Chapter 1 – Table of Contents

Chapter 1 - List of Figures

Chapter 1 - Introduction to Bridge Maintenance

1.1 Fundamentals of Bridge Maintenance

1.1.1 Target Audience

This manual provides fundamental information pertaining to bridge maintenance for those new to and for those advancing in their roles and responsibility within bridge maintenance. The manual serves as a refresher and/or a reference for those currently working in bridge maintenance. Program managers will find this manual useful in a review of an existing bridge maintenance program or when implementing new activities in existing programs.

The manual is designed to assist bridge maintenance workers and managers in addressing most common types of bridge distress. Practical procedures for preventive maintenance on highway bridges and culverts are outlined. This manual is not meant to be all-inclusive and does not rule out other maintenance procedures. It is a source of information for those responsible for maintenance and preservation of highway bridges and provides an understanding of strategies and methods of bridge maintenance programs. The manual is not intended to supplant existing agency guidelines or policies, but to be used as a source of information when the need arises. The manual is not a substitute for consulting an engineer with the appropriate qualifications to determine proper repair methods.

This manual is of value to engineers, program managers, supervisors, foremen, and field crews. Engineering consultants, academics, and industry representatives will also find this manual to be a valuable resource for maintenance techniques, materials and methods, concepts, strategies, and guidance.

1.1.2 Other Resources

The Federal Highway Administration (FHWA) and its training division, the National Highway Institute (NHI), offer many resources that are beneficial to those involved in bridge maintenance. These include:

- NHI Course 130088 Bridge Construction Inspection
- NHI Course 130054 Engineering Concepts for Bridge Inspectors
- NHI Course 130055 Safety Inspection of In-Service Bridges
- NHI Course 134029 Bridge Maintenance Training
- NHI Course 134108G TCCC Plan Reading: Bridge Plans (Web Based)

These and many other related courses can be found at

https://www.nhi.fhwa.dot.gov/default.aspx.

1.1.3 History of Bridge Maintenance

In order to meet the city of Rome's water needs, a system of 11 aqueducts was constructed between 312 B.C. and 226 A.D. Portions of this system, like the section of the Aqua Claudia pictured in Figure 1.1, remain standing to this day as a result of proper maintenance. Historic records indicate crews flushed the pipes of sediment, repaired breaches, and removed calcium carbonate build-up on a periodic basis. Aqueduct designers included access points at regular intervals for inspection and maintenance activities. Throughout the evolution of bridge building, maintenance has played a role in keeping highway structures in service. As designers continue to incorporate modern codes and materials into bridge design, bridge maintenance continues to develop and implement new materials, methods, and strategies to keep existing bridges in service.

Figure 1.1 Section of the Aqua Claudia, South of Rome

1.2 The Bridge Maintenance Unit

1.2.1 Organizational Structure

Most transportation agencies have a Central Office that performs administrative functions in support of the District (or Regional) offices. The people that repair and maintain the highway system work in the Districts.

Many Departments of Transportation (DOT) are organized by functional area. Units involved with the design of construction projects, developing standard specifications, and updating the Qualified Products List, for example, are commonly housed in a division separate from units responsible for snow removal, highway maintenance, and fleet management. District operations are overseen by administrative counterparts in the Central Office. Figure 1.2 and Figure 1.3 illustrate two different ways in which a DOT might incorporate the bridge maintenance function into their organization.

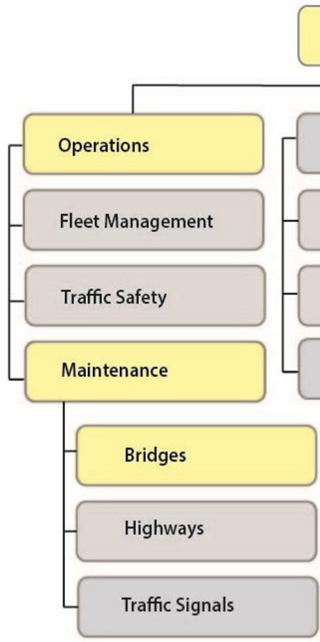


Figure 1.2 Organization Chart with Bridge Maintenance as Part of Operations

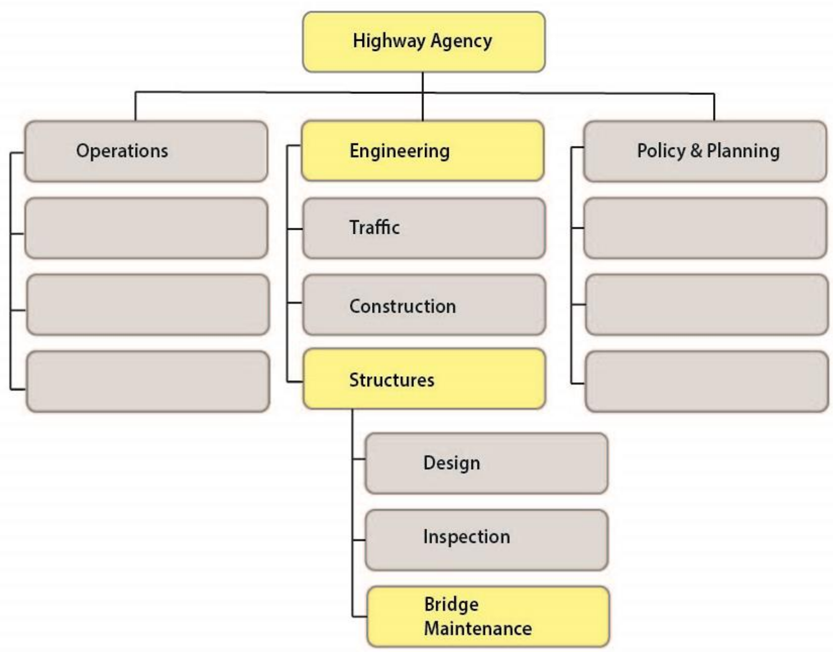


Figure 1.3 Generic Organization Chart with Bridge Maintenance as Part of Engineering

Organization may be less formal in smaller agencies. A single engineer may serve as bridge designer and bridge maintenance engineer. Some agencies are organized without specific job titles. In this instance, bridge maintenance is performed by the same crews that maintain pavement and other roadside assets such as drainage, guardrail, signs, lighting, etc.

Some examples of ways in which transportation agencies have integrated the bridge maintenance function within their organization are provided below:

- A unit in the Central Office controls all the bridge maintenance work for the entire agency, and all the work is contracted out.
- A unit within the Central Office provides technical advice or guidance. The District performs maintenance work.
- A unit in Central Office is responsible for major repairs and rehabilitation and the Districts are responsible for minor repairs, preventive and other ordinary maintenance activities.
- The Maintenance group in the Central Office works with the maintenance units in the District offices. The Central Office Structures group provides technical support to the maintenance units.
- The Structures group in the Central Office determines the bridge maintenance program and designs the repairs. Districts conduct the contract administration including the inspections and final acceptance of the work.
- One unit in the Central Office is responsible for the design and maintenance of highway structures. The agency does not have District offices.

There isn't a “best” place for bridge maintenance within an organization. Whether by function, personnel, or asset, each unit and the people working in it become effective through strong communication and support within and across organizational lines.

1.2.2 Developing the Work Plan

Just like there are many ways for a DOT or other transportation agency to integrate the bridge maintenance function within their organizations, there are also many ways in which these same organizations develop their bridge maintenance work plans. Figure 1.4 illustrates how one state’s DOT handles the decision-making process in the development of its work plan. In this example, the Regional Bridge Maintenance Engineer (RBME) determines if repairs are necessary, and if the repairs can be performed by state forces. It also shows how the Maintenance Management System (MMS) and Bridge Management System (BMS) are incorporated into the process.

Most bridge repair needs are identified through a periodic bridge inspection program. Bridge inspectors provide detailed information and photographs of existing bridge conditions. The inspection report and bridge inventory data are the primary sources of information for an initial determination of the various maintenance and preservation needs of a bridge. When a bridge has been identified as needing work, more detailed information is gathered during a field visit by maintenance personnel.

In a few agencies, inspectors are required to provide a list of maintenance actions and repair quantities to the Bridge Maintenance Unit. In addition to the inspection process, some agencies include periodic review of the bridge by maintenance personnel.

Agencies use Bridge Management Systems (BMS) to identify and prioritize bridge needs. This is typically a Central Office function. Districts compare BMS lists of maintenance needs to Districts’ internal lists of needs. The Districts are usually given the authority to modify the initial BMS list and the scope of work whether generated by the Central Office or District/Local office is typically adjusted by the staff responsible for the bridge maintenance program.

Some maintenance actions are done on a fixed cycle. Candidates for cyclical maintenance are determined through simple queries of the bridge management system. For instance, all bridges with concrete decks that have not been sealed in the last 10 years might be candidates for deck sealing. Deciding if it is worthwhile to seal a deck that is scheduled for an overlay or replacement filters the list further.

Bridge needs can arise suddenly. Impacts to the superstructure by over-height vehicles, severe weather events, and punch-throughs of the deck are not uncommon and add to the work load of the Bridge Maintenance Unit.

Agencies have various systems to identify and relay urgent needs to the Bridge Maintenance Unit. Some agencies have instituted a flagging system in the bridge inspection process to alert bridge maintenance of an urgent repair need.

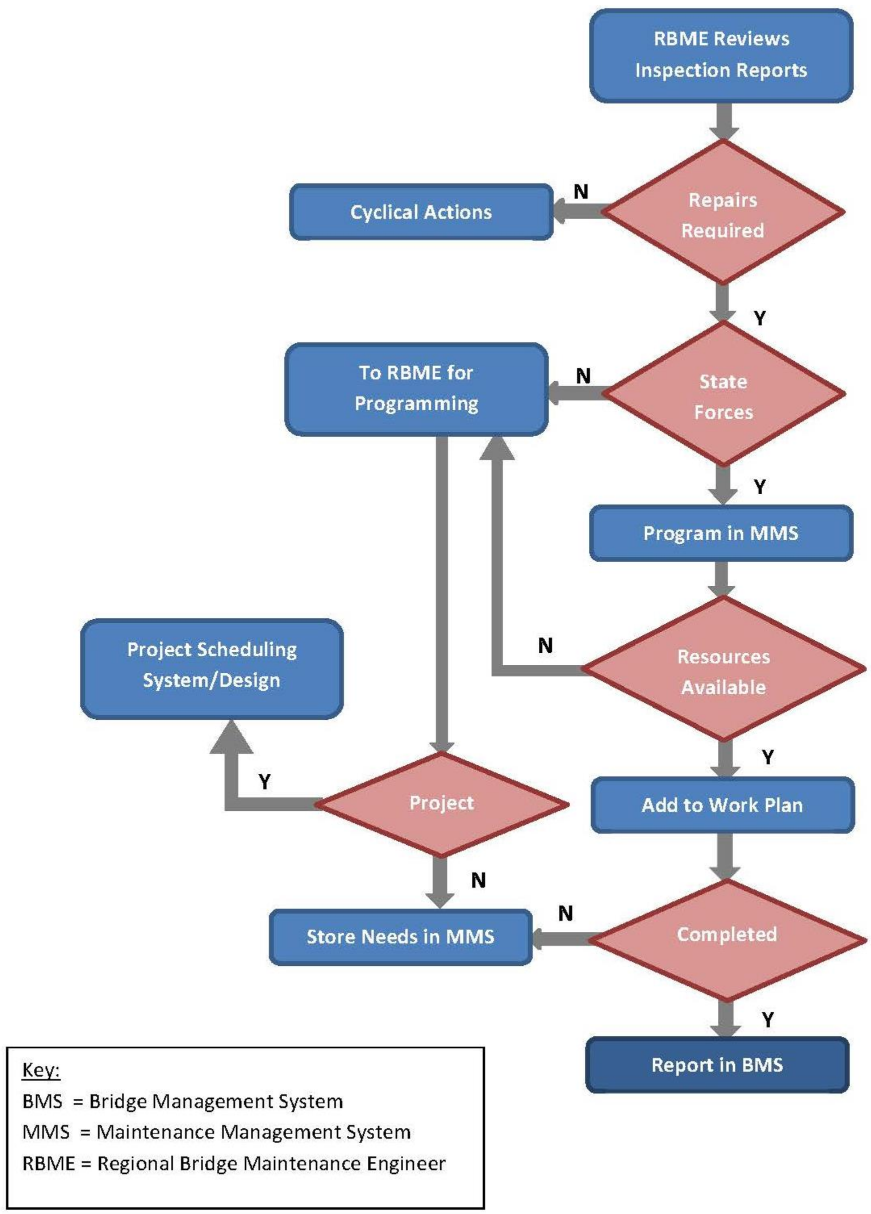


Figure 1.4 Example of Work Plan Decision-Making Process (Courtesy of New York State DOT)

1.3 When to Call the Engineer

Bridge maintenance staff may encounter conditions on bridges that require the attention of an engineer. Bridge inspectors inspect a bridge once every 24 months, but bridge conditions can change rapidly due to storms, floods, traffic impacts or overload, earthquakes, utility failures, and embankment erosion. It is possible that a bridge maintenance worker may have better access to view areas or conditions that were not visible to the bridge inspector during their routine inspections. In general, bridge maintenance staff should contact the engineer whenever any portion of the primary load path of the bridge is compromised. The Primary load path is the direction in which each consecutive load will pass through connected members. The sequence commences at the highest point of the structure working all the way down to the footing system, ultimately transferring the total load of the structure to the foundation.

Ultimately, the lowest structural member must be strong enough to support all members above it.

For most bridges the primary load path components are deck and slab elements, primary superstructure elements, and primary substructure elements. These components are discussed in the following sections.

1.3.1 Deck and Slab Elements

Decks and slabs transfer tire loads to the superstructure of the bridge. Any deck or slab conditions that could cause a full depth hole should be reported to the engineer. This may be heavily cracked concrete with intersecting cracks on top of the deck and underside that occurs within any 12 inch by 12 inch area or larger. These “deck punch-throughs” are also possible in steel grid decks that have cracked or missing grid pieces. In timber decks, failure to transfer tires loads most often comes in the form of cracking and rot.

1.3.2 Primary Superstructure Elements

The role of the superstructure elements of a bridge is to carry the loads transferred from the deck to the substructure. Superstructure elements are typically the elements of the bridge that span over obstructions or roadways. The following is an example listing of superstructure field conditions that warrant a call to the Engineer:

<u>Steel girders/ stringers/ floor beams/ truss members/ arched or cabled bridges</u>

- Any cracks found in primary members or welds to primary members such as girders, floor beams, pin and hangers, truss connections etc.
- Any section loss that exceeds 10 percent of the member thickness
- Bent, bowed, or distorted steel elements
- Broken cable elements or cable anchorages
- Missing or loose bolts, rivets, or broken welds
- Loss of bearing

<u>Concrete girders/ stringers and floor beams/ arches</u>

- Impact damage that bends or breaks reinforcing steel or prestressing strands
- Any material deterioration evidenced by dense crazed cracking
- Any loss of bearing

- Any fire damage that turns the concrete pinkish or produces spalling
- Cracking greater than 1/16 inch wide for prestressed and 1/8 inch wide for reinforced concrete particularly near midspan, or near supports
- Unsound concrete at or behind reinforcing steel

Timber girders/ stringers/ floor beams

- Any broken or split members
- Any rotting, crushing, or decay found near the ends of the members
- Any decay or fire damage that results in a 10 percent loss of the members section
- Loss of bearing
- Any broken or missing bolts or screws

1.3.3 Primary Substructure Elements

The substructure elements of the bridge take the loads from the superstructure and transfer the loads to the ground. Substructure elements include bent caps, columns, pier walls, abutments, footings, piles, trestles and towers. The following is an example listing of substructure field conditions that warrant a call to the Engineer:

Steel Substructure Elements

- Any broken or cracked members
- Any section loss that exceeds 10 percent of the member thickness
- Bent, bowed or distorted steel elements
- Missing or loose bolts, rivets or broken welds
- Erosion holes under or around bridge supports
- Buildup of soil in channels that restricts 20 percent or greater of the normal opening

Concrete Substructure Elements

- Impact damage that bends or breaks reinforcing steel or prestressing strands
- Any material deterioration evidenced by dense crazed cracking
- Any loss of bearing
- Cracking greater than 1/8 inch wide particularly in bent caps
- Erosion holes under or around bridge supports
- Any fire damage that turns the concrete pinkish or produces spalling
- Buildup of material in channels that restricts 20 percent or greater of the normal opening
- Cracking greater than 1/16 inch wide for prestressed and 1/8 inch wide for reinforced concrete particularly near midspan, over or near supports
- Unsound concrete at or behind reinforcing steel

Timber Substructure Elements

- Any broken or split members
- Any rotting, crushing or decay found near the ends of the members
- Any decay or fire damage that results in a 10 percent loss of the members section
- Any members that are not fully bearing

- Any broken or missing bolts or screws
- Erosion holes under or around bridge supports
- Buildup of material in channels that restricts 20 percent or greater of the normal opening

Culverts

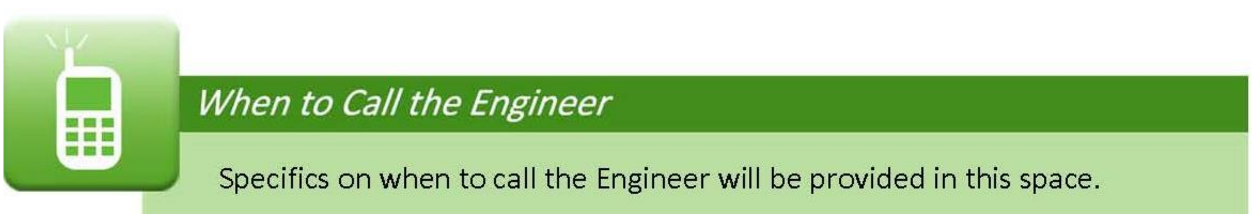
- Distortion along the length of the culvert in excess of 15 percent difference from the design dimensions, or if the distortion has changed since the previous inspection.
- Buildup of material in culvert that restricts 20 percent or greater of the normal opening
- Erosion of the soil under the culvert or around the headwall and wingwalls
- A dense network of random crack indicating material deterioration
- Any fire damage that turns the concrete pinkish or produces spalling
- Any material deterioration evidenced by loss of section in the flow line

Other situations that warrant a call to an engineer

- Cracked steel or aluminum joint assemblies
- Buckled approach slabs
- Signs of approach slab settlement that exceeds 2 inches
- Signs of any bridge substructure settlement not documented in the bridge inspection report
- Exposure or near exposure of the bottom of spread footings that are not founded on rock
- Noticeable changes in the location of channels under bridges
- Before the depth of the wearing surface is increased or the depth of integral concrete wearing surface is decreased due to maintenance operations
- Before removing full depth portions of decks or large areas of concrete decks below the top layer of reinforcing steel

The lists above provide common situations that would warrant a call to an engineer. These lists are examples and are not comprehensive lists of conditions that warrant engineering review. If the stability of a bridge is in question, an engineer should always be contacted. It is a good practice to send a photo of the situation in question.

In the following chapters of this document, a call out is provided to flag situations when the Engineer should be called. This call out will look like:



1.4 Terminology

The FHWA defines a bridge as "a structure, including supports, erected over a depression or an obstruction, such as water, a highway or a railway, and having a track or passageway for carrying traffic, or other moving loads and having an opening measured along the center of the roadway of more than 20 feet between undercopings of abutments or spring lines of arches, or extreme ends of openings for multiple boxes; it may also include multiple pipes." The purpose of this definition is to establish criteria to facilitate bridge inventory, inspection, and reporting requirements as outlined in the national Bridge Inspection Standards.

Bridge maintenance plans employ several categories of actions (see Figure 1.5). These categories, as defined in the FHWA Bridge Preservation Manual, are described in the followed sections.

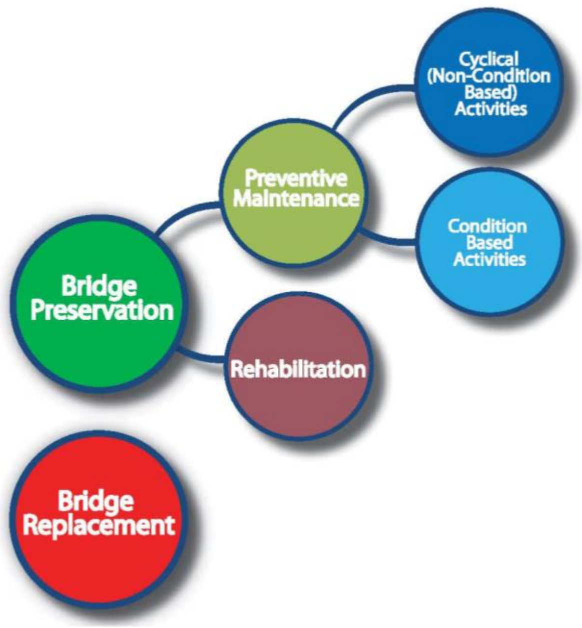


Figure 1.5 Bridge Action Categories as defined in FHWA Bridge Preservation Guide

1.4.1 Bridge Preservation

As defined by the FHWA Bridge Preservation Guide, bridge preservation includes "actions or strategies that prevent, delay or reduce deterioration of bridges or bridge elements, restore the function of existing bridges, keep bridges in good condition and extend their life". Preservation actions may be cyclical or condition-driven and may be preventive or restorative.

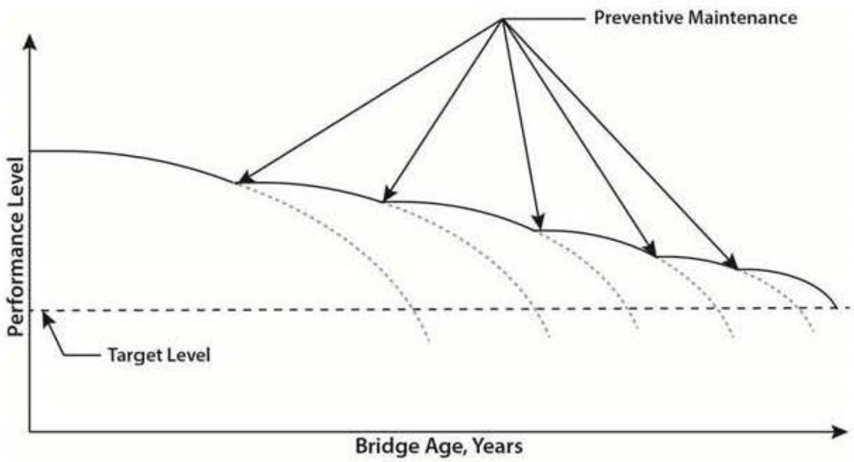
Bridge preservation actions can delay the need for costly replacement actions. Preservation actions are applied while the bridge is in good or fair condition, before the onset of serious deterioration. Bridge preservation encompasses preventive maintenance, repairs and rehabilitation activities. Functional improvement such as strengthening, widening, and raising vertical clearance are not considered preservation.

An effective bridge preservation program: 1) employs long-term strategies and practices to preserve the condition of bridges and to extend their service life, 2) has sustained and adequate resources and funding sources, and 3) has adequate tools and processes to ensure the appropriate treatments are applied at the appropriate time.

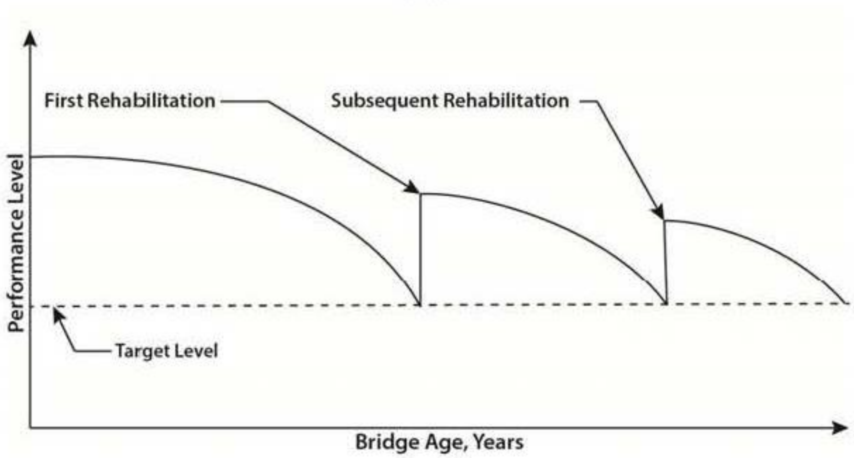
1.4.2 Preventive Maintenance

The American Association of State Highway and Transportation Officials (AASHTO) Subcommittee on Maintenance defines Preventive Maintenance as “a planned strategy of cost-effective treatments to an existing roadway system and its appurtenances that preserves the system, retards future deterioration, and maintains or improves the functional condition of the system (without substantially increasing structural capacity).”

Bridge owners apply preventive maintenance to elements or components of structures with significant remaining useful life. A part of bridge preservation, preventive maintenance is a strategy of extending useful life by applying cost-effective treatments to sound bridges (good or fair condition). The concept of preventive bridge maintenance suggests that a planned strategy of cost-effective treatment should be performed to keep bridges in good or fair condition, retard future deterioration, and avoid large expenses in bridge rehabilitation or replacements. This strategy is depicted in Figure 1.6, which shows conceptually how multiple preventive maintenance actions can be an alternative to multiple, costly rehabilitation.



(a)



(b)

Figure 1.6 Bridge Life Extension by (a) Preventive Maintenance Only, and (b) Rehabilitation Actions with No Preventive Maintenance

Preventive maintenance includes cyclical actions and condition-based actions. Bridge rehabilitation is not considered a preventive maintenance action.

1.4.3 Cyclical Maintenance (Scheduled Maintenance)

Cyclical maintenance, also called scheduled maintenance, involves activities performed on a pre-determined interval or schedule. Cyclical maintenance prevents an element from becoming deficient, not to improve it. Like an oil change for a car, cyclical maintenance actions are included in the work plan because the element is due for maintenance.

Agencies have identified a number of activities to be performed on cycles. These activities are considered necessary, but do not alter the condition rating of the structure. Cyclical maintenance is considered to have a long term benefit to the bridge. The influence of cyclical maintenance on the service life of the element and the bridge, as a whole, is difficult to measure.

Examples of cyclical maintenance include bridge washing, bearing lubrication, concrete sealing, and slope clearing. Bridge washing, for instance, is done to remove de-icing chemicals from concrete elements and superstructure, flush road grit from expansion joints, and flush the drainage system. Some bridge owners wash bridges annually, other owners set a two year interval.

The cycle for sealing concrete is typically based on the service life projection of the concrete sealer specified by the agency. For example, some agencies seal their concrete bridge decks every three or five years. Sealing concrete bridge decks is usually more frequent than sealing substructures because the deck, as a riding surface, abrades at a quicker rate than the substructure elements.

1.4.4 Corrective Maintenance and Repairs

Corrective maintenance actions are repairs. Elements needing corrective maintenance are those that have failed or are anticipated to fail. Some repairs, such as expansion joint repair and deck patching, are minor repairs. Major repairs are larger in scope and require a substantial effort to restore deteriorated components to a safe and serviceable condition. This includes work such as cap beam/pier column repair, wing wall replacement, structural concrete repairs, and steel beam repairs. It is important to consult with an engineer for the analysis and design of any major repair.

Selection of the correct repair technique can depend on knowing the cause of a deficiency and not just symptoms. If the cause of a deficiency is understood, the correct repair method will be selected, and the repair should be successful. A general procedure to follow for designing and executing a repair involves the evaluation and determination of the cause of the deficiency and the methods and materials to be used in the execution of the repair.

1.4.5 Critical Findings

National Bridge Inventory (NBI) regulations require agencies to monitor and address critical inspection findings in a timely manner. Critical findings are urgent. Critical findings are different from other work requests from the bridge maintenance and inspection offices. Chapter 2 of this manual goes into detail on nationwide bridge inspection procedures.

1.4.6 State of Good Repair

A State of Good Repair refers to a condition in which the existing physical assets, both individually and as a system, are functioning as designed within their useful service life and are sustained through regular maintenance and replacement programs. For bridges, the state of good repair means that physical conditions of bridge elements, components, and entire networks of bridges allow bridges to function as designed and are sustained through regular maintenance, preservation, and replacement activities.

1.4.7 Service Life

The service life of an asset is the total period during which the asset remains in use. Maintenance can extend service life.

1.4.8 Design Life

The design life of a structure is the estimated time that the bridge is expected to remain in service. Design life differs from service life as design life is a theoretical number, whereas service life is an actual number. In some cases, the service life of a structure can exceed the design life. Without preventive or corrective maintenance, the design life of a highway bridge may not be reached.

1.4.9 Rehabilitation

Rehabilitation of a bridge involves a significant amount of work to restore structural integrity, to correct major safety concerns, and in some projects to increase capacity of a bridge. Rehabilitation work can be done on one or multiple elements. Bridge rehabilitation is considered to be a bridge preservation action by some agencies. However, as stated by FHWA, "functional improvements such as adding a travel lane or raising vertical underclearance, while often considered as rehabilitation are not considered preservation". (FHWA, *Bridge Preservation Guide*, 2011, pg. 9).

Examples of bridge rehabilitation include but are not limited to: deck replacement, superstructure replacement, and pier replacement. These projects typically require significant engineering resources, long completion schedules, and considerable funding.

1.4.10 Replacement

As defined by FHWA, replacement is the "total replacement of a structurally deficient or functionally obsolete bridge with a new facility constructed in the same general traffic corridor." Bridge replacement is not considered a maintenance activity. This definition was provided by FHWA for management and administration purposes of the former Highway Bridge Program Fund. This program was later consolidated with many other programs in MAP-21.

1.5 Benefits of Preventive Maintenance and Consequences of Deferred Maintenance

1.5.1 Balanced Approach

Studies (e.g., http://www.fhwa.dot.gov/Bridge/management/index.cfm) have shown that a bridge preservation strategy that employs the right treatments at the right times is the most cost-effective strategy for the management of highway bridges. It costs less to maintain bridges in good condition than to maintain them in a deteriorated condition. Applying the wrong treatments or deferring maintenance altogether, leads to a major rehabilitation or possible complete replacement. Rehabilitation projects and replacement projects are costly.

Bridge repairs and rehabilitation improve the condition of the bridge. Each repair adds to the length of time the bridge will remain in service. As the structure ages further, the condition rating drops and soon another repair or rehabilitation becomes necessary. Eventually, the deterioration becomes extensive and the structure has to be replaced.

During the life of a bridge, some elements such as expansion joints and approach slabs are repaired several times, each time improving the element condition but not the overall bridge condition rating.

More extensive rehabilitation, such as deck or superstructure replacement have a greater effect on the bridge condition ratings, but are done less frequently. The deck may be replaced once during the life of the bridge. A second deck replacement project is not common as too many other elements of the bridge may also require replacement. At that point the service life of the bridge is reached. The bridge becomes a replacement candidate.

1.5.2 Funding Bridge Preservation

Bridge managers look to address the needs of all bridges in their inventory. They balance investments in new bridges, rehabilitation, and preventive maintenance activities. Just as using all available funds for bridge replacements would neglect the preservation of existing bridges, using all resources on preventive maintenance would ignore more significant needs, such as bridge replacements and rehabilitations.

Decisions on funding bridge preservation require clear objectives and measureable goals and are based on needs. An objective could be as simple as:

> Implement timely preservation treatments on structurally sound bridges, thereby extending their useful life.

This could be measured by determining a percentage of bridges in a state of good repair, based on condition ratings. Goals could be expressed as annual accomplishments in sealing decks or painting bridges on a set cycle. Needs would be based on an unbiased data collection process that can be imported into a management system to help prioritize. Such management systems are discussed in Chapter 2.

1.6 Chapter 1 Reference List

1. AASHTO. *AASHTO Maintenance Manual for Roadways and Bridges.* 4th Edition, Washington, D.C.: American Association for State Highway and Transportation Officials, 2007.
2. FHWA. *FHWA Bridge Preservation Guide*. Report Number FHWA-HIF-11042, Washington, D.C.: U.S. Department of Transportation, 2011.
3. FHWA. FHWA website showing overview of bridge management: http://www.fhwa.dot.gov/Bridge/management/index.cfm
4. NHI. National Highway Institute website: https://www.nhi.fhwa.dot.gov/default.aspx