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Development of a "Manual for Inspection, Evaluation and Maintenance of Movable Bridges"

by

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DEVELOPMENT OF A "MANUAL FOR INSPECTION, EVALUATION AND MAINTENANCE OF MOVABLE BRIDGES"

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INTRODUCTION

Movable bridges are the critical link in many highway transportation systems. Bridge owners have a substantial capital investment in these structures and a considerable annual expense for operating personnel and maintenance. A program of inspection, evaluation, maintenance, and repair/rehabilitation can improve the operational reliability and life of these structures, stabilize annual costs, and minimize breakdowns. The development and implementation of such a program by bridge owners requires a comprehensive industry standard that establishes criteria for in-service movable bridges. Limited reference material is presently available to bridge owners, and this information primarily applies to design of new movable bridges.

NCHRP Project 10-43, *Movable Bridge Inspection, Evaluation, and Maintenance*, was initiated with the objective of developing a manual to provide guidance for the inspection, evaluation, and maintenance of existing movable bridges, in a form suitable to be considered for adoption by AASHTO. The work is sponsored by AASHTO under the National Cooperative Highway Research Program of the Transportation Research Board, National Research Council.

A. G. Lichtenstein and Associates, Inc. was selected as the prime contractor to perform the work. The Lichtenstein team of Charles Minervino and Paul Blair are the primary researchers, assisted by subcontractors Imbsen Associates, Inc. and consultants Frank Rose, William Bowden, and Robert Cragg. This paper reviews the research conducted by the team, describes the format and content of the new Manual, and discusses several technical issues addressed in the Manual.

NBI INVENTORY OF MOVABLE BRIDGES

The National Bridge Inventory lists approximately 970 movable highway bridges in the United States. These structures are broken down into three primary types, as follows:

530	Bascules
270	Swing Spans
170	Vertical Lift Bridges

The NBI statistics indicate an aged population of movable bridges. More than 80% of existing movable bridges are at least 25 years old, and more than 50% are greater than 50 years old. The NBI further indicates that 386 (40%) are classified as structurally deficient and 360 (37%) are functionally obsolete.

Movable brides are distributed nationally among 34 states, with 21 of those states having more than 10 bridges. The states owning the most movable bridges are Florida with 176, Louisiana with 154, New Jersey and New York with 72 each, and Illinois with 68.

RESEARCH

The research team assembled and reviewed existing foreign and domestic practices, procedures and codes for structural, mechanical, hydraulic, electrical and control systems for movable bridges. The research included a literature search of libraries and databases for publications related to movable bridges. Over 300 documents were compiled, including specifications, references, articles, technical papers, manuals, etc. These documents were screened and reviewed for applicability to the manual. Appropriate material was separated into two categories: valuable as source material for the Manual; and other useful documents to be included as part of a comprehensive reference list. The team's search included investigating other industries, such as heavy equipment, defense, electronics, and industrial robotics, where technology transfer to movable bridges might be useful.

The research team distributed questionnaires to survey state and city Departments of Transportation on their current practices related to movable bridges in order to identify important issues to be addressed in the proposed manual and to obtain opinions on the treatment of those issues.

The researchers also sought pertinent unpublished information on typical and/or chronic maintenance problems and other practical experiences of owners, designers, consultants, maintenance personnel, equipment manufacturers, FHWA, the United States Coast Guard, and U. S. Army Corps of Engineers. The initial step in obtaining this information involved the distribution of an informational questionnaire to the movable bridge industry asking interested experts to volunteer to respond to telephone requests, written questionnaires, or personal interviews on specific issues within their area of expertise. As a result, the research team developed a resource base of specialists - engineers, designers, inspectors, maintainers, manufacturers, fabricators, contractors, etc. - who were willing to contribute opinions on technical issues via a directed inquiry.

The research revealed that available references do not contain the flexibility in design that is needed to accommodate rehabilitation work and do not fully address the inspection and maintenance of specialized components of movable bridges. The research team identified a number of technical issues to be resolved in the development of the new manual. In addition, it was determined that the new Manual would be prepared in four parts: General, Inspection, Evaluation, and Maintenance. In this way each part was aimed at the technical level of the projected users. Thus, Inspection and Maintenance parts are directed at the technical level, while the Evaluation part is aimed at experienced engineers. Several of the issues addressed in the new Manual are discussed below.

GENERAL

Systems Approach

The researchers believe it is important to expand the traditional approach of simply distinguishing between electrical, mechanical, and structural systems by developing a means of classifying movable bridge systems that better defines their operational and functional characteristics. Functional systems, entitled *support, balance, drive, control, interlocking, navigation guidance,* and *traffic control*, are used to categorize bridge components. Each component of the bridge is assigned to one (or more) of these systems, and is treated as an essential part of that system and as an individual component. The combination of these distinct systems encompasses the total operation of the bridge. The proper interaction of these systems is critical to safe, reliable operation. A breakdown in one system can have substantial impact on other systems.

Inspectors, evaluators, and maintainers are encouraged to use this systems approach as a means of ensuring that the function of an individual element is properly considered as part of the total assembly. The potential consequences on related systems from observed defects in an individual component must be properly recognized by the inspector. Since this concept has application to the inspection, evaluation, and maintenance parts of the manual, the researchers included this material in the General section.

INSPECTION

Scope

The Manual provides general guidelines for consistency in the scope of routine and indepth inspections. Routine inspections should be conducted at a minimum interval of 2 years with indepth inspections scheduled for every third cycle or a maximum interval of 6 years.

In general, a routine inspection should involve visual examination, measurement, and assessment of condition based on external signs of deterioration or defects such as corrosion, wear, abrasion, cracks, misalignment, clearances, fluid levels/leaks, lubrication, noises, heat, etc. Major disassembly of operating components is not necessary, but machinery covers and inspection ports or hatches should be opened for access. Accessible clearances and backlash in machinery components should be measured. Basic electrical testing should be done. The performance of functional systems and components during operation should be observed. Span balance testing is also considered an important part of routine inspections.

Indepth inspections include all the work of a routine inspection with the addition of more detailed inspection, measurement, and testing procedures. Mechanical components should be opened and closed where appropriate. Internal wear and clearances can then be measured and recorded. Hydraulic systems can be pressure tested. More comprehensive testing of electrical components, including vibration testing of motors and megger testing of insulation, should be done. Sequential performance testing of controls and interlocks should be conducted.

Component Inspection

A comprehensive program starts with the inspection and assessment of the existing facility. Consistent reporting by knowledgeable inspectors is vital to the bridge owner. FHWA recognized this need and published a primary manual entitled, The Bridge Inspectors Training Manual/90 (BITM/90 - replacement for **BITM/70**), which serves as the basis for bridge inspection training courses and describes procedures and techniques for inspecting the structural components and appurtenances of all types of bridges. One of the specialty supplements to this document is FHWA's *Bridge Inspectors Manual for Movable Bridges, 1977 (BIMMB/77)*, which provides detailed data on the composition of a variety of typical electrical/mechanical operating systems in use on movable bridges and describes procedures for inspecting and testing the components. While this manual provides a good general background for inspection, it was not intended to address evaluation, repair/rehabilitation, or maintenance of existing bridges and components, and is currently out-of-print.

The FHWA *Bridge Inspector's Manual for Movable Bridges, 1977* concentrates primarily on material necessary to supplement the *Bridge Inspector's Training Manual/70* in the area of mechanical and electrical inspection. Performance inspection of operating systems is not covered and inspection of hydraulic components is not addressed. The discussion of performance inspection of operating systems has been expanded somewhat in the new *Bridge Inspectors Training Manual/90*, but is based on a component by component evaluation. Operating System opening and closing sequences are explained, but discussion of the interaction between components and actual performance inspection procedures to determine that all components function properly and in sequence are not discussed in detail. There is only one paragraph addressing hydraulic components inspection. Guidance for evaluating inspection and testing findings is not present.

Numeric Condition Evaluation Code

At present no uniform numeric condition evaluation coding exists for mechanical, hydraulic, and electrical components. Practices vary from owner to owner and are, for the most part, currently based upon qualitative, subjective evaluation heavily influenced by the experience and knowledge of the individual inspector. It was recommended that uniform criteria be developed which could be utilized nationwide by inspectors with varying levels of expertise.

The Manual contains a recommended uniform numeric condition evaluation code for mechanical, hydraulic and electrical components. Many mechanical and hydraulic system components can be assessed based on physical evidence of wear or deterioration. Electrical components, however, sometimes give little visible evidence of distress. A simple PASS/FAIL System is not sufficient, as these components can continue to function reliably or breakdown shortly after inspection. A more rational approach to condition rating could be based on the percentage of manufacturer's rated life expended.

NBIS FHWA BITM90	AASHTO BMS CODING	OBSERVED CONDITION	PERCENT OF PREDICTED LIFE EXPENDED
9	1	NEW	<15%
7	2	GOOD	15-35%
5	3	FAIR	35-65%
3	4	POOR	65-85%
1	5	CRITICAL	>85%

EXCELLENT: No defects noted, component appears to be in new condition and functions as designed.

GOOD: Minor deterioration or wear noted, component appears to be functional.

FAIR: Obvious deterioration or wear noted, component appears to be functional, but no longer operating like new, component has useful remaining life

POOR: Significant deterioration or wear noted, component appears to be generally functional, but exhibits signs that failure will result from continued wear or deterioration, component is nearing the end of its useful life.

CRITICAL: Significant deterioration or wear noted, component appears to be marginally functional and exhibits signs that failure will result from continued wear or deterioration. Corrective action is required as soon as possible to avoid failure.

Predicted life would be based on the manufacturer's estimated service life for newly installed components. The Manual recommends that new components have a sticker recording the date of installation and that hourmeters be installed on primary electrical circuits so that subsequent inspectors can establish the extent of predicted life expended. For existing undated components, estimates of remaining predicted life can be made by an experienced electrical inspector, using bridge logs and maintenance records. When predicted life information is unavailable from manufacturers, the Manual contains tables with suggested predicted life for typical Electrical and Hydraulic components.

PREDICATED LIFE
ELECTRICAL COMPONENTS

COMPONENT TYPE	AVERAGE USAGE 400 to 4000 openings per year	
	Open to Environment	Closed Room or Sealed Unit
Motors and Generators (Overall)	35	70
Brushes in DC Brush-type Motors/Generators	10	20
Limit Switches	4	6
Motor Starters and Contactors	30	60
Open Wiring	20	40
Wiring in Conduit	30	60
Wiring Terminals	20	40

PREDICTED LIFE

HYDRAULIC COMPONENTS

COMPONENT TYPE	AVERAGE USAGE 400 to 4000 openings per year	
	W/O Fluid Testing	With Fluid Testing per Chapter 2.11
Accumulators, Reservoir	36	55
Pumps and Motors or Rotary Actuators	30	45
Cylinders	20	30
Operatikng Valves and Hydraulic System Sensors other than electromechanical limit switches	25	38
Open Wiring	36	55
Tubing (except flare fittings)	15	22
Flexible Hoses	5	7

The electrical table is based on IEEE tables for similar components in other industries modified for the environmental conditions encountered on movable bridges. Little source material was available for predicted life of hydraulic components. The data presented is based on experience and.judgement of the researchers. Comment from industry specialists was solicited by the researchers on the predicted life tables.

EVALUATION

The AASHTO *Standard Specifications for Movable Highway Bridges* prescribes design standards for new movable bridges. The specification does not contain modified criteria for assessment or rehabilitation of in-service bridges, but states that "the engineer should make engineering judgements in the selection of rating and rehabilitation criteria for each bridge".

Each existing movable bridge is subject to unique conditions of use, site and environmental factors, and existing design limitations which require special consideration in the evaluation process The new Manual provides guidances to evaluators in making the essential decisions regarding nonaction/rehabilitation/replacement of existing movable bridges and their components in a manner consistent with public safety and good engineering practice.

Operating Criteria

Strict application of the AASHTO operating criteria for new design in assessing in-service movable bridges would result in many reliable operating existing bridges not meeting code. The object of this portion of the new Manual is to provide guidelines for applying engineering judgement to individual code provisions on a case-by-case basis so that functioning movable bridges can be preserved without the economic and operating impacts that would result from mandated compliance.

The application of the design specification provisions to an in-service bridge must be considered item-by-item based on the site specific conditions. Code provisions that address worker or public safety should, in general, be carried over to in-service bridges, even if retrofit is required for compliance. Code provisions that apply to reliability, durability, and efficiency of operations can be enforced at the engineer's option based on the performance demands of the facility. Similarly, code provisions relating to sizing components and allowable stresses provide a standard against which the actual component performance and working stresses can be compared as the basis for engineering judgement on the need for compliance.

Guidance is presented in the form of discussion of a number of design code provisions where compliance may be troublesome in rehabilitation designs. The parameters that form the basis for the discussion are site specific and include: number of openings (max/min, daily/monthly/annual); traffic and pedestrian volume; navigation volume, size and type; detour length; risk associated with non-compliance; consequences of a component failure; failure modes; and others.

Analysis

The new Manual provides guidance for the basic analysis of an in-service movable bridge under actual operating conditions. The object of such analysis is to verity that the functional systems of the movable bridge are capable of operating safely under imposed loads.

It is intended that this analysis be based on the methods presented in the AASHTO *Standard Specifications for Movable Highway Bridges* by adapting the criteria for new bridges to the analysis of in-service bridges. The analysis should evaluate the primary structural, mechanical, hydraulic and electrical components which together provide operational safety of the bridges in the closed position carrying traffic and in the open/operating position.

The recommended methodology to accomplish the analysis is a sequential evaluation procedure, including the following:

- Live Load Capacity (Inventory/Operating Rating)
- Performance Checks
- Systems Analysis

The Live Load Capacity can be determined using procedures described in the *AASHTO Manual for Condition Evaluation of Bridges*. The movable bridge in the closed position is treated similarly to a fixed bridge. Consideration must be given in the analysis to the effects of the counterweight, mechanical end lifts, shear locks and other support devices which modify support conditions as described in the design specifications.

A qualitative review of the performance characteristics of the movable bridge during operation can identify deficiencies. The intent of this performance check is to determine if the bridge is adequately providing its intended service. The bridge should be evaluated based on its ability to meet user needs in a safe and reasonably efficient manner. The objective is to qualitatively evaluate the structure's performance related to needs rather than to compare an aged but functioning design to current code criteria. To this end, the evaluator should review available information from plans, calculations, inspection data, logs, operator interviews, maintenance records and other pertinent documents in order to determine how well the bridge operates under the existing range of service conditions.

The performance check should identify operating faults. These faults may be chronic or may occur as a unique incidents or repetitive events in response to the same intermittent conditions. Quantitative procedures are needed to determine appropriate corrective action and priority.

A quantitative systems analysis should be performed on the primary structural, mechanical, hydraulic, and electrical components using the procedure, loads and load combinations specified in the design code. The Systems Analysis determines stress or other load effects on the existing components. The results are then compared to allowable values that consider the age and condition of the element.

Vulnerability to Extreme Events

Vulnerability analysis and assessment of an existing movable bridge to extreme events is a process of identifying potential modes of sudden collapse, evaluating the level of risk and the likelihood of the failure. Many failure risks identified for fixed highway bridges also apply to movable bridges such as: scour, vessel impact, vehicle overload, seismic events, and brittle fracture and fatigue cracking. In addition, movable bridges are susceptible to additional risks resulting from the failure of mechanical/electrical components and/or bridge operator error.

Vulnerability assessment should be performed by an engineer having substantial experience in movable bridge design and operation. Each movable bridge presents unique potential vulnerabilities with outcomes that very in degree of possible hazard based upon circumstances at the specific bridge site. The Manual provides guidelines on the minimum requirements for vulnerability studies, but does not include detailed analysis procedures.

MAINTENANCE

Movable bridges require a high level of continuing preventive maintenance to remain in reliable operating service. The AASHTO *Manual for Bridge Maintenance, 1987,* addresses the maintenance of the components of fixed structures and highway systems, but does not consider movable bridges. The Manual contains a program of preventive maintenance for structural, mechanical, hydraulic, and electrical systems based on the experiences of bridge owners, operating personnel, maintainers, movable bridge engineers, industry representatives, and specialists in the maintenance of movable bridges.

Procedures for development of maintenance and operating manuals for individual bridges are described. Frequency and degree of routine maintenance are defined for component types and sub-systems based on their probability of failure, life expectancy, and manufacturer's recommendations. Generalized recommended spare parts lists are included for electrical, hydraulic and mechanical components based upon analysis of component failure probability and anticipated lead time to obtain necessary replacements in the event of a failure.

CLOSING

A *Manual for Inspection, Evaluation and Maintenance of Movable Bridges* is a necessary addition to the body of standards which guide our efforts at preservating the nation's transportation infrastructure. The management of our inventory of aging in-service movable bridges in a manner consistent with public safety, operational reliability, fiscal responsibility, and good common sense is a goal that can be achieved.