3.2 BRIDGE MANAGEMENT AND BRIDGE MAINTENANCE MANAGEMENT

3.2.1 Introduction

Surveys of U.S. bridges reported in 1994 indicate that more than 200,000 bridges have deficient capacity or lack functional performance on the roadway they serve; more than 100,000 are posted for restricted vehicle weight less than the legal load limit for the roadway they serve. More than 5,000 are completely closed [1]. Due to increased numbers of heavier trucks resulting from the North American Free Trade Agreement (NAFTA), the erosion in real dollars of budgets for upgrading bridges, and the continued expansion of truck freight volume, bridge maintenance efforts have not been able to reduce deficiencies much each year.

The source of many bridge deficiencies can be found in inadequate maintenance. Damage resulting from salt-contaminated debris buildup, plugged scuppers, leaky joints, and failed paint systems accelerates deterioration and compounds repair requirements. If left unrepaired, the damage ultimately imposes a severe limitation on the structure's operational capabilities. The longer maintenance is delayed, the worse the bridge situation will become.

Structures not classified as deficient must be included in a systematic maintenance program. This practice precludes the possibility of premature replacement or rehabilitation. A bridge maintenance management system is an integral and valuable tool in developing and managing the necessary databases to effectively maintain a bridge. Historically, bridge management systems (BMS) came to be thought of more as a computer program (e.g., PONTIS, BRIDGIT) than as a philosophy of managing the assets represented by bridges as a component of total transportation inventory [2]. Once management of the overall transportation agency began to move toward asset management, then bridge management again began to view the various computer programs as tools within the process [3]. The emphasis has shifted to network analysis to optimize the use of limited resources.

3.2.1.1 Bridge Maintenance Management Process

A systematic approach to bridge maintenance will provide a planned procedure for performing routine major or minor maintenance on all bridges. It will also provide priorities on bridge replacement that should optimize overall life-cycle costs of bridges as a major component of the highway network. The process should organize bridge maintenance into units including inspecting, planning, budgeting, scheduling, performing, reporting, and evaluating, all coordinated by a management information system.

Planning: Planning for bridge maintenance management involves the selection of objectives and the determination of the policies, programs, and procedures to be used to achieve those objectives. Of all management functions, planning is the one that has the most productive effect on the use of available labor, equipment, and materials. Inadequate planning is often the root cause of many of the difficulties in maintaining bridges that generate criticism of the status of bridge maintenance.

Planning should consider the entire bridge network and bridge maintenance needs over an extended period of time. Planning must also account for everything that affects or can affect the bridge network. Planning must begin by analyzing the bridge database consisting of the inventory, history, plans, and maintenance requirements to define priorities, needs, and quantities. The bridge maintenance work plan is basic to the system. Once the work plan is developed and budgeted, it is the base from which specific work orders are developed and scheduled.

Budgeting: Budgeting is the process by which the funds and resources to implement the plans are obtained. Government agencies are accustomed to reviewing line item budgets that break down the budget requests into defined classes such as "pay of personnel," "equipment purchases," etc. A performance-based budget that relates work to be accomplished with the required resources of labor, equipment, and materials and their associated costs is far superior because alternative budgets can be associated with needs.

Work-estimating procedures that are fairly standard are used to develop a budget. The maintenance plans evolved in the planning process indicate the amount of work required. Using the work estimates, costs are compiled and the budget developed. The plan may need to be revised to match the available budget. One key to effective budgeting is to collect and manage cost data within the bridge management system, and for this purpose, *NCHRP Synthesis of Highway Practices 227* (Collecting and Managing Cost Data for Bridge Management System) provides a comprehensive assessment of available practices and procedures [4].

Scheduling: Scheduling is the process of laying out future work. A good scheduling process develops work schedules on at least three levels: organizational, supervisory, and foreman (or working). Scheduling is a tool to help achieve project objectives without exceeding the budget. Scheduling accounts for labor, equipment, and materials. Schedules must be more detailed at the working level than at higher administrative levels. The workers' schedules are the final approved and budgeted work plans. The foreman's schedules are very specific as to location, date, time, and assigned crew. The work schedule reflects seasonal requirements. Since emergency work is always a possibility for public works agencies, the scheduling process also requires flexibility so emergency conditions can be met without undue strain on the organization.

Performing Maintenance: Performing is the process that is concerned with actual completion of the work in the field. The work should be done in a manner that conforms with prescribed quality and quantity standards. Materials, equipment, and labor are used as indicated in performance standards, or as nearly so as is practicable. Variations occur, but if these are consistently larger or smaller than the standards, either the standards are in error or procedures other than those prescribed are being followed.

The schedule is generally translated into performance through a work order system. Two types of work orders are usually applied: one for in-house forces and one for contract activity. The tasks specified in the work order should be planned in detail by the crews who will do the work. This may involve decisions about the specific work methods and the provision of resources as well as the actual performance of the work.

Reporting: Reporting represents the primary means of communication between those performing the work and those managing it. Work completed and the resources used are reported as they occur. This informs management that planned and scheduled maintenance goals have been met and provides data to account for funds budgeted. Obviously, standard reporting forms and methods that are easy to prepare and complete with the correct information generate the best data. Work completed must be entered into the inventory, database, and historical record to provide an updated record of bridges in the system.

Evaluating: Evaluating is the means by which the quantity and quality of work is measured and is the basis upon which management can exercise control actions. Provisions should be made so that those most involved with the actual work—the foremen, for example—regularly receive information so they can judge their own performance. Reports are provided to each administrative level appropriate to the needs of that level. Evaluations are based on comparisons between like crews or personnel performing like tasks with due account taken for extenuating factors such as individual work site specifics (i.e., compare apples to apples and oranges to oranges). Comparisons are also made against standards so the standards may be adjusted to make expectations reasonable and so planning and budgeting efforts are more accurate. Evaluation is also the system element that measures the effectiveness of all other elements and provides the means by which bridge maintenance and work performance can be improved. A bridge maintenance management system can supply the manager with the means to more effectively and efficiently accomplish the maintenance program. At the same time, the system will increase control of operations and provide credibility to the program since the manager will have information with which to respond to requests and to justify budgets.

3.2.1.2 Bridge Management System Requirements

General minimum standards have been developed to guide the development and implementation of bridge management systems. These requirements are intended to ensure that agencies can share data, concepts, successes, and failures as well as help each other improve in the continuous quality improvement sense.

- Data must characterize the severity and extent of bridge element deterioration.
- Data must include estimating costs of bridge maintenance actions.
- Statistics must be available to support the estimates of user costs.
- A history of conditions and actions taken on each bridge, excluding minor or incidental maintenance, must be available.
- A computer model (or some other objective analysis method) for network-level analysis and optimization must be resident that includes procedures to predict deterioration; identify feasible actions to improve conditions; estimate the cost of actions; determinate the least costly maintenance, repair, and rehabilitation strategy; perform optimization across the network; generate reports as needed for planning; monitor the status of maintenance actions; and update the database.

3.2.1.3 PONTIS

Many state DOTs have adopted a particular computer-based bridge management system called PONTIS (Latin for “bridge”) in their efforts to satisfy federal bridge management requirements. PONTIS supports a series of bridge management activities involving information gathering, information interpretation, prediction of bridge condition, cost accounting, decisionmaking, budgeting, and planning. It consists of a set of interconnected computer modules that address each of these functions systematically. PONTIS combines modules that predict deterioration, provide costs, and compare feasible actions. As inspections are reported and repairs are made, PONTIS is updated and refined with additional cost, deterioration status, and feasible action data. If precise historical data are not available, the operation can be started with engineering judgment values and national bridge inventory system data to generate initial predictive models that can be adjusted and refined as precise data on the bridge network become available.

PONTIS, like all computer-based bridge management systems, relies on significant mathematical assumptions to create predictive models [5, 6]. While it is not necessary for maintenance engineers to be experts in the mathematical logic that underpins these models, they do need to understand the strengths and weaknesses of the estimates and projections produced by the bridge management system.

3.2.1.4 Network-Level vs. Project-Level Management Decisions

PONTIS was designed to provide assistance in making network-level management decisions for groups of bridges in an area. The system helps a manager determine and support funding for maintenance needs to keep bridges in good condition. Bridge managers need a tool that demonstrates to those that make final decisions on funding programs that it costs less to maintain bridges in good condition than to defer maintenance and let bridges deteriorate. Other approaches have been developed for network-level optimization of bridge management decisions, but many of them require a more sophisticated methodology than PONTIS [7–10]. At the network level of a state agency with a large number of bridges, it is not normally necessary to have a detailed methodology to prioritize needs. The Florida DOT has modified the approach of the PONTIS program to yield project-level decision guidance [11]. Simplified approaches to bridge management optimization have been developed that offer promise for agencies with networks having small numbers of bridges [12, 13].

PONTIS was not designed to provide information for decisions needed to manage a specific bridge or for "project-level" decisions. Some management systems can provide project-level support. In these systems, bridge maintenance activities such as cleaning, patching, and joint sealing have been identified and performance standards have been developed. The performance standards include the resources (personnel, equipment, and materials) needed to perform a specified maintenance activity. The activities needed and the urgency required must be identified for an individual bridge. It is important for maintenance managers to keep in mind that any computer-based bridge maintenance management system that will generate project-level decision guidance requires a database with a greater level of detail on all of the bridges in the bridge network than does a system like PONTIS.

The Pennsylvania Department of Transportation (PennDOT) maintenance management system (called MORRIS) includes performance standards for 76 maintenance activities. The system also tracks personnel availability, equipment, and materials available to each bridge crew. PennDOT bridge inspectors identify maintenance needs for each bridge and give each need a priority. After the maintenance needs are input, the system develops bridge maintenance work orders for performing maintenance on specific bridges.

Since no two bridges are exactly alike, it is helpful to have the maintenance worker visit the bridge before the repair is planned to evaluate the requirements. Management systems are tools to assist managers. As the models and logic upon which they are based are refined, the results will more accurately reflect the conditions and appropriate response to properly maintain a specific bridge. However, there will always be a need for engineering judgment in the process.

Bridge management systems are not just applicable to large agencies. Local agencies can benefit from simplified computer-based bridge management systems to assist in setting priorities among their wide range of bridge needs. Kuznetsov et al. have reported how the city of Moscow has implemented this approach to create a BMS at the city level [14]. Good planning at the network level should facilitate good planning at the project level.

3.2.1.5 System Interfaces

In some agencies, the bridge maintenance management system is a part of the maintenance management system, and in others bridge maintenance management is a part of the bridge management system. Regardless of how the total management information system is organized, bridge maintenance management systems must interface with all other management information systems to avoid repetitive collection of data and duplication of data processing that provides input to the management information systems. Bridge maintenance management needs to interface with the maintenance management system; safety management system; pavement management system; bridge management system (if this system is not directly integrated with the bridge maintenance management system); and management system containing the fiscal and inventory control data. While all agencies are working toward complete integration of these database management systems, much of the integration has to be achieved by human interaction rather than by automated computer communication links. The Michigan DOT capitalized on the requirements of the Intermodal Surface Transportation Efficiency Act of 1991 to re-engineer its business processes and use new computer technology to facilitate organizational change [15]. By 1997, this re-engineering evolved into the Michigan DOT Transportation Management System, which, with a view toward incorporating asset management principles into the re-engineered process, integrated the Michigan DOT's data analysis across their previously separate pavement, bridge, congestion, safety, public transit, and intermodal facilities management systems.

3.2.2 Planning and Scheduling Bridge Maintenance

The key to successful execution of any bridge maintenance project is proper planning and scheduling of the work. Increased needs combined with reduced funds means that maximum advantage must be taken of every available hour and resource. This can only be done when a small part of the available hours are spent planning and scheduling the work. Planning and scheduling must be done prior to beginning the project and continue during execution of it.

If a bridge maintenance management system is available, it may be used to aid in the planning and scheduling process. Getting the work done can be divided into two areas: job layout and work performance. The first involves planning how the job is to be accomplished. The second involves coordination and efficiency of the work procedures.

3.2.2.1 Long-Range Planning and Scheduling

The planning and scheduling of bridge maintenance is performed on several levels. The worker may not be directly involved in the long-range planning. The general steps in the process are as follows:

(1) Needs are identified for all the bridges that are included in the planning region. These needs include procedures performed on a regular basis and procedures performed on an as-needed basis. A ballpark cost estimate is developed and a budget is prepared.
(2) After the budget is approved, a more detailed estimate is developed to determine the personnel and equipment requirements to accomplish the work. This resource estimate is compared to the personnel and equipment available. Special needs for certain skills or equipment that may not be available within the agency are also evaluated.
(3) If either personnel or equipment are lacking (including personnel with special skills needed), a decision is made regarding whether to contract out part of the work or to add to the in-house resources.
(4) Assignments are made for each bridge maintenance crew.

After crew assignments are made, schedules can be developed and work orders can be generated. In most agencies, the worker is responsible for and involved in developing the crew schedule. The scheduling process involves determining the urgency of the work; when in the year the work can be performed; when necessary approvals or permits can be obtained; and when the necessary support, equipment, and materials will be available. Realistic scheduling improves efficiency. Workers should be challenged, but if too little time is allotted to a job, short cuts and omissions will be encouraged or the schedule will not be taken seriously.

3.2.2.2 Work Orders

Work orders are prepared in advance to provide details of each job. The work order contains a description of the particular type of work to be performed, the exact location of the work, names of all workers assigned to the project, and the list of equipment and materials available or needed to do the work. The work order may be prepared by the bridge management system based on performance standards and condition data from the inspection, or it may be prepared manually by someone in the maintenance division after the assignment is made and the job layout is completed.

3.2.2.3 Job Layout

The worker (or a bridge maintenance engineer) usually performs the job layout after the job is assigned to the crew. This involves visiting the bridge to determine detailed work requirements. Factors that must be considered in preparation for each bridge maintenance project include the following:

- Traffic, employee safety, and environmental conditions.
- How the work will be performed.
- Job assignments for the crew.
- Equipment and materials required.

To prevent unnecessary delays, it is important to preplan every project. General guidelines can be created for the procedures that need to be followed for each factor of the bridge maintenance project. Each agency will have its own detailed process.

Traffic Control: Any project that will place workers or equipment on or adjacent to the roadway requires traffic control procedures that conform to uniform agency practices. This includes the correct use and placement of signs and flaggers. Adequate traffic control is often the most important safety factor of the crew's protection. Improperly planned traffic control can place the agency in a vulnerable position with respect to potentially costly liability judgments.

Environmental Considerations: Environmental factors are becoming a major source of delays in conducting bridge maintenance work. Typical concerns are air, water, or soil pollution and disposal of toxic materials, such as salvage material containing lead-based paint or creosote.

Employee Safety: The high cost of employee injuries and OSHA penalties have become a significant management concern of all transportation agencies. Some agencies require that fall protection schemes or confined space occupancy plans be developed and submitted for approval prior to beginning work that places workers in conditions associated with potential falls or confined spaces. Likewise, some agencies require higher level management approval for any bridge maintenance activity in which workers will be exposed to toxic materials or excavation with any potential for embankment collapse. Each agency needs to integrate worker and management safety training with any approval process to determine a reasonable system of checks and balances that properly considers worker safety in the planning process yet allows work to proceed in an orderly fashion.

Work Procedures: It is necessary to determine exactly what work must be performed. The worker should visit the site and make this determination. While at the site, the worker should determine the exact location of the work and the total units of work needed. Storage of equipment and materials at the site is also a consideration.

If performance standards are available, they can be compared to the work to be done to determine whether the standards are applicable or need to be modified. If the information in the performance standards is applicable, it can be used to help determine the resource requirements of the job with modifications as necessary. If performance standards are not available, a written description of the work to be performed should be prepared. Usually, a simple outline listing the items of work to be done and the order in which they will be accomplished is sufficient.

Job Assignments for Personnel: Performance standards aid in determining the number of workers required and either the classification of personnel or the skills that will be needed. If performance standards are not available, required skills for each item of work in the outline of work previously prepared should be noted. The knowledge of the actual work that is to be done and the conditions at the work site should temper the requirements. Variations may be required because of traffic conditions, unusual complexity of the job, or weather factors. These assignments should be compared with the capabilities of the crew, then the work should be assigned to the appropriate individuals in the crew.

Whenever possible and appropriate, individuals should be assigned specific tasks in accordance with their capabilities, the requirements of the job, and the available training opportunities. Specific precautions or instructions should be given to the employees at the time of assignment. If required skills are not available in the crew (e.g., a certified welder), arrangements should be made with an upper-level manager to obtain the necessary assistance.

Equipment Requirements: Performance standards aid in determining the type and amount of equipment required to properly perform the work. Modifications may be necessary if unusual work requirements are determined when work procedures are initiated, if personnel qualifications do not match standards, or if the equipment available is different from the equipment identified in the standard. If performance standards are not available, units of equipment required for items of work in any work procedure outline should be noted. Backup units or alternative plans may be necessary so equipment failures will not unduly delay completion of the work. This is especially important for critical tasks in the maintenance process or when reopening the bridge to traffic is critical.

Tools that might be required during the maintenance operation must also be considered and compared to the complement of tools readily available to the crews. If additional items are required, arrangements should be made to have them available and ready for use. Nothing can be more time consuming, inefficient, and destructive to morale than to have a crew inactive while one member drives back to a staging area for a vital tool. As anyone in the public sector knows all too well, an idle crew on the job site can also be damaging to an organization's public image. Every crew is obviously expected to carry a complement of standard tools.

Material Requirements: The amount of materials needed for the job can also be estimated from the performance standards, or estimated from past experience with similar jobs. If any materials requiring a special order are needed, the necessary paperwork should be prepared. A reserve of the materials should also be taken to the job site in case the estimated amounts are understated. Other materials that might be needed, such as wood for forming or aggregate for backfilling at approaches, should also be included. As is the case for other resources needed to perform the work, delay caused by a lack of proper preparation to secure materials is inexcusable.

3.2.2.4 Short-Term Scheduling Procedures

Once the job layout has been performed, the work can be programmed in the short-term schedule. Schedules are "roughed in" several months ahead of time, and as the time to do the work gets closer, the job layout is performed and scheduling becomes more precise.

When scheduling work for the month, it is important that maintenance activities be coordinated as much as possible. This includes such considerations as repairing concrete on several bridges in the same area at the same time, cleaning and painting several adjacent bridges, or ordering material for several jobs at the same time. As scheduling moves to a weekly level, it will become more detailed and should include the following items:

- Check to see if any work scheduled for the present week will be carried over into the new workweek because of emergencies, bad weather, or delays.
- Review the work scheduling to see what projects are scheduled to receive the highest priority.
- Review the monthly schedule to see what projects are scheduled and if adjustments are needed.
- Determine the employee days, equipment, and material required for the week.
- If manpower is still available, alternative or fill-in projects should be identified.
- Complete the schedule by assigning workers and equipment to the specific projects.

Obviously, inclement weather may disrupt the work schedule. It is important that other work be planned that can be performed in bad weather so that time will not be wasted. In many states, repairs in the winter months are generally limited to emergency patching, bridge cleaning, some joint sealing, and other emergency work. Personnel training and equipment repair are well suited to times when weather interferes with the actual conduct of maintenance. Upper-level management should examine the possibility of using bridge maintenance personnel in other areas of activity not as adversely affected by winter weather conditions.

3.2.2.5 Graphical Methods of Scheduling

One of the graphical scheduling methods commonly used in the construction industry can be used to plan the bridge maintenance work schedule. Two common methods that are easy to learn, understand, and use are the critical path method (CPM) and bar charts. These methods can be effective in developing and communicating the schedule process and also in using the schedule process to control and manage bridge maintenance. However, it is important that all personnel—from the crew supervisor to the high levels of maintenance management—have a common rudimentary understanding of how the CPM diagram or the bar chart is developed and what it tells a person. The potential positive effect of either method is limited if only the person developing the charts understands them.

3.2.3 Performing the Work

3.2.3.1 Job Execution

The daily routine of any job consists of preparing for the job at the yard and moving to the job site, performing the work at the job site including occupying and leaving the site, and cleaning up after the job at the yard. The daily routine can contribute to coordination and efficiency of performance of the work at the job site if the routine is properly and carefully planned.

Yard Preparation: Before leaving for the job site, the crew is first assembled to determine if changes must be made in job assignments because of absences or other reasons. Following the assignments, the crew should be informed of the tasks each is to perform, including those related to safety. This allows each crew member to know what his or her assignment is and who will act as support to whom. The crew then gathers the required equipment and material needed. Once the necessary resources (personnel, equipment, and materials) are assembled, the crew is informed of the staging location and proceeds to the work site.

If one job takes several days, the process is much simplified after the first day. Depending upon local rules, regulations, and agreements, it may be possible and even economical for the crew or some members of the crew to report directly to the work site. In any event, time getting ready is not wasted.

At the Site: When the crew arrives at the work site, the crew leader should review the safety procedures to be followed on the job and ensure that safety-related assignments are fully understood. Proper traffic control is then established by placing signs, cones, or other devices. Flaggers are stationed, if necessary. Once proper traffic control has been established, the crew can proceed with the work. Traffic control items should be periodically checked, and the site should be kept as clean and uncluttered as possible while the work is underway.

Leaving tools and materials lying around the work site is hazardous and unprofessional. When a job is complete, tools and excess materials should be properly stowed before leaving the site. Once the site is clean, clear, and again suitable for traffic flow, the traffic control devices can be removed. Opening the site to traffic requires that signs and traffic control devices be removed. Start at the work site and proceed away from it upstream in the direction of oncoming traffic with the most distant sign from the work site removed last.

Yard Cleanup: Certain tasks must be performed after the crew returns to the yard. These tasks include storing tools and materials in their proper locations, preparing equipment for the next day, and reporting the work accomplished. To save time the next work day, all equipment should be serviced, and fuel and oil added as needed. Any problems encountered with the equipment during the day should be reported. The final and perhaps most important task for the crew lead is to report the work accomplished during the day and ensure that work for the following day is planned with the resources available to perform it.

3.2.3.2 Personnel Resources

To ensure that the bridge maintenance job can be performed properly, the crews should be made up of personnel who have been trained to perform the specialty tasks that are required. These personnel may include the following:

- Carpenters to build formwork or to do necessary woodworking.
- Welders for steelwork.
- Concrete and masonry workers.
- Special equipment operators (e.g., crane operators).

Specialists such as these will be able to perform most of the skilled labor tasks in bridge maintenance. The remainder of the crew can be composed of general laborers who can assist the specialists and who can perform other required tasks. In addition, the crew should have the necessary equipment and stockpiled materials to ensure that the scheduled work can be performed.

3.2.3.3 Equipment

Each bridge maintenance crew should have as full a complement of tools and equipment as possible so no time is lost attempting to obtain items from other sources. The scheduling process will often reveal if necessary items are continually lacking and causing delays to bridge maintenance projects. These delays are often far more expensive than the cost of acquiring proper equipment and tools. Some suggested items in equipping a bridge maintenance crew are as follows:

- Flatbed truck with a winch and an A-frame (or other lifting equipment).
- Pickup trucks, as needed.
- A variety of air-powered tools.
- Air compressor.
- Small concrete mixer or mortar mixer.
- Oxygen and acetylene welding and cutting equipment.
- Heavy-duty hydraulic jacks—180 kn to 450 kn (20 ton to 50 ton) capacity.
- Portable arc welding unit with electric service outlets.
- Heavy-duty electric drill fitted with an electromagnet.
- Small, portable high-pressure water pump.
- Sandblasting equipment.
- Hand tools for steel, carpentry, concrete, and mechanical work.
- Staging (scaffolding).
- Spray-paint outfit.
- Tow cable and chains.
- Radio equipment.
- Chain saw.
- Heavy-duty chain hoist.
- Miscellaneous survey equipment (tape, level and rod, theodolite or total station, etc.).

3.2.3.4 Materials

Each bridge maintenance crew should have a small supply of materials, especially for emergency repairs. Many materials can be accumulated from salvaged materials or materials leftover from new bridges.

- Timbers for blocking and cribbing—usually salvaged material.
- Assorted bridge planks.
- Steel decking.
- Assorted I-beams, angles, channels, and plates.
- Steel reinforcing bars.
- Sheet piling.
- Timber and steel piling.
- Cement, mortar, masonry sand, and aggregates.
- Epoxy.
- One gallon of penta or creosote and brushes.
- Paint, primer and finish, paint brushes.
- Nails, spikes, bolts, nuts, washers, drift pins, and lag screws.

3.2.4 Reporting Bridge Maintenance Accomplishments

3.2.4.1 Why Report?

New personnel often question the importance and urgency of reporting work accomplished. After all, the job got done and that is what counts. Maintenance engineers and managers need to communicate the importance of reporting as a means of building an information base to help do things better and more efficiently. The following list includes some of the results of reporting that might be of interest to maintenance personnel:

- Develops a historical record of maintenance and repair on each bridge.
- Maintains a record of regular periodic and special expenditures as a basis for developing and justifying future budgets.
- Maintains a current record to establish cost-to-performance relationships.
- Provides a source of information to enable maintenance engineers and managers to develop maintenance trends, and to establish the need for additional cost controls or work item controls.
- Develops a source of information for public relations, for accomplishment reports, and for the defense of tort liability claims.
- Provides a record of cost to compare with budget cost estimates.

It is important for bridge maintenance personnel at all levels to understand the necessity of reporting work accomplishments in order to "close the loop" on the bridge management process. This can be compared to balancing one's checkbook at the end of the month so that the checkbook register matches the bank's statement of available funds. In the case of bridge management systems, reporting work accomplishments allows the flow of information upon which decisions are made to come full circle and "balance out."

3.2.4.2 Report Requirements

Each state has specific reporting requirements. In general, maintenance managers need much common information. Five general classifications are used to describe the types of information any reporting system should include:

Who: Indicate who performed the work by specifying the crew or individual in charge of the work. This permits the work to be charged to the proper department and permits future verifications and follow-up in case of discrepancies or claims. The actual coding of the "who" identifier will vary with state requirements.

What: Report the activity number that has been assigned to the specific type of work performed. The amount of work performed should also be recorded. The performance standards for each of the activities indicate how the amount of work is to be measured. The report of "what" and "how much" is used to evaluate crew performance, the suitability of standards, and project progress and is also used for budget comparisons.

When: Report the date (or dates) on which the work was performed. This information is helpful in determining when work should be scheduled in future years and is required for scheduling periodic maintenance, particularly preventive maintenance.

Where: Report the location of the bridge by reference to a route or a milepost (or both) and to the bridge number. This information correlates the work to the repair history of the bridge. In addition, this information allows sorting by road types and locations.

How: Report the resources that were used and the process used to get the job done. The hours of labor, types of equipment, and type and amount of materials used are included. This permits computing the cost of performing the work and provides resource utilization data. This information also permits managers to determine the monthly resource needs for use in future scheduling.

3.2.4.3 Reporting Procedures

The actual reporting of the work performed has many variations. Many states already collect the major portion of the information needed to create the comprehensive database for an integrated bridge management and bridge maintenance management system. Some states use separate forms for bridge maintenance and other states include bridge maintenance reporting in the general reporting for all highway maintenance or for the personnel/payroll reporting system. Whatever administrative data processing system is used, maintenance field personnel will be relied upon as the source of the information. Generally the person in charge of the crew is also charged with reporting data. Errors can result if more than one person from a crew is responsible to input data.

As the report information is minimized, accuracy and reliability of the information will increase. The goal is to ask only for what is needed to conduct the necessary maintenance management functions and to ask that any given data item be reported only once. Thus, if the payroll system collects information on hours worked by each employee, the equipment management system collects information on equipment unit use, and the materials management and inventory system collects information on materials use, then these databases should be interconnected with the bridge maintenance management system so that data can be transferred into it for compilation into bridge maintenance reports.

With the move to larger and more integrated transportation management information systems attempting to incorporate all information needs into one management information system, there is a tendency to attempt to use one universal reporting form to collect all data for the entire department. Maintenance engineers and maintenance managers should analyze any such attempt carefully with respect to the reporting capabilities of maintenance personnel and the burden this type of reporting will place on them. Information reporting overload often leads to reporting errors or unrealistic reporting. (For background material on this process, consult NCHRP Report 344, *Maintenance Contracting*.)

3.2.5 Contract Maintenance for Bridges

All state DOTs contract for some portion of their maintenance work. A bridge maintenance program requires purchasing and procuring a wide variety of materials, supplies, equipment, and services. Routine purchasing and procurement is usually handled with procedures established at the department level. Contracting represents a specialized area of procurement that is becoming more common in all maintenance work. Contracting for maintenance should be based on the agency's need to be more efficient and effective, not on some arbitrary policy decision. A thorough maintenance management analysis in making a decision on whether or not to contract for bridge maintenance should consider the following factors. (The discussion presented here on contract maintenance applies equally to contracting for roadway maintenance.)

- Limitations on in-house staff.
- The need for specialized equipment not currently in the agency inventory.
- The need for specialized personnel in conjunction with limitations on acquiring such personnel or limitations on the potential to train current personnel to reach the needed skill level.

- The need to cover peak work loads when the agency resources are geared to an average work load significantly below the peak load.
- The potential to obtain required services at lower total system cost.
- The need to conduct emergency maintenance for which the agency does not have the capacity to respond.
- Legal restrictions on the amount of work that can be performed by agency forces, legal restrictions on contracting, or employee agreements restricting contracting.

Contracting is a formal process governed by state laws and department policies and regulations. It is common for contracts of different types and of different amounts of money to entail different restrictions on the agency's ability to enter into them. Before bridge maintenance engineers and managers propose entering into a contract for bridge maintenance services, they should consult with higher level management and, if needed, department legal staff to ensure that a contract can be drawn up which will meet the functional need of the maintenance group and will conform to any contracting restrictions on the agency. This is especially important when any portion of the bridge maintenance is funded with federal reimbursement funds or when the maintenance activity could be interpreted as rehabilitation work subject to federal guidelines. Individuals new to state DOT operations needing to familiarize themselves with the proper methods of contracting for bridge maintenance should consult the AASHTO guide for an excellent general reference on the subject [16].

State DOTs are almost universally required to submit any contract for bridge maintenance to a competitive bidding process. Some agencies do have a minimum contract amount under which the contract is not subject to competitive bid or legally defined emergency conditions under which the agency is freed from any competitive bidding process requirement. Maintenance engineers and managers should become aware of these restrictions and any conditions under which the restrictions are not applicable.

3.2.5.1 Lump Sum Contracts

Lump sum contracts are only suitable if the amount and scope of work can be defined precisely, as might be the case in the complete replacement of specific elements of a structure. There must be reasonable assurance that unexpected conditions, such as deterioration of adjoining elements, will not cause delays, increase materials requirements, or cause other problems. Unanticipated difficulties can also arise when some portion of the work is not defined in sufficient detail, thereby causing a situation where the agency and the contractor cannot agree on the intended interpretation of the plans and specifications. If the contract is written to allow some flexibility in the amount of work required for a single price, the contractor will have to assume the worst case to protect its interests, which tends to increase the contract cost. Thus, it is recommended that lump sum contracts for bridge maintenance only be used for projects for which all features can be easily and conveniently described in the plans and specifications.

One variation of the lump sum contract allows some flexibility in the quantity of work performed. This variation solicits a lump sum bid for an element of work but specifies that a variable number of units of that work element may be required to be completed. For example, perhaps a contract for the complete replacement of damaged or defective piles in a wood trestle bridge specifies a minimum and maximum number of piles to be replaced. The exact number is to be determined as the work progresses. The maximum and minimum amount of work must be specified in the contract for the protection of both parties. The price in contracts of this kind is a single lump sum for all labor, equipment, and materials to do one element of work, complete and in place. This lump sum price may also be used for some items in a unit price contract.

3.2.5.2 Unit Price Contracts

If the amount and scope of work can be defined within reasonable limits, say 10% or so, the unit price contract is usually the best choice for bridge maintenance contracts (as it is for bridge and highway construction contracts). Unit price contracts are the most common contracts used by transportation agencies for construction projects. In unit price contracts, the contractor receives payment for the actual amount of work done and the contracting agency retains a reasonable degree of control over the extent of the contract. Frequently, some well-defined items within a unit price contract are more appropriately handled as a lump sum.

For bridge maintenance projects, special modifications can be made to a unit price contract to increase its flexibility. This is done to make the contract more convenient to administer and to eliminate sources of controversy between agency personnel and the contractor. An example of such a modification in bridge maintenance might be a contract to repair, rather than to replace, a concrete deck. The contract could specify that removal of the deteriorated concrete and its replacement will be paid for in one of three ways, depending how work progresses. First, the agency could pay for removal and replacement of the concrete with no reinforcing steel exposed. Second, it could pay for removal and replacement of deteriorated concrete with the top layer of reinforcing steel completely exposed and cleaned. Third, it could pay for removal and replacement of the full-depth slab. Each item would be paid for on a square meter (or square foot) basis for all work and materials required. In this example, a complete survey of the deck condition would be required so that the contract documents could provide a reasonably precise estimate of the quantity of each type of deck repair required.

Whenever possible, unit price contracts should be used for bridge maintenance work instead of other types of contracts. A limited number of labor and equipment hours can, and probably should, be included as bid items to account for unexpected conditions. This will permit some flexibility within the contract; however, excessive use of these bid items should be avoided since they are likely to raise costs and have other undesirable effects similar to a cost reimbursement contract, as described below.

3.2.5.3 Cost Reimbursement Contracts

If it is impossible to define the amount and scope of work required, it may be necessary to resort to a cost reimbursement contract. In such contracts, the contractor is reimbursed at a predetermined rate for labor, equipment, and materials used. Cost reimbursement contacts require a great deal of inspection and record keeping on the part of the agency to verify the contractor's charges. If federal participation will be requested, discussions prior to executing the contract must be held to ensure that the contract will be approved for reimbursement. A common difficulty in obtaining federal reimbursement for work performed under a cost reimbursement contract (also on work done by agency personnel under force account) is the lack of a complete audit trail for all work done because of typical deficiencies in the record-keeping system.

Another key problem with many cost reimbursement contracts is that there may be a perceived, if not actual, loss of competition. A rigorous and detailed inspection based on good specifications is about the only way complaints of reduced competition can be deflected. Cost reimbursement contracts have been successfully used as an adjunct to force account projects where highly skilled personnel or specialized equipment is needed for only a part of the force account project.

Cost reimbursement contracts have also been used to contract for a variety of maintenance services over a fixed time period (6 months, 1 year, 18 months, etc.). Examples of the types of work that have been included in such contracts include the following:

- Remove and replace concrete curb.
- Remove and replace concrete deck or portions of a deck.
- Remove concrete or block slope protection.
- Repair damaged reinforcing steel or structural steel.
- Repair miscellaneous painted areas.
- Remove, repair, and replace damaged railing or balustrade.
- Remove or replace bridge sidewalks.
- Repair scupper and drain systems.
- Repair pier, pier caps, or abutments.

Contracts have been awarded to the lowest bidder on the basis of specified quantities of labor (foremen, laborers, welders, concrete finishers, painters, various equipment operators among 15 categories of labor); equipment (various sizes and types of trucks, front-end loaders, cranes, concrete mixers); and traffic control and management items (cones, flashing arrow boards, signs, barricades, steel plates). Crew size furnished by the contractor is determined by the size of the project but typically ranges from five to eight persons. Except in emergencies, the contract typically allows a 7-day notice to the contractor of specific work that is to be performed, including recommended equipment and labor requirements. This type of contract permits maintenance agencies to use contractor resources to offset reduced agency staffing levels and to smooth out demand for maintenance services in peak work load periods. The following represents some precautions to be noted before implementing fixed-time-period cost reimbursement contracts for bridge maintenance services:

- Items and quantities of items used in the bidding process should be carefully selected. Unbalancing of bids can result if items are shown that are rarely used or if unrealistic quantities are indicated.
- Every effort should be made to encourage competition between contractors. If a single contractor becomes too entrenched in a district, prices can become unreasonably high.
- The state's representative should be particularly well trained and experienced. The representative should have hands-on experience in bridge maintenance and should also be well-grounded in contract management and administration.

Cost reimbursement contracts should be used only when a thorough engineering and management evaluation indicates they are the most cost-effective means of conducting the needed bridge maintenance.

3.2.5.4 Negotiated Contracts

In some instances, it may be necessary to resort to a negotiated contract for bridge maintenance. Negotiated contracts are used when they are the best way to get the best value for the price paid. They are commonly used to procure professional engineering services. However, there may be circumstances when services other than engineering may need to be procured through a negotiated contract. If only one feasible source exists for some needed maintenance service, a negotiated contract is the only logical agreement. Even when there is more than one source, if there is some important difference among the possible competitors—such as experience records or safety records—a negotiated contract may be the appropriate agreement.

3.2.5.5 Cost Comparison of Contracting vs. Performing Work In-house

Cost of Contracting: When deciding whether to contract or when estimating the total cost of a project to be done by contract, the incidental costs of contracting should be included. Incidental costs may include the following:

- Administrative costs of preparing requests for a proposal or bid documents and plans.
- Costs of selecting the contractor or vendor, particularly for negotiated contracts.
- Administering the contract while the work is being done.
- Inspecting the work.
- Field record keeping.
- Consultations with the contractor.
- Verifying charges, approving final results, and approving invoices for payment.

In-house Cost: When comparing contracts to in-house work, there is a tendency to compare the salaries of the agency employees with those of a contractor, while ignoring the hidden cost to the agency of having the employees on the payroll (overhead, etc.). Other costs beyond salaries to perform work in-house are as follows:

- Overhead costs such as employee benefits, work space, administrative support (payroll, etc.), and tools.
- Cost of keeping employees on the payroll during bad weather, during winter months, or in other times when the work load does not require the full work force.
- Cost of purchasing equipment and keeping it operational.
- Liability costs associated with the maintenance operation, such as injury to employees and the traveling public.

3.2.6 Quality Control and Quality Assurance of Bridge Maintenance Operations

Quality Control/Quality Assurance (QC/QA) is an important part of supervision. QC is normally performed within the group or the maintenance crew. It includes performing quality work safely, on schedule, and within budget. QA is performed from outside the group. QC is the responsibility of the bridge maintenance worker. NCHRP Report 422 [17] provides useful guidance in setting up a quality assurance program that also considers and incorporates principles of good quality control.

3.2.6.1 QC at the Work Site

There are two general classifications of items to be reviewed at the work site. The first is how well the work is being performed in terms of quality of results and the amount of work being done, or productivity. The second is how the work is being performed in terms of safety to the workers and the public.

While the quality review would often be considered the most significant and the most difficult to review, it is often far easier to perform than the safety review. Even if performance standards have not been developed, standard practices, formal or informal, are usually available. However, safe practices and total crew motivation to perform the work safely are almost always different matters since small errors of omission or commission can produce unfortunate or even tragic results. The general attitude of a crew toward satisfactory or unsatisfactory work practices can be revealed in a number of ways that would only be noticed by someone looking specifically for such indications. In addition, it is often tempting for an agency to overlook departures from the best practices because of expediency, or to avoid cautioning or reprimanding a foreman who attains high performance and productivity through the use of shortcuts or questionable practices that carry relatively high risks of causing personal injuries.

3.2.6.2 Technical Site Review

If performance standards have been developed for the work, the reviewer should use them as a guide. State construction standards are also a good resource for basic repair methods and procedures. The person conducting the review should be thoroughly familiar with such documents before visiting the site to take full advantage of his or her available time there.

When bridge maintenance crews are asked to perform work for which plans, sketches, or engineering drawings have been developed to guide the work, workers should be thoroughly familiar with these before visiting the site. It is best if field personnel are consulted during the preparation of any such documents so that the workers are familiar with the project from its conception. This provides an opportunity for the project to be developed in a way that considers the capabilities of the crews that may be assigned to the work.

In agencies where performance standards have not been developed or plans are not needed for a bridge maintenance project, the work is done by standard practices, with or without written instructions. Thus, a worker must use a base of experience or knowledge of satisfactory practices to evaluate the progress of work at the site. In smaller agencies with a stable work force and relatively light work loads, this process can be satisfactory for as long as those conditions prevail. Unfortunately, as more bridge maintenance work is required and if turnover of employees is frequent, a lack of written standards can become a significant problem.

Even if standards or plans are available, there are a number of specific items related to quality control that would not usually be shown on such documents and that should be reviewed by the worker. Items that workers are supposed to keep in mind are best laid out in checklists by topical area.

3.2.6.3 Traffic Control Site Review

Almost all bridge maintenance activities interfere with normal traffic flow to some extent. While all traffic control is based on the MUTCD or the state manual on traffic control, it is not reasonable to expect the worker to be familiar with all of the MUTCD. A traffic control checklist should be developed for the worker to monitor aspects of traffic control at the site. This checklist should include factors the maintenance engineer or maintenance manager considers important to quality control of traffic safety and protection of workers.

3.2.6.4 Site Review of Tools and Equipment Use

All work related to highway maintenance is inherently associated with some level of risk and danger because of the proximity to traffic flow and the nature of the tools, equipment, and materials used. This is especially true for bridge maintenance work because of the restricted areas in which the work must be performed and because of the necessity to do a lot of handwork. Every precaution that is practicable should be taken to ensure that the use of tools and equipment presents the least risk possible to workers and the public. A checklist of key points regarding the use of tools and equipment should be available to supervisors for their use when visiting work sites.

3.2.6.5 Site Review of Rigging and Climbing Practices

Among the inherent risks and hazards of bridge maintenance is the difficulty of performing work at a significant height above the ground or the water. This requires that personnel be protected when working at such heights and that tools, equipment, and materials be safely and efficiently transported to the work level. When visiting sites involving activities that use cranes, staging, ladders, worker lifts, or other devices, the worker should be particularly alert to practices and procedures that create unnecessary hazards. A supervisor making a site visit should have a checklist available of the significant issues regarding climbing and rigging practices.

3.2.6.6 Budget Monitoring

A major control task is monitoring budget expenditures and accomplishments. Two major elements of this task are controlling funds to keep spending within budget limits and reallocating work. The first requires continuously current information on actual expenses. Necessary changes or reallocations can then be based on accurate information.

A method of controlling the budget is redirecting resources. This determination applies primarily to labor and equipment use where scheduling has the most impact. Adjustments may include the following:

- Change work scheduling.
- Add or reduce labor.
- Add to or reduce the equipment fleet.
- Reduce peak demand for labor and equipment.

3.2.6.7 Schedule Monitoring

Methods of developing and monitoring work schedules for bridge maintenance crews are quite straightforward and require little additional comment. Interruptions of bridge maintenance activity for emergency repairs or because of bad weather tend to be frequent enough that such schedule interruptions are usually ignored. However, an important part of quality assurance is to make certain that the schedule is updated to properly account for interruptions. The schedule must be realistic and it must be current. Completing maintenance assignments on schedule has the following direct impacts on performance:

- Efficiency can be measured by success in meeting schedules.
- Support and equipment has to be scheduled ahead for the next assignment and adjustments influence other activities; therefore, they should be minimized.
- Interruptions tend to be the same over a year's time so that they cancel out when comparing performance between years or between crews.

3.2.6.8 Methods of Quality Assurance

QA is performed from outside the maintenance crew. Some agencies have formal QA programs that are developed to measure the crew performance. The QA evaluation may be generated by the bridge management system. Components of the evaluation could include the person-hours, equipment, and materials used in accordance with performance standards; acceptable condition ratings at the next inspection cycle; and accidents or injuries related to crew assignments.

If there is no formal QA program, QA is probably taking place on an informal basis. The disadvantage of informal QA is that it is often subjective and rarely quantified. Therefore, it may be applied based on the experience of the person making the evaluation. The items that are checked are often based on recent problems. A carefully developed QA program that everyone understands, that is considered fair, that provides objective evaluations, and that provides quantitative results will have the best results. (It is again suggested that NCHRP Report 422 [17] be consulted.)

3.2.7 Bridge Inspection

3.2.7.1 Inspection Process

Bridge maintenance crews and bridge inspection teams need to work in close coordination. The inspectors are the primary source of identified bridge maintenance needs.

A thorough, well-documented inspection is essential to determine bridge maintenance requirements and make practical recommendations on suggested actions to correct the deficiency or preclude the development of bridge defects or deficiencies. Regular inspections should be considered a primary maintenance responsibility. Besides searching for defects that may exist, inspections should also look for conditions that may indicate possible future problems.

Regular inspections are conducted every 2 years under the federally mandated inspection program. The emphasis of this program is establishment of rehabilitation and replacement priorities. As bridge management systems become fully operational, these data management systems will be able to generate maintenance and repair needs and establish short-range and long-range budgets.

The AASHTO manual [18] should be the general guide for managing the conduct of bridge inspections for individuals new to bridge maintenance and management. The second edition incorporating interim revisions though 2000 is available [18].

3.2.7.2 NBI Program

The 1968 Federal-Aid Highway Act established the National Bridge Inspection (NBI) Program, which requires states to inventory and inspect all structures on the federal aid highway system. The program has been expanded to include all bridges on public roads that are not on the system. The federally mandated Structure Inventory and Appraisal System especially benefits states that implement a detailed system to inspect bridge maintenance and to provide the data needed (current condition of the bridge) to implement a bridge maintenance management system.

3.2.7.3 Performing the Inspection

The following make up the basic content of a bridge inspection.

Waterway or Stream Channel: Anticipating problems and taking adequate protective steps will avoid or minimize the possibility of serious difficulties in the future. Some important conditions to investigate are as follows:

- Adequacy of the waterway opening under the structure. Sand or gravel deposits may reduce the size of the bridge's waterway opening.
- Soundness and performance of the existing bank and shore protection.
- Possible waterway obstruction. Debris or plant growth can contribute to scour and present a possible fire hazard.
- Streambed erosion and scour around piers, abutments, and under the bridge.

A channel profile record for the structure provides valuable information on the tendency toward scour, channel shifting, degradation, or aggradation. The record should be revised as significant changes occur. These indications can help predict when protection of pier and abutment footings may be required.

Abutments and Piers: When inspecting concrete abutments and piers, specific types and locations of defects should be particularly noted. Those likely to occur most frequently are as follows:

- Spalling and deterioration of concrete at the water line.
- Deterioration of concrete under bridge bearings.
- Cracks in abutments, especially at the corners where the wings join the face of the abutment. These cracks should be observed over a period of time to determine if they are growing. When a crack enlarges, this indicates that movement is taking place in the abutment or pier. Movement can be an indication of subsurface problems.

Timber abutments and piers are subject to specific types and locations of defects. Those that should be investigated are as follows:

- Decay that usually occurs at the ground line, the water line, or at bolt holes.
- Missing or broken bracing.
- Broken or cracked piles resulting from ice or debris collisions.
- Decayed, cracked, or crushed pile caps.
- Tipped or rotated abutment caps.

Bearings: All bearing devices, both fixed and expansion types, should be examined to make certain that they are functioning properly. Unexplained changes in the bearings can indicate serious problems in other portions of the structure. Pier or abutment movement is an example of such a problem. When problems exist, the following inspections should be made:

- Check anchor bolts for damage and nuts for tightness.
- Check anchor bolt nuts on the expansion bearing for proper setting to allow designed movement.
- Check expansion bearings for indications of proper movement.
- Check for dirt and debris in and around bearings.
- Check for excess bulging, splitting, or tearing in elastomeric-type bearings.
- Check grout pads and pedestals for cracks, spalls, or deterioration.
- Check condition of roller nest bearings.

Bearings should be examined carefully after any unusual occurrences, such as heavy traffic damage, earthquake activity, and battering from debris during flood flows. Any bearings, fixed or expansion, that show signs of distress or malfunction should be reported promptly to the appropriate official.

Beams or Stringers: Beams or stringers can be fabricated from timber, steel, or concrete. Each material presents specific maintenance problems for which inspection is needed.

Timber Beams: Defects commonly found in timber beams or stringers are as follows:

- Split, broken, or decayed stringers.
- Lack of surface treatment that allows large longitudinal cracks to develop that can extend the full length of the beam.
- Crushing of the stringer at bearing areas, which normally indicates serious decay problems and reduces live-load-carrying capacity.
- Loose bridging or diaphragms between timber stringers.

Steel Beams: Defects commonly found in steel beams or stringers are as follows:

- Rust below expansion joints.
- Rust on the beam caused by moisture coming through deck cracks.
- Paint deterioration such as peeling, blistering, or cracking.
- Looseness of beam connections.

- Cracking and corrosion around rivets and bolt heads in built-up girders.
- Cracks in welds and base metal.

Concrete Beams: Defects commonly found in concrete beams are as follows:

- Disintegration of the structural slab forming the horizontal section of a T-beam.
- Inoperative bearings from freezing of sliding plates.
- Damaged T-sections that expose reinforcing steel to corrosion.
- Cracked beam ends.

Any of the defects mentioned with respect to concrete beams are particularly significant when found in a prestressed beam. If an open crack is found in a prestressed-concrete beam, the appropriate official should be notified immediately.

Trusses: Trusses are nominally classified in three broad categories based on their position with respect to the roadway. They are categorized as high trusses, pony or half through trusses, or deck trusses. Inspection of any truss should begin by sighting along the roadway rail (or curb line) and along the truss chord members to determine any misalignment in either the vertical or horizontal planes. Each truss member should be checked. Inspection should include the following:

- Observe the truss alignment and grade.
- Check truss span bearings and expansion plates, ensuring freedom of movement.
- Check straightness of compression members.
- Examine truss and bracing members for traffic damage.
- Check all upper and lower lateral bracing members for damage and proper functioning.
- Examine the paint and determine the extent of corrosion, particularly around bolt and rivet heads. Connection details are especially susceptible to corrosion.
- Check the pins at the connections and make certain nuts and keys are in place.
- Check for loose, rusted, or missing rivet heads and bolts.
- Examine tension members for cracks, particularly at connections.
- Check for loss of steel thickness from rust.

Decks: All decks should be examined for skid resistance to determine if a hazard exists. A check should be made to ensure that decks drain properly and that there are no areas where water can pond. Drains and scuppers should be open and clear because poor deck drainage can contribute to deterioration. Drain outlets should not discharge water where it can be detrimental to any parts of the structure, cause fill and bank erosion, or spill onto a traveled lane below.

Timber Decks: Timber decks should be examined for decay at their contact surfaces where they bear on the stringer, and between layers of planking or laminated pieces. The following conditions may also create maintenance problems: loose nails or spikes; openings between planks over abutments and over piers that may allow dirt to sift through; and split, worn, broken, or decayed planks.

Steel Decks: Steel decks should be checked for corrosion and welds that are not sound. A check should also be made for the following conditions: dirt collected in open-grid decking on the top of stringers, deteriorated paint, and loose welds where a steel deck is fastened to the stringers.

Concrete Decks: Concrete decks should be examined for cracking, leaching, scaling, potholing, spalling, and other evidence of deterioration. Each defect should be evaluated to determine its effect on the structure. Any evidence of deterioration in the reinforcing steel should be inspected closely to determine its extent. Decks that are treated with de-icing salts are especially apt to be affected. Cracking of concrete allows moisture and chemicals to penetrate to the reinforcing steel, which then rusts, expands, and causes spalling of the concrete.

Wearing Surfaces: Asphaltic concrete or other wearing surfaces on a deck can hide deck defects. The surface must be examined very carefully for evidence of deck deterioration. Cracking, breaking up of the surface, or excessive deflection can indicate such deterioration. Any evidence of water passing through cracks in slabs should be noted. Areas where deck deterioration is suspected may require removal of small sections of the surface to facilitate a more thorough investigation.

Approaches: Approaches are an important adjunct to a bridge. Approaches should be level with the bridge deck. If the transition between the approach and the structure is not smooth and even, additional impact loads of substantial energy can be introduced onto the bridge, which can cause extensive and serious structural damage over extended time periods. Approach pavement conditions should be checked for unevenness, settlement, or roughness. Cracking or unevenness in an approach slab may indicate a void under the slab caused by fill settlement or erosion. The joints between the approach pavement and the abutment back wall, which are designed for thermal movement, should be examined to determine if there is adequate clearance and a proper seal. The shoulders, slopes, drainage, and approach guardrail should also be evaluated as part of the inspection of the approaches.

3.2.7.4 Inspection Reports

The NBI inspection report varies among states. However, it always includes condition and inventory information in a standardized record-keeping system suitable for computer data files. The information is provided to the Federal Highway Administration and is updated on a regular basis. It is included as part of the national Structure Inventory and Appraisal System that is used to establish eligibility for and priority for bridge rehabilitation or replacement.

The inspection report includes numerical ratings that represent the condition of each bridge element. The meaning of this rating varies somewhat among the states and among the bridge elements. Normally the rating ranges from "1" to "9," with a "9" meaning new condition and a "1" meaning the bridge is currently closed. In between, typically "8" means "good," a "6" or a "7" means that minor repair or maintenance is required, a "4" or a "5" means that major repair is needed, a "4" usually signals that major repair is urgently needed, and a "2" rating means that the bridge should be closed to traffic. Since the ratings are interpreted somewhat differently among the states, each state should have clearly expressed definitions of each rating for use within its jurisdiction.

Inspection reports include written descriptions, sketches, and photographs to provide details of the findings. The report should also provide the location of problems and estimates of their extent.

3.2.7.5 Inspection Performed by Maintenance Supervisors

Bridge maintenance crews should also function as inspectors whenever they are in the field working. It is important to look for defects that might represent a potential safety hazard or a defect that will cause problems at some time in the future. It is much easier and more cost-effective to correct the problem while the crew is already at the site than to go back at some future date.

Maintenance crews may spend more time at the bridge site than the inspector does. When cleaning and preparing for a repair, they may discover or expose problems that the inspector did not see. The best results can be achieved when the bridge maintenance personnel and the inspectors work together as a team.

3.2.7.6 Resource Estimating

The condition inspection reporting system should include information that can be used for estimating the resources necessary to maintain or rehabilitate a bridge. The accuracy of estimating is improved when it is performed in the field in conjunction with the inspection. The estimate made in the field is a "quantities" estimate that can be used for computing a cost estimate later in the office. Working together, the engineer and the supervisor can anticipate specific procedures that are needed, and the accuracy of the estimate will be improved. When preparing estimates, engineering office personnel are hindered by a lack of familiarity with a specific site and the special circumstances likely to be encountered. They are, therefore, limited to the use of statistical averages for determining time and resource requirements. Field estimate data eliminate this problem. The obligation for the engineer and the supervisor to perform the maintenance activity within the estimate is easier to fulfill when the field estimate procedure is used.

3.2.7.7 Identifying Fracture-Critical Bridges

A fracture-critical bridge must have one or more fracture-critical members (FCMs). An FCM is a tension member or component whose failure will produce a sudden collapse of the structure. It is important to know if a bridge is fracture critical when evaluating damage or performing repairs.

The portion of a member in tension is being pulled apart, which causes any cracks to grow, and fracture is the final result. Hangers, suspension cables, and some truss members are normally in axial tension. Maximum tension is in the bottom flange at mid-span of beams. A continuous span is typically in its critical tensile stress in the top flange over an interior support. High stresses may concentrate in tension members at points where the cross-sectional area changes or where there is a member discontinuity.

Redundancy: Redundancy is the ability of other members of a structure to help carry the load when a member becomes weak or fails. Lack of redundancy in a bridge makes it more susceptible to sudden collapse when a member fractures. Three different forms of redundancy may result from a particular design approach: load path, structural, and internal redundancy.

Load path redundancy is associated with a minimum number of structural members supporting the bridge deck. A bridge with less than three trusses or girders supporting the deck is not considered redundant, and therefore, it is classified as fracture critical. There can be degrees of redundancy depending upon girder spacing, stiffness of the deck and framing system, and other interdependencies of the structural elements. For some bridges, it may be necessary to have a professionally qualified structural engineer conduct a bridge capacity analysis to predict the failure scenario.

Structural redundancy refers to the support provided by the cantilever effect created after a continuous member is weakened. This effect occurs only on interior spans with members that are continuous across supports on both ends. Thus, there must be a minimum of three continuous spans to have a structurally redundant span, which for three spans would only be the center span.

Internal redundancy relates to crack propagation through the cross section of a member. Many members are composed of several parts. A crack in one part must start again as a new crack in each separate part to completely penetrate the cross section in an internally redundant member. Built-up members with plates attached by rivets or bolts, reinforced-concrete members, cables, and members composed of several separate sections all have internal redundancy. Rolled steel members and members with built-up sections from welding do not have internal redundancy.

Many agencies define fracture-critical members in terms of load path redundancy, but structural redundancy and internal redundancy should also be considered in the evaluation. Examples of fracture-critical spans are spans supported by two or fewer single web girders, trusses, suspension spans, cross girders, caps, and tie members on tied arch spans. Spans supported by four or less pin-and-hanger assemblies also qualify as fracture-critical spans.

Fatigue and Fracture: It is very important for the bridge owner to identify a crack or flaw before the member fractures. Physical characteristics make certain members more susceptible to fracture. The magnitude of the total stress and the number of times a member is stressed contribute to fractures. Certain design details can contribute to the beginning of a crack. Residual stresses in the member itself can also increase the tendency to crack. An inspector's efficiency in identifying FCM problems is significantly enhanced by an understanding of fatigue and fracture.

A fracture requires a driving force. This force normally results from the load on the bridge. The force on a particular member cross section is called stress and may take the form of compression, tension, or shear. Compression squeezes or pushes down on a member and tends to help resist crack growth. A crack in a compression member is rare, and such cracks would not be expected to show evidence of growing. Since tensile forces pull the member apart, cracks in tension members are a serious concern. Cracks in tension members can be expected to grow perpendicular to the direction of the tensile force and produce fracture. Shear is similar to tension except that the force is in a sliding or slicing direction across the cross section so that shear tends to tear the material. Some cracks may grow as a result of shear stresses. Shear forces act at 45° to the direction of the force. Bridge members may be resisting only one of these forces, or a member may have to simultaneously resist a combination of these forces.

A fracture may be the result of an overload when the member is stressed beyond its capacity of the material yield point. This is rarely the case for bridges designed to carry standard legal loads. More often, repeated loads that do not exceed the legal limit cause the cracks. Repeated flexing and stressing of the material at a point below the yield limit produces an "internal working" of the molecular bond within the material that gradually reduces the strength of the material in what is called fatigue failure. One load is a cycle. A cycle must subject the member to a certain magnitude change in stress or stress range before it is significant in causing fatigue cracks. Bridges that carry a large volume of heavy loads are more likely to experience fatigue failures than low-traffic-volume bridges.

Fatigue crack initiation is related not only to the number and size of the stress cycles, but also to the degree to which design details affect the fatigue resistance of a member. Stresses concentrate at locations where the rigidity of the member changes. To be most effective in their respective activities, both bridge designers and bridge inspectors need to be aware of the effect of these design details. Welds, bolt holes, rivet holes, notches, copes, flame cuts, and grinding marks all contribute to stress concentrations. However, bolt or rivet holes cause stress concentrations to a lesser extent than some of these other items. Service flaws that can contribute to fatigue include collision damage, damage from improper straightening, or cross-section area loss from corrosion.

Material Considerations: The two types of fracture are ductile and brittle. When ductile fracture occurs, the material stretches before it separates into two parts. The fracture is slow, and often there is time to prevent a disaster. A brittle fracture occurs very rapidly and is of particular concern to the bridge owner. Certain members are more likely to fail by brittle fracture. Because they tend to break rather than bend, members composed of thick plates are more likely to experience a brittle fracture than members made of thinner plates. Cold temperatures reduce metal ductility and increase the likelihood of a brittle fracture. Modern bridges are designed and specified to be constructed of steel with minimum toughness to resist brittle fracture. Old bridges were not required to meet such specifications and may need to be tested to determine the steel toughness, analyzing the bridge's potential for a fracture failure.

Design Considerations: Fatigue cracks initiate at locations in steel members where the rigidity of the member changes. Usually these locations result from a design engineer attempting to save material to reduce bridge weight and save money. Cover plates added to rolled section beams to avoid specifying a larger size rolled section change the rigidity in ways that increase susceptibility to fatigue cracks along the edge of the cover plate. If the designer uses a thin-web rolled section and increases the beam rigidity by adding stiffener plates to the web, this encourages fatigue crack development. Fatigue cracks may develop from in-plane bending when the load is distributed from the floor directly to the member. Fatigue cracks may develop from out-of-plane bending when the floor load is transferred to the member through a secondary member. This produces a twisting action that places excess stress levels on thin parts of the member that are not well suited to resisting the forces. Bridge inspectors should report all cracks to professionally qualified structural engineers who can evaluate the nature of the cracking and determine how critical it is with respect to needed bridge maintenance.

Loads on the Structure: The loading rate on the structure can also be an important factor in whether the fracture will be brittle or ductile. Static loading (dead load) is least likely to produce brittle failure. Dynamic loading (live load) is far more likely to produce brittle or sudden failure. Since bridges undergo a combination of static and dynamic loading, it is important to identify bridges where the dynamic loading is exceptionally high. Bridges that receive heavy pounding loads resulting from low approaches or poor vertical alignment are candidates to watch carefully.

Repeated loads that produce high-stress cycles cause fatigue cracking. Large loads relative to the average design load create stress cycles that cause fatigue damage. A particular design detail may be capable of carrying a limited number of cycles caused by a very heavy but legal load using the structure. When the number of stress cycles exceeds the limit, cracking will occur at locations in the structure that can be predicted quite reliably. Thus, a knowledge of the loading history of a bridge is helpful in evaluating the probability of fatigue cracking.

Crack Initiation and Propagation: Most cracks in steel bridges occur at predictable locations. Cracks occur at areas of stress concentration. Normally, they originate at a flaw. The flaw is often associated with a weld. When a fatigue crack caused by in-plane bending grows to a size visible to an inspector, typically at least 80% of the service life of the member has already been destroyed. A small crack has been growing beneath the surface in a semi-elliptical pattern, and after it reaches the surface of the steel, it must penetrate through the paint before it is visible to the inspector. Sometimes a rust stain will allow an inspector to detect a crack earlier. Nondestructive testing (NDT) can help verify the existence and extent of a crack after it has been initially found. However, NDT is not very effective in general inspection to find cracks initially. Indications of cracks are generally found by visual inspection.

3.2.7.8 Testing Existing Bridge Components

To properly plan a bridge maintenance repair, it is sometimes necessary to obtain more information on the condition of the existing material than can be obtained from a visual inspection. Tests are performed to provide the information required. While the maintenance supervisor normally would not perform the tests, maintenance personnel should know when they are needed and what the results of the tests mean.

Reinforced-Concrete Corrosion Survey: Several tests are available to investigate concrete element deterioration from reinforcing steel corrosion.

Delamination Survey: Sounding the surface of a reinforced-concrete deck can determine the presence of delaminations (internal cracks caused by corrosion of the reinforcing steel). A grid is laid out on the deck surface. The surface is sounded (usually by a drag chain), and the delaminations are noted. The areas containing delaminations are marked on the surface and mapped for a report of the survey. The amount of delamination is computed as a percent of the surface area. Concrete spalls are not included.

Cover Depth Over Reinforcing Steel Using a Cover Meter: Devices are commercially available that use a magnetic field to detect the presence of reinforcing steel within concrete. If the size of the steel bar is known, the devices can estimate the depth of concrete over the bar. An estimate of the depth of concrete cover is needed if part of the surface is to be removed in any maintenance procedure. It is helpful to check the precision and calibration of the instrument at one location on the deck by exposing a reinforcing bar and comparing the reading to the actual depth. This is especially helpful because the concrete may contain magnetic particles that disturb the instrument measurements. The exposed reinforcing bar can be used later as a half-cell test bar ground connection.

Chloride Content: Powdered samples of concrete are collected with a concrete drill at several increments between the concrete surface and the level of the reinforcing steel. The chloride (salt) content of the powder is measured in kilograms per cubic meter (pounds per cubic foot) with a portable kit in the field or sent to a laboratory for testing. The threshold chloride contamination is 16 kg per cubic meter (one pound per cubic foot).

Corrosion Potential Survey: This procedure determines the potential for reinforcing steel corrosion by measuring the electrical potential of the reinforcing steel. Electrical measurements are made by placing a probe, connected to a half-cell corrosion detector, on the deck surface at predetermined points based on a grid established on the concrete deck surface. The surface is usually wetted for a better electrical contact. This probe is grounded to an exposed reinforcing bar in the deck that is in contact with the reinforcing steel bar mat being tested, and an electrical connection is made. The half-cell corrosion detector reads the electrical potential of the steel at the predetermined points, and these readings are recorded. A corrosion potential survey is not recommended if the deck contains epoxy-coated reinforcing steel or galvanized reinforcing steel (epoxy-coated bars are insulated from each other, and readings on galvanized bars merely indicate the electrical potential of the zinc coating). Also, this test cannot be used if the concrete is overlaid with a dielectric material.

Corrosion Contour Map: Corrosion tests are typically tied to a 1.3-meter (4-foot) or smaller rectangular grid established on the deck. The test findings are recorded at the proper location on a sketch of the deck, and contours are plotted to show the areas that have delamination, chloride contamination, and active corrosion.

Newer Corrosion Tests: Concrete deck deterioration from salt contamination is a continuing major expense in bridge maintenance. Research and development efforts to find faster, more reliable, and more precise methods of detecting and quantifying corrosion damage continue to make bridge maintenance management more effective.

One such effort is the development of a rate of corrosion measurement that is based on determining the polarization potential of the reinforcing steel. Corrosion current is calculated from a simple equation and expressed in terms of mill-amperes per square meter (or square foot) of the reinforcing steel area. The test should be conducted at locations of highest corrosion potential (peak negative values) as determined by the half-cell test. Corrosion rate tests should not be carried out where epoxy-coated or galvanized reinforcing steel is used.

A second such test is the permeability of concrete test. This test determines the relative permeability of the concrete (or a concrete overlay). The permeability is indicated by the electrical charge passed through the concrete, expressed in coulombs.

Noncorrosion-Related Concrete Tests: A number of tests can be conducted on a reinforced-concrete deck to determine characteristics that may be useful in planning bridge maintenance.

Cores: Cores can be drilled out of the deck to provide a sample of the hardened concrete. These cores can be tested for compressive strength. However, since most deck problems are related to durability rather than strength, cores are rarely tested for compressive strength. Cores can be used for petrographic analysis, air content analysis, materials compatibility tests, or chemical contamination tests. Since coring is moderately expensive and destructive, cores are typically taken only when other evidence indicates further investigation is warranted.

Alkali Silica Reactivity: Some aggregates react with cement and create a gel in the hardened concrete. Over time, this gel expands, causing cracking and disintegration of the bond between the concrete ingredients. A uranyl acetate and ultraviolet light test is available to determine presence of the gel. Little can be done to prevent this problem on existing bridges, except to do everything possible to avoid using reactive aggregates in future construction and repairs.

Tests for Special Problems: Tests are available that are usually considered too expensive to be routinely used in testing for routine maintenance conditions. However, one of them might be used for special situations.

Ultrasonic Pulse Velocity: Ultrasonic pulse velocity measurements measure the time of transmission of an ultrasonic pulse of energy through a known distance of concrete. The velocity of the pulse is proportional to the dynamic modulus of elasticity (or hardness), which in turn is an indicator of concrete strength. The test evaluates homogeneity and determines crack location. The results can be affected by many factors including variations in aggregate and the location of reinforcing steel. The results obtained are quantitative but they are only relative in nature; thus, they need to be correlated with corings to yield absolute values.

Radiographic (X-ray) Inspection: Radiographic inspection can be used to locate cracks, reinforcing steel, and internal voids within the concrete. Up to 200 mm (0.65 foot) of concrete can be penetrated. The method is not destructive but requires access to the back of the bridge element. It is very expensive and must be used with great care because of the potential radiological health hazard.

Computer-Assisted Tomography: Computer-assisted tomography scanning uses a nuclear source to develop a cross-sectional view of a member. It yields information on the size and location of aggregate, cracks, voids, density, and extent of corrosion. This method is not destructive and can be used to scan members up to 1 meter (about 3 feet) thick. It is very expensive, gives no direct measure of strength, and poses a significant potential health risk to the user.

3.2.7.9 Tests for Steel Members

Various testing methods are available for evaluating steel members that are suspected of having problems. When maintenance work is being planned on steel bridge members, it is important to determine the strength of the steel, the ingredients in the steel, and the existence and location of flaws or cracks in the steel that cannot be seen by visual inspection.

Coupon Samples: A small coupon sample is taken from an area of the steel member where its location will not cause problems (as determined by a professionally qualified structural engineer). The sample can then be tested for tensile strength and steel ingredients (for load capacity and weldability). This test is destructive, so it is used sparingly.

Dye Penetrant Test: This test is used to identify and enhance surface cracks in steel members. It is simple and inexpensive. A photograph will provide a permanent record.

Magnetic Particle Testing: This method locates surface cracks in steel by an induced magnetic field. The magnetic particles are fluorescent and suspended in a slurry. The magnetic field attracts the particles to discontinuities in the steel surface. This method is quick and low cost although only applicable to surface defects.

Ultrasonic Testing: This method uses sound waves to locate cracks or flaws inside steel members. It is commonly used on welded splices, cover-plated ends, and pin-and-hanger details. It is most effective in identifying cracks that are perpendicular, rather than parallel, to the direction of the sound wave. It is not destructive and can be used to measure the member thickness.

Radiographic (X-ray) Inspection: Radiographic inspection locates cracks by using a film cassette with an x-ray or gamma ray source placed on opposite sides of the member. It produces a permanent record of the crack. Up to 350 mm (about 14 inches) of steel can be penetrated. This method is expensive, hard to use, and poses a health risk to the operator unless extreme care is taken in its application.

Acoustic Holography: This method locates cracks using an array of ultrasonic transducers to produce a multidimensional picture and a permanent record. The test is expensive and somewhat experimental.

3.2.7.10 Tests for Timber Members

Wood is one of the oldest building materials used for bridges. In spite of this long history, testing methods are still under development to add to those currently available.

Pointed Probe: A pointed probe (e.g., an ice pick) can be used to subjectively measure the quality of existing timber.

Increment Bores: Increment bores are used to obtain samples of the interior cross section of the timber member. Since decay starts on the interior of a treated timber member, this test is needed to determine if a member should be removed as part of a repair operation.

Advanced Timber Testing: The following are two of several efforts to develop additional testing capabilities for timber bridge members:

(1) Sonic Pulse Velocity Testing: This method indicates relative timber strength and section loss as a single value based on a transmitted pulse velocity that is proportional to density and the modulus of elasticity. Correlation of results with samples of known strength is needed to yield an absolute value. Some success has been reached in making measurements from a boat to test timber at a depth of 1 meter (about 3 feet) below the water line.

(2) Handheld Moisture Meters: Moisture meters are available to measure the moisture content of solid wood, including glue-laminated members. These meters may be either conductance meters or dielectric meters. They can provide a rapid estimate of moisture content. They also can infer strength based on electrical parameters measured, but these inferences may or may not be reliable. Measurements must be compared to a calibration curve to obtain an indirect measure of moisture content. Preservatives (e.g., creosote) and adhesives (in glue-laminated members) can significantly affect readings.

3.2.7.11 Load Tests

Most analytical methods of measuring the capacity of a bridge member predict the stress that will be produced in that member from a certain weight vehicle [19]. The prediction is based on a simplified application of structural theory combined with experience factors. To allow for unknown field conditions, the analytical methods are usually somewhat conservative. Sometimes very expensive repairs can be avoided by using a more precise method to measure the actual stress in a member by applying a test load to the bridge. Strain gauges are attached to the member at prescribed points determined by a professionally qualified structural engineer, and the strain produced by different loads is measured. The strain readings are converted to stress levels to yield a precise estimate of the load capacity. Studies by Kim et al. [20] and Briaud [21] comparing load testing to analytical methods suggest that actual stresses and strains are typically appreciably less than those predicted by standard analytical methods [15, 16].

3.2.8 Preliminary Site Visit to Plan a Bridge Repair

State DOTs follow different procedures in responding to bridge inspection findings. If maintenance or repair needs have been identified, a bridge inspection supervisor or local (or assistant) bridge maintenance engineer will review the report, decide if an engineer should visit the site, and determine who should perform the work. The options vary significantly with respect to what work is contracted and what work is conducted in-house. Decisions are based on the degree to which a particular state has special crews that perform bridge maintenance or whether this type of maintenance is generally a contract process. The site visit provides valuable input to prioritizing bridge maintenance needs.

After the assignment has been made, someone must visit the site to collect information to plan the repair. Depending upon the state and the type of work to be done, the supervisor may be totally responsible for the site visit or the supervisor may work with an engineer (or other person with extensive bridge repair experience and knowledge). The basic information needed to plan the repair is considered first, followed by special considerations for each component of the bridge.

3.2.8.1 Basic Information Required

It is important that the person who performs the preliminary site visit understand the limits of his or her knowledge and experience. If structural members are damaged, a professionally qualified structural engineer should be involved in the inspection. Some types of damage may look similar to past cases, but the type of stress or the type of structure can cause the repair to require different safety procedures.

Quantities: If maintenance and repair quantities have been provided, they should be verified in the field. Since some time may have passed since the inspection was done, conditions may have changed enough to change the estimated quantities required.

Location: The exact location of the damage should be verified so that the crew can locate it without any difficulty. This will contribute to efficiency on the job.

Traffic Control: The roadway should be studied in both directions to verify that any traffic control plan developed under the guidance of the MUTCD and the state manual is appropriate and applicable for both worker safety and motorist safety.

Staging Area: A place is needed near the site to safely store equipment and materials.

Repair Work Not Specified: Check for other damage not included in the work order. It is more cost-effective to do all needed maintenance and repairs in one trip. However, this must be balanced against any backlog of more critical repairs needed elsewhere, and additions to the original work order need to be agreed to by maintenance engineers and managers at higher levels of management.

3.2.8.2 Channel Damage

Problems with the channel have the potential to change rapidly if a major storm occurs. Debris may direct the water force toward a vulnerable portion of the bridge substructure. Damaged riprap may leave an abutment footing unprotected. To avoid a potential catastrophe, channel repairs should be treated with appropriate urgency. Major floods can provide an opportunity to assess the potential for bridges to resist scour under extreme water flows [4].

Cause: The cause of channel problems should be identified and corrected, if possible, as part of the repair.

Type of Repair: Determine if the problem is caused by local scour or if it is related to a change along a significant length of the channel (which might be best solved with a bridge modification).

Size of Material: To determine what size of material needs to be used to correct a scour problem may require an analysis of specific characteristics of the stream flow by a professionally qualified hydraulics engineer.

Materials and Equipment: The equipment you have available may dictate the method or repair you can choose. The type of material available may be a significant factor in determining how much material is needed.

Permits and Damage to Adjacent Property: Evaluate if special permits will be needed or special precautions will be necessary for environmental control. The potential negative impact of any repair on adjacent property needs to be evaluated.

3.2.8.3 Approach Damage

Approaches can present special problems because roadway maintenance crews (who may not be aware of the effects of approach roadway damage on the bridge) often maintain the approaches. NCHRP Synthesis of Highway Practice 234 provides a comprehensive examination of the problems associated with settled bridge approaches and the maintenance treatments appropriate to their repair [21].

Settlement: Settled approach roadways to bridges are often merely built up with asphaltic patching material. Bridge maintenance personnel should determine if the settlement is related to any scour problem behind the abutment.

Pavement Pressure: If joints in a concrete approach roadway become filled with incompressible materials, the pavement will push on the bridge abutment when it expands in hot weather. In this case, a relief joint will need to be installed in the approach roadway to prevent damage to bridge bearings, bridge joints, etc.

Repaved Approach Roadway: When an approach roadway is repaved, any overlay or additional depth of pavement should not extend across the bridge because it will change the dead load of the bridge. Neither should there be a bump left at the end of the bridge because it will create dynamic loading on the bridge.

Drainage and Debris: Check any maintenance of the bridge approach to ensure that surface water from the bridge deck will continue to drain away from the bridge, and that trash does not accumulate at the transition from the approach roadway to the bridge.

Major Voids Under Approach Slab: Some DOTs have recently discovered large voids under approach slabs and the backs of abutments. These voids were so deep that they remained undetected as they developed into larger cavities. The net effect was that the approach slab had been bridging the hole to continue carrying traffic. The extent of such problems is generally unknown, but if they develop at all frequently, the effect commonly referred to as "the bump at the end of the bridge" will not be solved by mud-jacking or pavement overlays.

3.2.8.4 Deck Damage

The deck is exposed to many elements, including de-icing salts, abrasives, and mechanical wear from vehicular traffic. Since the deck provides the riding surface for traffic, damage that can be tolerated elsewhere on the structure is a major problem on the deck. Thus, repairs to the deck are sometimes seen as "emergency" conditions. The goal of bridge maintenance is to prevent deck problems that require an emergency response.

Preventive Maintenance of Concrete Deck: Good maintenance of a concrete deck requires more information than a biennial bridge inspection typically provides. Reinforcing steel corrosion causes most concrete deck problems. Once the steel corrosion starts, extensive rehabilitation is required for permanent repair. Thus, the most cost-effective process is to perform concrete bridge deck maintenance before spalls and potholes begin. If tests indicate no corrosion of the steel and no delamination of the concrete, and if the salt contamination of the concrete is minimal, then annual flushing of the deck or resealing may be the most cost-effective maintenance possible. If tests indicate any of the above conditions exist, repair—and perhaps removal and replacement—of the deck may be required.

Temporary Concrete Deck Repairs: If the level of salt contamination in the concrete and the areas of delamination are extensive, it may be more cost-effective to replace the deck than to repair it. In this case, patching with a material and process that will least interfere with traffic and last as long as possible may be best while a deck replacement is being programmed and budgeted.

Timber Deck: Unless the damage to a timber deck is isolated, it is generally better to replace the entire deck than to replace a few planks at a time. This is especially true for laminated timber decks.

Orthotropic Bridge Decks: Cracks of a minor nature in an orthotropic bridge deck will not require restriction of traffic other than during the repair period. After the cause of the crack has been determined and corrective action taken, the crack can be repaired with a welded cover plate. These bridges generally have an abrasive wearing course that has to be removed and replaced over the work area.

Steel Grid Decks: Steel open-grid decks usually require little maintenance. Since their failure exposes raw steel to corrosive elements, the welds or rivets that join the grid end and hold down the steel grid decks should be replaced if broken. Broken welds should be removed by grinding and then welded again. Grid sections with severe corrosion and section loss should be replaced. Steel grid decks tend to become slippery when wet or frost covered. Studs that are about 8 mm (about 5/16 inch) in diameter and about 10 mm (about 3/8 inch) high may be welded on intersections of the cross members, providing a grip surface that overcomes slipperiness.

Joint Repairs: To properly protect the bridge components below the deck, the joints should be waterproof. To be waterproof, the joints must be sealed. If a bridge deck joint is not sealed because it is an older joint design, consider remodeling the joint to accommodate an effective sealer. Some agencies are retrofitting bridges to eliminate as many bridge joints as possible. Bridge joints should only be eliminated if a professionally qualified structural engineer has determined that stresses will not be transferred to other parts of the structure, thus creating additional problems. If a bridge joint fails, it may create a problem for traffic using the bridge, and emergency repair may be needed until a full joint repair can be scheduled.

Rail Repairs: Vehicular collisions are the primary cause of bridge rail damage, and the cost of repair may be recovered if the errant vehicle can be identified. It is important to check other parts of the structure to make certain that the rail impact did not cause problems elsewhere on the bridge.

3.2.8.5 Superstructure Damage

Superstructure repairs often require more time and resources than repairs to other parts of the bridge. Planning is important to ensure that these resources are available when needed and are used efficiently. The site visit is essential to effective planning.

Access: Access is always an important consideration for repairing superstructures. Depending upon the access to the superstructure, it may be necessary to consider rigging a platform from the bridge, erecting a scaffold from the ground, working from a barge, or using mechanical platforms.

Lifting and Support: Repair of superstructure damage often requires lifting and supporting parts of the bridge. An engineer should design this procedure. However, the feasibility of the procedure needs to be verified during the site visit. Think about the number and size of jacks required, shoring requirements, jacking and shoring locations, foundation and terrain for shoring, and the opening and condition of deck joints.

Steel Beams: Any crack or fracture in a steel beam, girder, or truss should be considered a sign of serious distress, and immediate corrective action should be taken. In some instances, the only action required may be to drill a hole at the end of the crack to control further crack growth. Cracks in steel beams usually occur at welded areas. Indiscriminate field welding or making improvised attachments to beams is discouraged unless a professionally qualified structural engineer has analyzed the beam's stress conditions and recommends welding as an appropriate solution.

Trusses: Most truss bridges are made of steel, although some old bridges with wrought iron trusses are still in use. Repair normally consists of replacing a damaged member or strengthening weakened members by adding steel reinforcing plates. The type (tension or compression) and magnitude of the stresses on each member must be determined before beginning repairs. A professionally qualified structural engineer should assist in this assessment and in the development of the repair procedures.

Timber Beams: Certain types of cracks in timber bridge beams can result in a loss of load-carrying capacity and may require immediate repair or replacement before traffic is allowed to return to the bridge. Using U-bolts fitted around the beam and extending through the deck can sometimes temporarily repair timber beams with a longitudinal crack. A new beam may also be fastened alongside the damaged beam by this method. Normally all the stringers that have decayed must be replaced.

Reinforced-Concrete Beams: The concrete deck is normally an integral part of the beams. Since they carry the load together as one unit, damage or repairs to one affect the other. Repairs may be cosmetic or structural. Cosmetic repairs are appropriate only on small areas where the reinforcing steel is not damaged. To perform structural repairs to concrete beams, the bridge should be supported by shoring. Spalling of the deck surface above the beam can affect the strength of a concrete T-beam. Corrosion of the main longitudinal reinforcing steel in the bottom of simple span beams can cause the concrete cover to spall, exposing the reinforcing steel to further corrosion. A crack at the end of the beam that extends diagonally upward away from the bearing is an indication of shear failure.

3.2.8.6 Substructure Damage

Substructure repairs are often unique; therefore, a general list of things to look for during a site visit for a typical substructure repair is difficult to compile. However, most of the considerations for superstructure repairs also apply to substructure repairs. Access to the repair area certainly needs to be checked, and lifting a support may also be necessary.

Cracks: Before a method is identified for repairing a crack, it must be determined if the crack is active (moving). A moving crack should be sealed with a flexible material. A passive crack can be sealed with a rigid material. If possible, determine if the crack is a full-depth crack. This is hard to do in an abutment.

Wet or Dry Repair: The method of repair and its associated cost may be quite different depending upon whether the repair can be performed in a dewatered area or whether it must be done underwater.

Column Repairs: Column repairs often cover a deeper problem with a jacket or layer of concrete. Determine if the repair is only intended to protect the column against additional damage or if it is intended to replace the column's lost load-carrying capacity. A corroding steel pile, a concrete pile with corroding reinforcing steel, or a decaying timber pile may all continue to deteriorate under a concrete repair jacket. This could result in serious consequences if the jacket is not designed to carry the column load.

3.2.8.7 Emergency Damage

When damage to a bridge presents an immediate safety hazard, priorities are different than on other site visits. The objective is to assess the urgency of the situation and to begin to take appropriate actions.

Close or Restrict Use of the Bridge: A standard procedure to implement an immediate bridge closing should be available in every agency so it can quickly be put in place once personnel making an on-site visit determine that the bridge needs to be closed. The procedure should outline who and what agencies must be contacted, what signs must be erected, how to establish a detour, and how to use the mass media to inform the public. A professionally qualified structural engineer should be contacted if there's a question about whether the bridge should be closed or only restricted in the way vehicles are permitted to use it.

Emergency Repair: After the immediate safety issues are resolved, the repair urgency is determined and the maintenance and repair process can proceed according to the priority set on the repair. After the type of repair is determined, the personnel and equipment needed can be mobilized and the necessary materials can be located while the repair details are worked out. Special provisions for working at night and lodging the repair crew near the site may also be necessary.

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