level – used for measuring deck cross-slopes and approach pavement settlement
- D-meter (ultrasonic thickness gauge) – used for accurate measurements of steel thickness
- Electronic Distance Meter (EDM) – used for accurate measurements of span lengths and clearances when access is a problem
- Line level and string line

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Table 1, Continued

Tools for documentation:

- Inspection forms, clipboard, and pencil – used for record keeping for most bridges
- Field books – used for additional record keeping for complex structures
- Straight edge – used for drawing concise sketches
- Camera – used for visual documentation of the bridge site and conditions
- Chalk, keel, paint sticks, or markers – used for element and defect identification for improved organization and photo documentation
- Center punch – used for applying reference marks to steel elements for movement documentation (e.g. bearing tilt and joint openings)
- "P-K" nails – Parker Kalon masonry survey nails used for establishing a reference point necessary movement documentation of substructures and large cracks

Tools for access:

- Under bridge inspection equipment – used for superstructure and various areas of substructure
- Ladders – used for substructures and various areas of superstructure
- Boat – used for soundings and inspection; safety for over water work
- Waders – used for shallow streams

Table 2. Examples of State-of-the-Art Bridge Inspection Tools

Method	Advantages	Limitations
Ultrasonic Testing (UT) 	UT makes use of mechanical vibrations similar to sound waves but of higher frequency. Used for pin inspection, penetration welds (plate girder flanges, circumferential welds in pipe, etc.), length and thickness measurements	Surface condition critical. Permanent record has limited value.
Eddy Current (EC) 	Can detect near-surface defects through paint.	Magnetic properties of weld materials can influence results. Orientation of probe during scanning can affect results.
Ground Penetrating Radar (GPR) 	A technique that utilizes electromagnetic waves to examine concrete and other non-ferrous materials. Used for detection of embedded metals, thickness of materials, mapping of reinforcement location and depth of cover.	Environmentally sensitive to the presence of moisture, road salts, electromagnetic noise.
Impact Echo (IE) 	Access to only one side of the structure is needed, and it gives information on the depth of the defect.	Best applied for determining member thickness.
Ultrasonic Pulse Velocity (UPV) 	Portable equipment that is easy to use.	For testing, access to both sides is needed. No information on the depth of a defect is provided.
Infrared Thermography (IR) 	A global technique that covers greater areas than other test methods, making it cost effective. Provides an indication of the percentage of deteriorated area in a surveyed region.	Proper environmental conditions are required for testing. Anomalies are difficult to detect the deeper they are in the concrete.

Table 3. Typical Bridge Elements and Inspection Technologies

Bridge Element	Deterioration Type	State-of-the-Practice	State-of-the-Art	Emerging Technology
Concrete Deck	Delamination / Rebar Corrosion	Mechanical Sounding	Impact Echo	Ground Penetrating Radar
			Infrared Thermography	
Steel Pins / Hangers / Eye Bars	Cracks / Fatigue Cracks	Dye Penetrant / Magnetic Particle	Ultrasonic	Advanced Ultrasonic
Steel Beams / Girders / Trusses / Cables	Cracks / Fatigue Cracks	Dye Penetrant / Magnetic Particle	Eddy Current	Advanced Ultrasonic
			Ultrasonic	Infrared
			Radiography	
			Acoustic Emissions	
			Strain Gauges	
Concrete Pre-Stressed Girders	Tendon Corrosion	Mechanical Sounding	Strain Gauges	Magnetic Flux Leakage
Concrete Post-Tensioned Girders	Tendon Corrosion, Grout Holes	Mechanical Sounding	Strain Gauges	Magnetic Flux Leakage
			Acoustic Monitoring	Ultrasonic
			Impact/Ultrasonic Echo	Thermography
			Ground Penetrating Radar	Vibration Testing
			X-Ray	
Bearings	Movement, Lack of Movement	Mechanical Measuring	Tilt Meter	Remote Sensor Bearings
Concrete Substructure –Columns / Piers	Delamination / Rebar Corrosion	Mechanical Sounding	Ground Penetrating Radar	
			Ultrasonic Pulse Velocity	
			Infrared Thermography	
			Tilt Meter	

Table 3, Continued

Bridge Element	Deterioration Type	State-of-the-Practice	State-of-the-Art	Emerging Technology
Foundations	Erosion / Scour	Mechanical Probing	Sonar	
			Ground Penetrating Radar	
			Time Domain Reflectometry	
			Remote Monitoring	
			Parallel Seismic	