Proposed Revisions to the AASHTO Movable Bridge Inspection, Evaluation and Maintenance Manual

FINAL REPORT

Prepared for
The National Cooperative Highway Research Program
Transportation Research Board
of
The National Academies

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WSP | Parsons Brinckerhoff
New York, NY
January 2016

ACKNOWLEDGMENT OF SPONSORSHIP

This work was sponsored by one or more of the following as noted:

☒ American Association of State Highway and Transportation Officials, in cooperation with the Federal Highway Administration, and was conducted in the National **Cooperative Highway Research Program**,

☐ Federal Transit Administration and was conducted in the **Transit Cooperative Research Program**,

☐ Federal Aviation Administration and was conducted in the **Airport Cooperative Research Program**,

☐ Research and Innovative Technology Administration and was conducted in the **National Cooperative Freight Research Program**,

☐ Pipeline and Hazardous Materials Safety Administration and was conducted in the **Hazardous Materials Cooperative Research Program**,

☐ Federal Railroad Administration and was conducted in the **National Cooperative Rail Research Program**,

which is administered by the Transportation Research Board of the National Academies.

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EXHIBITS

ACKNOWLEDGMENTS

The contractor, *WSP | Parsons Brinckerhoff, Inc*. conducted research under Project 14-32, *Proposed Revisions to the AASHTO Movable Bridge Inspection, Evaluation, and Maintenance Manual* for the T-8 Movable Bridges technical committee of the Highway Subcommittee on Bridges and Structures of the American Association of State Highway Transportation Officials (AASHTO), with funding provided through the National Cooperative Highway Research Program (NCHRP). The NCHRP is supported by annual voluntary contributions from the state Departments of Transportation. *Michael J. Abrahams P.E.* was the Principal Investigator and *Scott Snelling P.E.* was the Deputy Principal Investigator for this research project.

Key contributors included *Ahmad Hammad, Ph.D., P.E., S.E., Jamal Grainawi, P.E., S.E.,* and *Moussa Issa, Ph.D., P.E., S.E.* for structures; *Mike Elza, P.E.* for mechanical; and *Mark VanDeRee, P.E.,* and *Grace Patino* for electrical. A NCHRP technical working group guided the research efforts. The NCHRP Senior Program Officer, *Waseem Dekelbab, Ph.D., P.E., PMP,* managed the research project and guided the preparation of this report.

ABSTRACT

The objective of this research project was to update the American Association of State Highway Transportation Officials (AASHTO) *1998 Movable Bridge Inspection, Evaluation, and Maintenance Manual (1998 Manual)*. The *1998 Manual* no longer reflects the latest research and developments in bridge design and evaluation, and does not reflect current best practices for the inspection, evaluation, and maintenance of the nation's inventory of movable bridges.

The research team prepared a *2015 AASHTO Manual for Existing Bridges (2015 Manual)* that includes:

- Descriptions of new movable bridge elements.
- Clarifications regarding recommended types and extent of movable bridge inspections, frequency, and inspector qualifications.
- New "Suggested Inspection Forms."
- High-resolution photographs (replaced dozens of very poor quality images).
- Updated movable bridge inspection procedures such as: wire rope retirement criteria, suggested acceptable span balance conditions, electrical inspection of medium voltage equipment, and electrical insulation (Megger) testing.
- New electronic format with search, bookmark, and embedded hot-link functions.

The *2015 Manual* provides current, state-of-the-art guidance to owners and practitioners in the movable bridge industry. The *2015 Manual* intends to increase public safety by assisting owners and practitioners in developing and maintaining the nationwide inventory of movable bridges using the latest developments in movable bridge design, inspection, evaluation, and maintenance practices.

SUMMARY

The American Association of State Highway Transportation Officials' (AASHTO) *1998 Movable Bridge Inspection, Evaluation, and Maintenance (1998 Manual)* no longer reflects the latest research and developments in bridge design and evaluation, and does not reflect the current best practices for the inspection, evaluation, and maintenance of the nation's inventory of movable bridges.

The objective of this research project was to update the *1998 Manual*, especially regarding element-level bridge inspection practices. The proposed revisions are consistent with adopted AASHTO specifications and manuals, and the Federal Highway Administration (FHWA) *National Bridge Inspection Standards* and the *Bridge Inspector's Reference Manual*.

This research project included the following tasks:

- Phase I: Planning (approximately August 2013 to February 2014)
  - Task 1. Review the Relevant Literature and Practices
  - Task 2. Summarize Developments since *1998 Manual* and Conduct Gaps Analysis
  - Task 3. Prepare an Outline of Manual Sections Requiring Modification
  - Task 4. Prepare Interim Report No. 1
- Phase II: Revise Manual (approximately June 2014 to January 2015)
  - Task 5. Execute the Approved Work Plan to Revise the Manual
  - Task 6. Quantify the Potential Impact of the Proposed Revisions
  - Task 7. Develop Standardized Descriptions for Inventory and Inspection
  - Task 8. Prepare Interim Report No. 2
- Phase III: Prepare Final Report (approximately February 2015 to July 2015)
  - Task 9. Incorporate Review Comments and Prepare Ballot Items
  - Task 10. Prepare Final Report

CHAPTER 1

Background

The American Association of State Highway Transportation Officials' (AASHTO) *1998 Movable Bridge Inspection, Evaluation, and Maintenance Manual (1998 Manual)* is still available. However, since 1998, there have been many new developments in bridge design and analysis methodologies, as well as many developments in bridge inspection, evaluation, and maintenance that the *1998 Manual* did not include. For example, the AASHTO Highway Subcommittee on Bridges and Structures (HSCOBS) has adopted the AASHTO load and resistance factor design (LRFD) methodology contained in its *Bridge Design Specifications*, the *Manual for Bridge Evaluation*, and the AASHTO *Guide Manual for Bridge Element Inspection*. AASHTO also adopted a 2007 companion document, *LRFD Movable Highway Bridge Design Specifications*. There is a concurrent NCHRP Project 20-07, *Review of the AASHTO LRFD Movable Highway Bridge Design Specifications for Future Updates* (under a separate NCHRP contract).

1.1 Problem Statement and Research Objective

The *1998 Manual*, which predates all of these newer documents, no longer reflects the latest industry standards, practices, and developments in bridge design and evaluation. Therefore, the *1998 Manual* has lost much of its relevance in addressing the inspection, evaluation, and maintenance of the nation's inventory of movable bridges.

A more up-to-date and relevant document is needed to provide current, state-of-the-art guidance to owners and practitioners in the movable bridge industry. The objective of this research project was to produce a *2015 Manual for Existing Movable Bridges (2015 Manual)* that revises the previous *1998 Manual* and applies the latest developments in movable bridge design, inspection, evaluation, and maintenance practices. The result is a guidance document that will lead to a national inventory of movable bridges that is safer, in better condition, and better maintained.

The *2015 Manual* is consistent with adopted AASHTO specifications and manuals, the Federal Highway Administration (FHWA) *National Bridge Inspection Standards* and the *Bridge Inspector's Reference Manual*.

1.2 Research Scope and Tasks

This research project was carried out in three phases. Exhibit 1 illustrates the various tasks within the three phases described below:

- Phase I: Planning

– Task 1. Review the Relevant Literature and Practices

    - The research team reviewed relevant literature, specifications and manuals, currrent practices and other information available from bridge owners. This task investigated all engineering disciplines to determine the current state of knowledge and considered research findings from both domestic and foreign sources.

- Task 2. Summarize Developments since *1998 Manual* and Conduct Gaps Analysis
    - The research team compiled and summarized industry developments and identified gaps between the *1998 Manual* and current best practices.
- Task 3. Prepare an Outline of Manual Sections Requiring Modification
    - The research team prepared a detailed outline identifying the proposed areas of the *1998 Manual* that would require modification or deletion (e.g., combining Part 2 and Part 3 from the *1998 Manual*). The outline also identified those elements in the *1998 Manual* requiring additional new information (e.g., best practices for documentation and reporting of inventory, inspection, and maintenance). The NCHRP Project Panel reviewed the outline and the research team incorporated the panel's comments into the subsequent outline.
    - The research team corresponded each gap, development, and redundancy identified during Task 2 with the appropriate section of the outline and incorporated each into the *2015 Manual*.
- Task 4. Prepare Interim Report No. 1
    - The research team prepared Interim Report No. 1, which documents Tasks 1 through 3, and provided an updated work plan for the remainder of NCHRP Project 14-32. The updated plan described the process and rational for the work proposed for Phase II and Phase III.

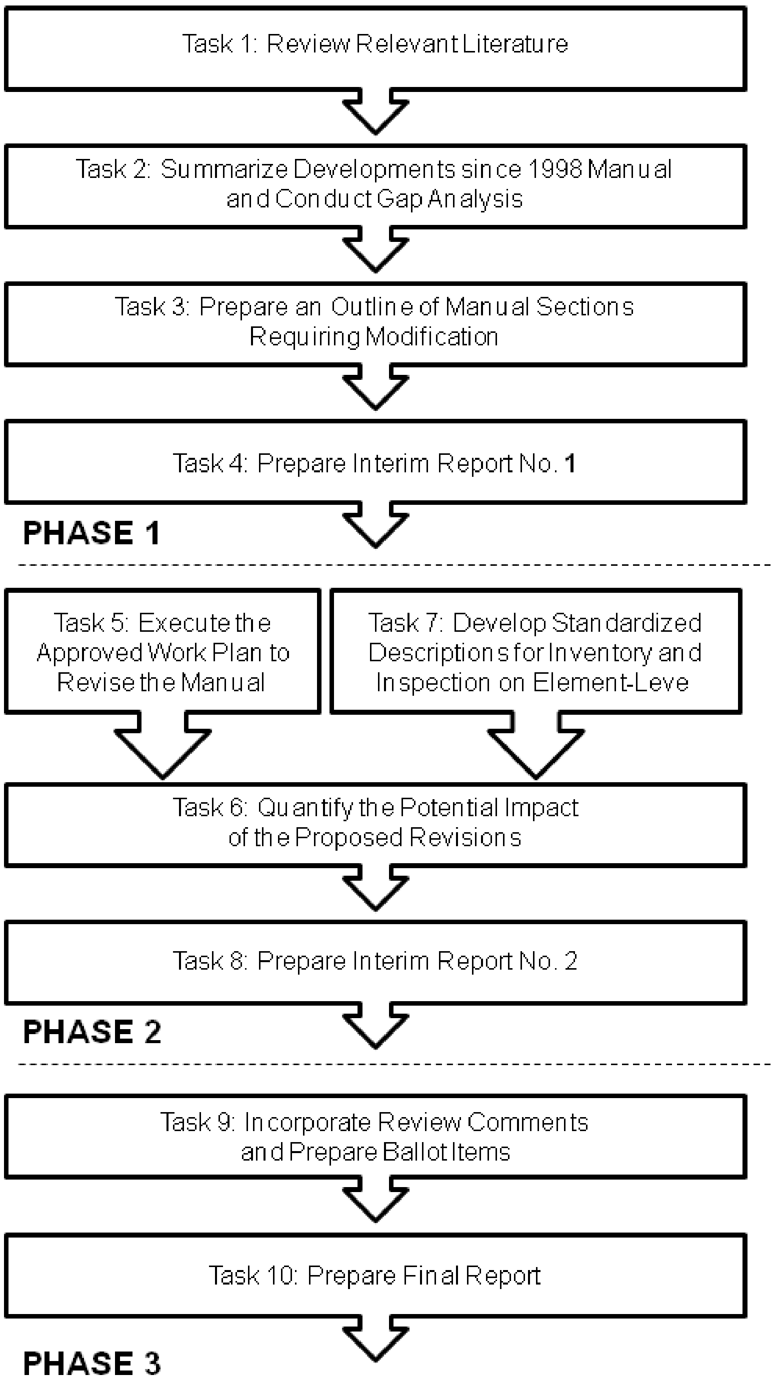
- Phase II: Revise Manual

- Task 5. Revise the Manual According to the Approved Work Plan
    - The research team revised the *1998 Manual* to be consistent with the detailed outline prepared under Task 3.
- Task 6. Quantify the Potential Impacts
    - The research team considered public safety, inspection procedures, and resources needed for implementation and quantified the potential impacts of the proposed revisions to the *1998 Manual*.
- Task 7. Develop Standardized Descriptions for Inventory and Inspection
    - The research team developed standarized descriptions for inventory and inspection based on element-level condition assessment methods.
- Task 8. Prepare Interim Report No. 2
    - The research team prepared Interim Report No. 2 which documented the results of Tasks 5 through 7.

- Phase III: Prepare Final Report

- Task 9. Incorporate Review Comments and Prepare Ballot Items
    - The research team incorporated the comments from the NCHRP Project Panel into the *2015 Manual* and prepared ballot items for the AASHTO Subcommittee on Bridges and Structures (SCOBS). The AASHTO SCOBS proposes to publish the ballot item version of the *2015* Manual.
- Task 10. Prepare Final Report

Exhibit 1. Research Scope and Tasks



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Source: WSP | Parsons Brinckerhoff

1.3 Deliverables

The research team prepared the following deliverables during this study:

- Task 1 – No stand-alone deliverable.
- Task 2 – No stand-alone deliverable.
- Task 3 – No stand-alone deliverable.
- Task 4 – Interim Report No. 1 documented results of Phase I (Tasks 1, 2, 3, and 7). Report submitted to the NCHRP Project Panel for review on February 7, 2014 and re-submitted on May 20, 2014.
- Task 5 – No stand-alone deliverable.
- Task 6 – No stand-alone deliverable.
- Task 7 – No stand-alone deliverable.
- Task 8 – Interim Report No. 2 documented results of Phase II (Tasks 5, 6, 7, and 8). Report submitted to the NCHRP Project Panel for review on January 30, 2015.
- Task 9 – Ballot item version of the draft *2015 Manual* submitted to the NCHRP Project Panel for review on June 22, 2015.
- Task 10 – Final Report (results of Phases I, II, and III) submitted to the NCHRP Project Panel for review on July 22, 2015. The second revision of the Final Report was submitted on August 4, 2015. The third revision of the Final Report was submitted on November 2, 2015.

CHAPTER 2

Research Approach

The research approach for this project included performing a literature review and industry outreach, and incorporating WSP | Parsons Brinckerhoff's extensive experince in the inspection and maintence of movable bridges.

2.1 Annotated Literature Review

The literature review included over 100 references, identified through searches of the Transportation Research International Documentation (TRID) database and known websites [e.g., the Federal Highway Administration (FHWA), the Urban and Regional Information Systems Association (URISA), the American Association of State Highway and Transportation Officials (AASHTO) GIS for Transportation (GIS-T) Conference Proceedings, etc.].

This section—which organizes the list of references according to the relevance of information—summarizes the major issues, concerns, and manner in which the *2015 Manual* addresses the issue(s).

1. AASHTO. *Movable Bridge Inspection, Evaluation, and Maintenance Manual* (AASHTO 1998). Washington, D.C.: American Association of State Highway and Transportation Officials, 1998.
   - The AASHTO *1998 Manual* consists of 606 pages organized in the following parts: 1.) General, 2.) Inspection, 3.) Evaluation, 4.) Maintenance, Appendices, Glossary, and Index. The *1998 Manual* discusses condition inspections of hydraulic equipment for movable bridges.
   - This manual no longer reflects the latest research and developments in movable bridge design and evaluation, and does not provide current guidance for the inspection, evaluation, and maintenance of the nation's inventory of highway movable bridges. In particular, the manual does not incorporate Load Resistance Factor Design (LRFD) reliability-based methods, nor does it incorporate element-level condition assessment methods. It also does not provide clear guidance regarding recommended scope and frequency of routine and in-depth mechanical and electrical inspections. However, the AASHTO *1998 Manual* does provide guidance regarding safety inspections of movable bridges and evaluation methods based on Working Stress Design (WSD).

2. FHWA. *Bridge Inspector's Manual for Movable Bridges* (FHWA 1977). Report No. FHWA-IP-7710. Washington, D.C.: United States Department of Transportation, 1977.
   - The AASHTO *1998 Manual* superseded and incorporated, without changes, much of the material in this FHWA *1977 Manual. However,* the AASHTO *1998 Manual* omitted some outdated information from the Inspection section of the FHWA *1977 Manual*. The 180-page FHWA 1977 *Manual* includes the following sections: Introduction; I. Movable Bridge Design and Operation; II. Movable Bridge Components; III. Special Machinery; IV. Inspection and Reporting; V. Electrical Equipment; VI. Movable Bridge Controls; VII. General Testing and Inspection; VIII. Movable Bridge Safety; Appendix; Glossary; Bibliography; and Index.
   - In general, practicing movable bridge inspectors appreciate this FHWA *1977 Manual* due to its succinctness, completeness, and clarity. Many movable bridge inspectors continue to use it as a primary reference, even though the AASHTO *1998 Manual* was intended to replace it. The

FHWA *1977 Manual* is often the first reference document provided to engineers that are newly joining the movable bridge industry, so that they can efficiently learn about the various movable bridge types, equipment, and major issues. One major omission is that there is no discussion regarding the condition inspection of hydraulic equipment on movable bridges.

3. U.S. Government. "National Bridge Inspection Standards" (NBIS), *Code of Federal Regulations*, Title 23, Part 650. U.S. Government Printing Office, Washington, D.C., 2004 with Final Rule in 2009.
   - The primary purpose of the NBIS is to locate and evaluate existing bridge deficiencies to ensure the safety of the traveling public. The NBIS do not address element-level bridge inspection methods. The NBIS define proper safety inspection and evaluation and apply to all structures defined as highway bridges located on all public roads. The standard includes coverage of complex bridges, which are defined to include "*movable, suspension, cable-stayed, and other bridges with unusual characteristics.*" The types of bridge inspections, each of which are applicable to movable bridges, include: routine, in-depth, fracture critical member, underwater, damage, and special inspections.
   - Section 650.311 "Inspection Frequency, (a) Routine Inspections. (1) Inspect each bridge at regular intervals not to exceed 24 months."
   - Section 650.313 "Inspection Procedures, (f) Complex Bridges. Identify specialized inspection procedures, and additional inspector training and experience required to inspect complex bridges. Inspect complex bridges according to those procedures." While not explicitly stated, section 650.313 provides the requirement for mechanical and electrical systems and components of movable bridges.

4. U.S. Government. *Moving Ahead for Progress in the 21st Century Act* (MAP-21) law, Section 1111, National Bridge and Tunnel Inventory and Inspection Standards Program. U.S. Government Printing Office, Washington, D.C., January, 2012.
   - MAP-21 is a bill "*to authorize funds for Federal-aid highways, highway safety programs, and transit programs, and for other purposes*." The bill also provides a framework and direction for investment in the nation's highways and railways for continued safety and serviceability. MAP-21 requires states to perform element-level inspections of all bridges on the National Highway System and report the results to the U.S. Secretary of Transportation within two years of the date of enactment of the legislation. The states are required to use this element-level inspection data to develop risk- and performance-based asset management plans to systematically prioritize bridge preventative maintenance, rehabilitation, and replacement. MAP-21 also requires a study on the benefits, cost effectiveness, and feasibility of requiring element-level data collection for bridges not on the National Highway System for submission to Congress.

5. FHWA. *Bridge Inspector's Reference Manual* (BIRM). Publication No. NHI 12-049. Washington, D.C.: United States Department of Transportation, 2002, revised 2012.
   - The 2,004-page BIRM serves as the primary reference for a three-week-long comprehensive training program on bridge inspection. The program consists of a one-week course, FHWA-NHI Course No 130054, "*Engineering Concepts for Bridge Inspectors*," and a two-week course, FHWA-NHI Course No 1350055, "*Safety Inspection of In-Service Bridges.*" Together, these two courses meet the definition of a comprehensive training program in bridge inspection as defined in the NBIS. The BIRM and the associated courses also address element-level bridge inspection methods.
   - This latest version of the BIRM presents updated bridge inspection techniques and equipment. Subjects include movable bridges, as well as other specialty topics including: culverts, fracture critical members, cable-stayed bridges, prestressed segmental bridges, underwater inspection, non-destructive evaluation, and critical findings. In particular, Chapter 16 – Complex Bridges includes the 68-page Section 16.2 on Movable Bridges. This section provides

an overview of major types of movable bridges, including mechanical and electrical equipment. Both the FHWA/NBI Component Condition Rating Guidelines and the AASHTO Element-Level Condition State Assessment are discussed with regards to movable bridge evaluation methods. In general, the BIRM is incomplete regarding mechanical and electrical movable bridge inspections of movable bridges and the associated element definitions.

6. AASHTO. *Manual for Bridge Element Inspection* (MBEI). Washington, D.C.: American Association of State Highway and Transportation Officials, 2013.
   - The 253-page MBEI was developed to improve upon and supersede the 2011 AASHTO *Guide Manual for Bridge Element Inspection*, as well as the Commonly Recognized (CoRe) Elements for Bridge Inspection. Element-level inspection goes beyond NBIS safety inspections and provides a means to inform performance-based decisions for bridge management.
   - This manual organizes bridge elements into three categories:
     - National Bridge Elements (NBEs) – This is the minimum element set to define safety and load capacity of bridges. They include decks, slabs, girders, columns, abutments, etc.
     - Bridge Management Elements (BMEs) – These are the elements that define secondary bridge components such as protective coatings.
     - Agency Developed Elements (ADEs) – The manual also supports the creation of agency-defined elements to ensure flexibility for bridge owners.
   - This manual does not include movable bridge specific elements.
   - For mechanical, electrical, and hydraulic movable bridge components, individual bridge owners may choose to create their own ADEs. As of 2013, several states have created movable bridge specific ADEs, including Louisiana, Florida, Washington, and Maryland.
   - Element conditions are categorized as: 1-Good, 2-Fair, 3-Poor, and 4-Severe. Conversely, NBIS safety inspection component condition rating codes range from 9 to 0 where 9 is the best rating possible.

7. FHWA. *National Bridge Inventory* (NBI). Washington, D.C.: United States Department of Transportation, 2014.
   - Exhibit 2 shows the number of movable highway bridges by state and size (largest to smallest). The research team downloaded the data from www.fhwa.dot.gov/bridge/struct.cfm on May 13, 2015. The total number of movable bridges inventoried in the United States is 831 of which 205 are structurally deficient, 332 are functionally obsolete, and 537 are deficient structural types. The research team did not consider the year built or the year reconstructed when calculating the number of deficient bridges.

Exhibit 2. Number of Movable Highway Bridges by State and Size

	Movable-Lift	Movable - Bascule	Movable - Swing	Total Movables
Total	184	451	196	831
Louisiana	46	14	84	144
Florida	3	131	9	143
New York	25	33	11	69
Illinois	4	51	2	57
Washington	32	13	5	50
New Jersey	11	29	9	49
Wisconsin	8	34	0	42
California	5	16	16	37
Maryland	0	22	3	25
Massachusetts	1	18	6	25
Michigan	1	20	3	24
Oregon	9	8	3	20
Virginia	4	10	5	19
Maine	10	1	5	16
North Carolina	1	7	5	13
Connecticut	2	7	4	13
Texas	7	1	5	13
Delaware	0	9	2	11
Ohio	5	5	1	11
Mississippi	2	5	3	10
South Carolina	0	3	6	9
Minnesota	2	1	2	5
Georgia	0	3	1	4
New Hampshire	2	2	0	4
Indiana	0	3	0	3
District of Columbia	0	1	1	2
Iowa	0	0	2	2
Pennsylvania	0	2	0	2
Alabama	1	0	0	1
Hawaii	1	0	0	1
Idaho	1	0	0	1
Rhode Island	0	0	1	1
Tennessee	0	1	0	1
Vermont	0	1	0	1
Puerto Rico	1	0	0	1

Source: Federal Highway Administration

8. The following states do not have any reported movable highway bridges: Alaska, Arizona, Arkansas, Colorado, Kansas, *Kentucky*, Missouri, Montana, Nebraska, Nevada, New Mexico, North Dakota, Oklahoma, South Dakota, Utah, West Virginia, and Wyoming.

9. Louisiana Department of Transportation and Development (LADOTD). *Pontis Inspection Manual*. Baton Rouge, LA: LADOTD, 2009.
   - The LADOTD manages its movable bridges with custom mechanical and electrical elements using Pontis software. The LA-DOTD's inventory includes 101 movable bridges (seven bascule, 49 swing, 37 vertical-lift, and eight pontoon) on the federal-aid highway system and an additional 42 off-system movable bridges. The 780-page Pontis manual includes the 129-page "Part 3: Inspection of Movable Bridges." Detailed discussion regarding the inspection of hydraulic equipment is included, one of the few such references.
   - "Part 1: Element Guide" also includes the following customized movable bridge element definitions: 540 open gearing, 541 speed reducers, 542 shafts, 543 shaft bearings, 544 brakes, 545 emergency drive and backup power system, 547 hydraulic power units, 548 hydraulic piping system, 549 hydraulic cylinders/motors/rotary actuators, 550 machinery base, span locks/toe locks/heel stops/tail locks, 560 span locks/toe locks heel stops/tail locks, 561 live load shoes/wedges/strike plates/buffer cylinders, 562 counterweight support, 563 access ladder and platforms, 564 counterweight, 565 trunnion-straight/curved rack, 570 transformers and thyristors, 571 submarine cable, 572 conduit and junction boxes, 573 programmable logic controllers, 574 control console, 580 navigational light system, 581 cables-vertical lift, 582 bridge specific element (lift), 583 bridge specific element (swing), 584 bridge specific element (pontoon), 586 bridge specific element (bascule), 590 barriers – movable bridges, 591 traffic warning gates – movable bridges, 592 traffic signals, 585 fender system/pier protection.
   - "The personnel who perform inspection of movable structures should have experience beyond that, which may be sufficient for the inspection of fixed bridges. This may seem obvious for the inspection of electrical, mechanical, and hydraulic equipment. Also, it is true for the inspection of the structural components of a movable structure."

10. Florida Department of Transportation (FDOT). *Bridge Inspector's Field Guide of Structural Elements*. Tallahassee, FL: Florida Department of Transportation, 2008.
    - FDOT manages its movable bridges with custom mechanical and electrical elements using Pontis software. FDOT's inventory of 98 movable bridges includes three lift bridges, 94 bascule bridges, and one swing bridge. The 148-page field guide includes 26 pages of definitions for movable bridge mechanical and electrical elements. FDOT customized the Pontis software to include the following mechanical and electrical element definitions: drive system; gears; shaft bearings and couplings; brakes; hydraulic power units; piping and cylinders; control and interlock system; transformers/thyristors; submarine cables; programmable logic controllers and control consoles; miscellaneous and traffic control elements; navigational light system; operator facilities; resistance and warning gates; traffic signals.

11. Washington State Department of Transportation (WSDOT). *BridgeWorks Movable Elements*. Olympia, WA: WSDOT, 2006.
    - WSDOT has done element level inspections of mechanical and electrical components since 2006 using customized element definitions and in-house software called BridgeWorks. A hierarchy is established to categorize the elements (approximate quantity of 250) according to discipline (Mechanical or Electrical) and system. For movable bridges, within the mechanical discipline, there are the following systems: span drive machinery; center lock machinery; end lock machinery; span support systems; wedge and end lift machinery; counterweights; traffic control and pedestrian gates; and miscellaneous. Within the electrical discipline, there are the following systems: power distribution and grounding; span drives and lock drives; control system; wire, conduit and junction boxes; traffic and pedestrian control; navigation control; and

miscellaneous. WSDOT's BridgeWorks program also includes custom mechanical and electrical systems and elements for tunnels, suspension bridge maintenance travelers, and floating bridges.

12. Maryland State Highway Administration (MDSHA). *Pontis Element Data Collection Manual*. Andover, MD: MDSHA, 2003.
    - This 79-page manual includes one page for Movable Bridge Machinery, which is designated as Non-CoRe with element number 349. Inspectors are directed to "Make comments in the verbiage under the appropriate element number/letter combination: 34a Trunnion Bearings, 34b Gears, 34c Couplings, 34d Motors, 34e Brakes, 34f Auxiliary Brakes, 34g Hand Crank, 34h Speed Reducers, 34i Differential, 34j Bearings, 34k Central Locks, 34l Load Supports, 34m Console, 34n Machinery Room, 34o Tenders House, 34p Electrical System, 34q Counterweight, 34r Pits, 34s Shaft Alignment, 34t Cleanliness." Note that the electrical system is considered a sub-element of movable bridge machinery.

13. AASHTO. *AASHTOWare Bridge Management Software* (BrM) http://aashtowarebridge.com/. Washington, D.C.: American Association of State Highway and Transportation Officials, 2013.
    - Formerly known as Pontis 5.2, AASHTOWare Bridge Management Software (BrM) accommodates the new element definitions defined in the AASHTO *Guide Manual for Bridge Element Inspection*.

14. AASHTO. *The Manual for Bridge Evaluation* (MBE), 2nd Edition. Washington, D.C.: American Association of State Highway and Transportation Officials, 2011.
    - The MBE serves as a standard and provides uniformity in the procedures and policies for determining the physical condition, maintenance needs, and load capacity of the nation's highway bridges. The MBE has been developed to assist bridge owners by establishing inspection procedures and evaluation practices that meet the *National Bridge Inspection Standards* (safety-type inspections). In 2011, a new one-page sub-section titled 2.4.3 Element Level Inspection was added to acknowledge and reference the AASHTO *Manual for Bridge Element Inspection*. The 615-page MBE has the following eight sections: Introduction, Bridge Files (Records), Bridge Management Systems, Inspections, Material Testing, Load Rating, Fatigue Evaluation of Steel Bridges, Nondestructive Load Testing, and Illustrative Examples.
    - The MBE indicates "Inspections should not be confined to searching for defects which may exist, but should include anticipating incipient problems. Therefore, inspections are performed in order to develop both preventative as well as corrective maintenance programs."
    - The MBE does not provide guidance regarding movable bridges, but directs readers to the AASHTO *Movable Bridge Inspection, Evaluation, and Maintenance Manual*. While the MBE does not apply to mechanical or electrical components, it can be used to evaluate movable bridge structures. The MBE uses Load and Resistance Factor Rating (LRFR) and Load and Resistance Factor Design (LRFD) probability-based methods for structural evaluation.

15. American Railway Engineering and Maintenance-of-Way Association (AREMA). *Bridge Inspection Handbook*. Lanham, MD: AREMA, 2008.
    - Of particular interest are the 22-page Chapter 5 "Bridge Nomenclature", which includes movable bridge nomenclature, and the 47-page Chapter 10 "Movable Bridges".
    - Regarding condition rating systems, Chapter 5 of the AREMA handbook states: "In addition to detailed notes describing specific conditions or deficiencies, it is common practice to assign a condition rating." "Condition rating systems can be very complex or very simple." "Rating system should be tailored to the needs of the individual railroad...and clearly defined…with each inspection report" "An example of a relatively straightforward system would be: P1-Requires immediate attention, P2-Poor condition, keep under observation until repaired, P3-Fair condition, should be monitored, P4-Item noted, but of no concern."
    - Chapter 10 is divided into general inspection information followed by sections on Operator's House, Swing Bridge, Bascule Bridge, Vertical Lift Bridge, Electrical Inspection, Mechanical

Inspection, Lubrication, Signal System, and Fenders and Dolphins. The sections include information on track, safety, and signal and communications. "*By their nature of being movable, these bridges require structural, mechanical, and electrical attention*."

– In general, the AREMA handbook provides a concise overview text and photographs of systems and equipment found on movable bridges. The handbook also provides useful lists of common problems or types of deterioration associated with each movable bridge component or system.

16. Canadian Standards Association. *Canadian Highway Bridge Design Code*, CAN/CSA-S6-06 including Supplement Nos. 1, 2 and 3. Toronto, Ontario, Canada: CSA, 2013.
    – Section 13 Movable Bridges "specifies the requirements for the design, inspection, maintenance, construction, and rehabilitation of conventional movable highway bridges, i.e. bascule (including rolling lift), swing, and vertical lift bridges, and deals primarily with the components involved in the operation of such bridges." Of the 1,078-page code, the 68 pages in Section 13 address movable bridges–primarily design issues–and only the ¼-page-long sub-section 13.14 addresses the inspection of movable bridges.
    – Sub-section 13.14 indicates "The [design] Engineer shall specify the frequency and types of inspection recommended for long-term durability and trouble-free operation of the movable bridge." At a minimum, this includes "(a) annual visual and aural inspection at the start of each season and (b) comprehensive inspection at not more than two-year intervals. The comprehensive inspections shall include structural safety, wear and alignment of mechanical components, and any breaks, defects, or hot spots in the electrical system. All inspections shall be followed by a written report."

17. U.K. Department of Transport. "The Assessment of Highway Bridges and Structures," *Design Manual for Roads and Bridges*, Volume 3, Section 3, Part 4. London, England, 2001.
    – This standard gives criteria for the assessment of highway bridges and structures in the United Kingdom. However, there is no discussion regarding movable bridges or mechanical and electrical equipment.

18. Eurocode 3. Part 2-1 BS EN 1993-2, *Design of Steel Bridges*, 2008.
    – This code specifies rules for the structural design of steel bridges and steel elements of composite bridges and bridges mainly of other construction materials. There is no explicit discussion of movable bridges, but the code may be applied to the design of movable bridge structures. The new structural Eurocodes offer increased economy in design over most existing codes of practice. However, the assessment of existing structures is specifically outside the scope of the Eurocodes.

19. FHWA. *Bridge Evaluation Quality Assurance in Europe*. Report No. FHWA-PL-08-016. Washington, D.C.: United States Department of Transportation, 2008.
    – This report, the result of cooperation between AASHTO, FHWA, and the National Cooperative Highway Research Program (NCHRP), presents European bridge inspection practices related to quality assurance. "*The scan team found that European agencies use their bridge inspection programs to insure highway user safety, meet durability and serviceability expectations, and enhance capital investment decisions*." In particular, the report notes that Sweden and Germany require mechanical and electrical inspections of movable bridges.

20. NCHRP. *Bridge Inspection Practices*. Synthesis 375. Washington, D.C.: Transportation Research Board, 2007.
    – This synthesis report includes information on bridge inspection practices from 40 state transportation departments and from roads agencies in eight nations (Denmark, France, Finland, Germany, Norway, South Africa, Sweden, and the United Kingdom), as well as several provincial and municipal transport agencies in Canada. In particular, the report noted that Finland uses

specialists to perform special movable bridge inspections and maintenance on an annual basis and that the Canadian province of Ontario inspects its movable bridges at 24-month intervals. [Note: Ontario has since updated the movable bridge inspection interval to 12 months.]

– Of the 32 state agencies that responded to the NCHRP questionnaire regarding complex bridges, 14 state agencies (44 percent) mentioned performing inspections of movable bridges.

– Exhibit 3 summarizes the scope and frequency of movable bridge inspections performed by 10 state departments of transportation.

Exhibit 3. Routine Inspections of Movable Bridges

State Department of Transportation	Name	Scope	Interval	Note
Alabama	Special C – Suspension and Movable Bridges	Entire	N/A	N/A
Florida	Movable Bridge	Operation	12 Months	Poor condition
Maryland	Drawbridge	Equipment		Team has electrical engineer and mechanical engineer
Michigan	Movable Equipment, Routine	Equipment	72 Months	Movable bridge equipment
New Jersey	Movable Bridge - Type I Movable Bridge - Type II Movable Bridge - Type III	Equipment	N/A	In-depth electrical, mechanical equipment inspection Medium-depth electrical, mechanical equipment inspection Visually monitor operation of electrical, mechanical equipment
North Carolina	Movable Span Inspections	Entire	12/ 24 Months	A special inspection crew and trained electricians are responsible for conducting inspections.
Oregon	Movable Bridge	Entire	12 Months	Cursory inspections for operation.
Virginia	Movable Bridge			Special team having an electrical engineer, a bridge safety engineer and a mechanical engineer
Washington	Movable Bridge Operation	Operation	1 Month	Trial opening of span
	Special Feature - Movable		12 Months	Inspector has special training or experience
	Movable Bridge Equipment	Equipment	72 Months	In-depth for electrical and mechanical equipment
Wisconsin	Movable Bridge	N/A	12 Months	N/A

Source: NCHRP, *Bridge Inspection Practices*. Synthesis 375.
N/A = Not Applicable

21. Hollingsworth, B. *Standardizing Mechanical Inspections of Movable Bridges*. St. Petersburg, FL: Heavy Movable Structures, 3rd Biennial Symposium, 1990.

– This paper discusses both the technical and managerial considerations and benefits if mechanical inspections of movable bridges were to be standardized. Opportunities for standardization include inspection procedures, scopes, and forms. Mr. Hollingsworth concludes that "*Owners and consultants should work together in developing standard machinery inspection programs to better protect and serve the traveling public.*" Twenty-three years after publication,

much of the work proposed in this paper towards standardization of mechanical movable bridge inspections remains to be completed and the issues discussed remain relevant and insightful.

22. Birnstiel, C. *A Proposed Scope for Movable Highway Bridge Machinery Inspection*. St. Petersburg, FL: Heavy Movable Structures, 3rd Biennial Symposium, 1990.
    – This technical paper proposes a "scope-of-work description for the inspection of mechanical and *electrical* components and systems of movable highway bridges…, especially for the biennial inspection program." "Because the mechanical and electrical machinery as installed differs so much from bridge to bridge, the scope cannot simultaneously be completely general and all inclusive." "The scope statement is supplemented by inspection checklists, report format, and proposed guidelines for numerical rating of the mechanical and electrical equipment." Twenty-three years after publication, much of the work proposed in the paper towards standardization of mechanical and electrical movable bridge inspections remains to be completed and the issues and draft solutions discussed in this paper remain relevant and insightful.

23. Parsons Brinckerhoff. *Bridge Inspection and Rehabilitation – A Practical Guide*, New York, New York: John Wiley & Sons, Inc., 1993.
    – Of particular interest is the 23-page Chapter 7, Movable Bridges, by Michael J. Abrahams. The chapter covers the inspection and rehabilitation of movable bridges. Although reference is made to structural items, the emphasis is on the various components particular to movable bridges: the operating machinery, controls, and power. The discussion treats movable highway bridges in particular, but is also applicable to railway bridges. While this chapter pre-dates the adoption by AASHTO of element-level inspection and LRFD evaluation methods, it remains a useful reference.

24. Abrahams, Snelling, VanDeRee. *Bridge Engineering Handbook*, 2nd Edition, Superstructure Design, Chapter 9 Movable Bridges, 2014 (publication pending).
    – This chapter provides a broad overview of the types of movable bridges in the United States, including typical mechanical and electrical equipment. The 34-page chapter also addresses typical design, maintenance, and inspection issues related to movable bridges. The 2nd edition is an update of Chapter 21, Movable Bridges, in the 2000 *Bridge Engineering Handbook*, authored by Michael J. Abrahams.

25. Birnstiel, C. *ICE Manual of Bridge Engineering*, Chapter Movable Bridges, London, England: Institution of Civil Engineers, 2008.
    – This chapter provides "an elementary introduction to movable bridge engineering. Movable bridges are classified and various types are described and illustrated with examples built in the United Kingdom, Europe, and America. Span drive and stabilizing machinery is treated and the interdependency between the superstructure, mechanical and hydraulic machinery, and electrical controls is emphasized. A movable bridge is a machine and, as such, dynamic effects [are] considered. Major design issues, including safety and redundancy, are discussed as well as design specifications and future trends in the architecture and engineering of movable bridges."

26. Wire Rope Technical Board (WRTB). *Wire Rope User's Manual 4th Edition*. Alexandria, VA: WRTB, 2005.
    – The *Wire Rope User's Manual* is a comprehensive source covering areas such as wire rope components; identification and construction; handling and installation; operation, inspection and maintenance; and physical properties. The 160-page manual provides detailed guidance with regards to wire rope inspection procedures and rope retirement criteria, as well as guidance related to the inspection of the grooves of sheaves and drums. Wire ropes are typically a critical component of vertical lift type movable bridges, as well as occasionally being used on other specialty types of movable bridges, such as retractile.

27. American National Standards Institute (ANSI)/American Gear Manufacturers Association (AGMA). *Appearance of Gear Teeth – Terminology of Wear and Failure*. ANSI/AGMA 1010-E95. Alexandria, VA: ANSI/AGMA, 1995 (Revised 2004).
    - This 68-page nomenclature standard identifies and describes the classes of common gear failures and illustrates, with color photographs, degrees of deterioration.

28. SKF Group. *Bearing Failures and their Causes* PI-401. Goteborg, Sweden: SKF Group, 1999.
    - This 44-page reference identifies and describes the classes of common roller bearing failures and illustrates, with color photographs, degrees of deterioration. It also identifies the causes of the failure and recommended corrective actions. SKF, the author and publisher, is a major manufacturer of roller bearings, also known as anti-friction bearings or ball bearings.

29. Wisconsin Department of Transportation (WIDOT). *Structure Inspection Manual*. Madison, WI: WIDOT, 2011.
    - The Wisconsin inventory includes 52 movable highway bridges, which are state and locally owned. The 140-page Part 3: Inspection of Movable Bridges is nearly identical, including the section on the condition inspection of hydraulic equipment, to that found in the LADOTD manual. However, unlike Louisiana, Wisconsin does not perform element-level inspections for its movable bridges. Unique to the Wisconsin manual is an appendix with forms that can be used in the field to guide the mechanical inspection and submitted as the inspection report.

30. Indiana Department of Transportation (INDOT). *Bridge Inspection Manual*. Indianapolis, IN: IDOT, 2010.
    - This manual covers all areas related to bridge inspection. Part 5: Movable Bridges includes six chapters covering the inspection of movable bridges of all types. Chapter 1: General; Chapter 2: Bascule Bridges; Chapter 3: Functional Systems; Chapter 4: Electrical Systems; Chapter 5: Hydraulic Systems; and Chapter 6: Mechanical Systems. Of particular interest is Chapter 5: Hydraulic Systems, since it is one of the few detailed references regarding the condition inspection (as opposed to shop commissioning inspection) of movable bridge hydraulic equipment.

31. International Electrical Testing Association (ANSI/NETA). Maintenance Testing Specifications for Electrical Power Distribution Equipment and Systems. Portage, MI: NETA. 2011.
    - The NETA *Maintenance Testing Specifications for Electrical Power Distribution Equipment and Systems* was developed for use by those agencies responsible for the continued operation of existing electrical systems and equipment. It guides them in specifying and performing the necessary tests to ensure that these systems and apparatus perform satisfactorily, minimizing downtime and maximizing life expectancy.

32. FHWA. *Manual on Uniform Traffic Control Devices for Streets and Highways* (MUTCD). Washington, D.C.: U.S. Department of Transportation. 2009, (Revised 2012).
    - The MUTCD defines the standards used by road managers nationwide to install and maintain traffic control devices on all public streets, highways, bikeways, and private roads open to public traffic. The MUTCD is relevant to movable bridges because roadway traffic must be safely stopped when the span is opened, such as for a navigable vessel. Mechanical and electrical movable bridge inspections often include the traffic control devices, such as warning and barrier gates in the scope of work. Many older, existing movable bridges have traffic control devices that do not comply with the MUTCD and may present traffic safety issues.

33. FHWA. R*ecording and Coding Guide for the Structure Inventory and Appraisal of the Nation's Bridges*, Report No. FHWA-PD-96-001. Washington D.C.: Office of Engineering, Bridge Division, Bridge Management Branch. December 1995 (Revised 2000).

– This 124-page guide was prepared for use by federal, state, and other agencies in recording and coding the data elements that will comprise the National Bridge Inventory database. The coded items in this guide are considered to be an integral part of the database that can be used to meet several federal reporting requirements, as well as part of the states' needs. These requirements are set forth in the *National Bridge Inspection Standards* (23 CFR 650.3). The guide is incomplete with regards to mechanical and electrical movable bridge inspections of movable bridges and the associated element definitions.

34. Oregon Department of Transportation (ODOT). *Bridge Inspection Program Manual*. ODOT, 2013.
    – This manual covers all areas related to bridge inspection including bridge condition ratings using two quite different systems: FHWA Rating Codes and the AASHTO Element Rating Codes. Inspection of Movable Bridges is covered in Chapters 14, 18, 25, and 26. ODOT currently performs an annual cursory inspection on all electrical and mechanical drawbridge operational systems, under the state's jurisdiction. This annual operational inspection is followed by a more in-depth inspection, at least every six years.

35. Koglin, T. *Movable Bridge Engineering*. New York: John Wiley & Sons, 2003.
    – This reference book provides an overview of the design, inspection and maintenance of movable bridges in the United States.

36. Hool, G. and Kinne, W.S. *Movable and Long Span Steel Bridges*, New York: McGraw-Hill Book Company, 1924 (1st Edition), 1943.
    – This historic reference book provides an overview of the design of movable bridges.

37. Hovey, O.E. *Movable Bridges*, Volumes I and II, New York: John Wiley & Sons, 1927.
    – This historic reference book provides an overview of the design of movable bridges.

38. Minervino, C. *Development of a Manual for Inspection, Evaluation and Maintenance of Movable Bridges*, St. Petersburg, FL: Heavy Movable Structures, 6th Biennial Symposium, 1996.
    – This technical paper provides an overview of the development process under NCHRP Project 10-43 for the *AASHTO Manual for Inspection, Evaluation, and Maintenance of Movable Bridges* during its preparation and until two years prior to its final publication. The research portion of NCHRP Project 14-32 included compiling 300 documents and grouping them into two categories regarding their use in the *Updated Manual*: source material and reference lists. The research team also distributed questionnaires to survey state and city Departments of Transportation on current practices and important issues related to movable bridges.

39. Catbas, F.N., Malekzadeh, M. and Khuc, T. *Movable Bridge Maintenance Monitoring*. Orlando, FL: Florida Department of Transportation, 2013.
    – This technical report summarizes research in which a representative movable bridge in Florida District 4 was outfitted with a structural health monitoring system. The selected bridge was a double leaf bascule bridge. The structural health monitoring system used approximately 200+ sensors on critical structural, mechanical, and electrical components, as well as weather and traffic. Failures of key components were simulated and statistical analysis techniques were used to aid the filtering and interpretation of the collected data.

40. Catbas, F.N., Gul, M., Gokce, H.B., Frangopol, D. and Grimmelsman, K.A. Critical Issues, *Condition Assessment and Monitoring of Heavy Movable Structures: Emphasis on Movable Bridges*. Structure and Infrastructure Engineering Journal, 2013.
    – This journal article discusses considerations related to applying structural health monitoring to mechanical and structural components of movable bridges.

41. Gokce, H.B., Gul, M., and Catbas, F.N. *Implementation of Structural Health Monitoring*, Washington, D.C.: Transportation Research Board, 2011.

– This paper discusses the application of long-term structural health monitoring for movable bridges. It analyzes asset management data and prioritizes the components and types of deterioration or failures to which movable bridge structural health monitoring systems should be targeted.

42. New York State Department of Transportation (NYSDOT). *Crane Preventative Maintenance Checklist*. Albany: NYSDOT, accessed 2013.
    – This three-page checklist identifies items that should be inspected during a typical preventative maintenance check of a crane. Items on the checklist include structural, mechanical, hydraulic, and electrical components and assemblies.

43. Crane Certification Association of America (CCAA). *Overhead Crane Inspection and Preventative Maintenance Checklist*. Novi, MI: CCAA, 2013.
    – This one-page checklist provides the requirements for visual and operational inspection of overhead cranes. This industry-standard checklist complies with, but goes beyond, the "periodic inspections" required by federal regulation in OSHA CFR 1910.179. The CCAA checklist includes approximately 75 inspection items, including structural, mechanical, and electrical components and assemblies.

44. Hoist Manufacturers Institute (HMI). *Hoist Inspection and Hoist Maintenance Personnel Manual*. Charlotte, NC: HMI, 2002.
    – This 85-page manual was prepared by the HMI to provide information and suggestions for hoist inspection and maintenance personnel. The manual is based upon the requirements of ASME B30.16 *Safety Standard for Overhead Hoists* (Underhung). The manual includes chapters describing the various types of hoists, hoist components, and the motions of which each is capable, as well as appendices for a glossary of various hoist terms, hoist reference documents and standards, and hoist inspection report forms (templates). Chapters provide procedures on the various types of inspections, maintenance procedures, and inspection reports. Inspection types include: hoist inspection, daily or prestart hoist inspection, frequent and periodic hoist inspections, hook inspection, wire rope inspection, load chain inspection, electrical components inspection, hoist braking system inspection, and trolley inspection.

45. Rehm, Kelley. *Bridge Inspection: Primary Element*, Arlington Heights, IL: Roads and Bridges. 2013.
    – This magazine article, authored by AASHTO's program manager for bridges and structures, provides an overview of the "continuing efforts to help ensure safe bridges for the traveling public by advancing more inclusive ways to look at bridge health." It states that "Bridge-element inspection methods are now recognized as the new accepted national standard for the National Highway System by inclusion in the Moving Ahead for Progress in the 21st Century (MAP-21) legislation."

46. NCHRP. *A Strategic Plan for Bridges and Structures*, Washington, D.C.: Transportation Research Board. 2013.
    – This Final Report summarizes the strategic plan for highway bridges and structures of the AASHTO Subcommittee on Bridges and Structures (SCOBS). The strategic plan helps the bridge community to identify, prioritize, and conduct research in compliance with MAP-21.
    – The objectives in prioritized order are to: 1.) Extend Bridge Service Life, 2.) Assess Bridge Condition, 3.) Maintain and Enhance Knowledgeable Workforce, 4.) Maintain and Enhance AASHTO Specifications, 5.) Accelerate Bridge Delivery and Construction, 6.) Optimize Structural Systems, 7.) Model and Manage Information Intelligently, and 8.) Contribute to National Policy.

2.2 Industry Outreach

The research team conducted industry outreach by presenting the proposed new movable bridge element-level definitions and proposed manual revisions at conferences and soliciting industry comments for incorporation into the *2015 Manual*. The research team presented its findings at the following conferences:

- AASHTO Subcommittee on Bridges and Structures, Columbus, Ohio on June 22 to 26, 2014.
- Heavy Movable Structures Symposium, New Orleans, Louisiana on September 18, 2014.
- AASHTO Subcommittee on Bridges and Structures, Saratoga, New York on April 20, 2015.
- Pacific Northwest Bridge Inspectors' Conference in Portland, Oregon on April 7, 2015.
- Southeast Bridge Preservation Partnership in Montgomery, Alabama on April 13, 2015.

CHAPTER 3

Findings and Applications

The research team synthesized the information gathered and organized the “lessons learned” into three parts: 1.) “gaps” or differences between the *1998 Manual* and current best practices, 2.) redundancies in the *1998 Manual*, and 3.) industry developments since the *1998 Manual*. The research team used this information as a basis for revising the *2015 Manual*. The next sections summarize the key findings and applications.

3.1 Gaps Between the 1998 Manual and Current Best Practices

The research team identified differences (i.e., “gaps”) between current best practices and information contained in the *1998 Manual*. The research team intended the *2015 Manual* to be as complete and updated document as possible. However, some gaps were not addressed because they were beyond the scope of work for the research project. Section 4.4 of this document highlights items for future research.

Compared with current best practices, the *1998 Manual* contains the following gaps:

- Inadequate element condition definitions.
- Inconsistent structural, electrical, and mechanical inspection methods and scopes.
- Insufficient information regarding hydraulic machinery inspection and standards.
- Lack of guidance regarding emergency inspections after an extreme event.
- Need to include wire rope retirement criteria, similar to that found in ANSI elevator specifications and the CFR for mining equipment. Clarify retirement criteria for other mechanical or electrical elements such as bearings, gearing, limit switches, etc.
- Need to clarify requirements regarding when drive machinery should be load-rated for motor sizing, brake settings, and machinery torque capacity.
- Need to clarify requirements regarding the numerical condition rating associated with bearing clearance measurements, gear tooth wear measurements, visual condition of roller bearings, and visual condition of gearing, etc.
- Need to better define movable span balance. While Section 2.2.2.2, Balance System, in the manual discusses span balance in general terms, the manual lacks clear guidance regarding acceptable conditions for balance, both while closed and over the full range of motion of the movable span. The design standard specification also provides some guidance on balance but only in the fully closed position.
- Need to incorporate the NETA maintenance testing standards for electrical insulation resistance testing of conductors and windings.
- Need to expand electrical testing methods to provide motor winding polarization indexes (PI) and dielectric absorption rations (DAR), per the NETA maintenance testing specification.
- Need to address normalization of values for ambient temperatures (although the *1998 Manual* addresses the need to track electrical insulation resistance trending). Normalization is important when evaluating the electrical insulation resistance trending.
- Need to address medium voltage–above 600 V to 50 kV–circuits and equipment which the *1998 Manual* does not thoroughly address. The manual should incorporate advancements in non-

destructive testing technology (e.g., the use of partial discharge testing to determine insulation integrity of medium voltage cables and equipment).

- Need to better determine qualifications of the inspectors to ensure safety, welfare, and the public's implied consent.

3.2 Redundancies in the 1998 Manual

The *1998 Manual* contains several redundancies:

- Section 2.5, Mechanical Components, repeats similar information in both illustrations and text.
- Figure 2.5.4-1 and Figure 2.5.4.1.1-3 are identical.
- Figure 2.5.5.2.2.3-1 and Figure 2.5.5.2.6-3, both present similar chain-type couplings. However, chain-type couplings are uncommon, not recommended by AASHTO, and should warrant only tangential discussion. Regarding this example, the *2015 Manual* does not include images of chain couplings.

The *2015 Manual* consolidates or eliminates other redundant information. For example, Chapter 2.4, Structural Components in the *1998 Manual*, repeats the discussion of structural components such as pier protection fenders. However, the AASHTO *Manual for Bridge Evaluation* already includes a discussion of these structural components.

The *1998 Manual* includes Chapter 2.7, Hydraulic Compoents, although hydraulic equipment should be discussed in the Mechanical Components section. The *2015 Manual* reorganizes the discussion of hydraulic components and incorporates items that are specific to movable bridges, such as counterweights, in the Mechanical Components section.

3.3 Industry Developments Since the 1998 Manual

The research team identified developments such as new technologies, laws, or practices that have emerged since the publication of the *1998 Manual*. Load Resistance Factor Design (LRFD) has largely replaced AASHTO Standard Specifications for bridge structures. This development has included the publication of the AASHTO *LRFD Movable Highway Bridge Design Specifications*, 2nd Edition, with 2008, 2010, 2011, 2012, 2014, and 2015 Interim Revisions. The AASHTO *Manual for Bridge Evaluation* guides the structural elements of existing movable bridges.

Other developments since the *1998 Manual* include:

- FHWA‘s adoption of element-level condition assessment. Element-level inspections collect information in a format that is focused on bridge management. This supersedes the previous safety focused inspections for the National Bridge Inventory.
- Increased use of hydraulic machinery for movable bridge operations.
- Increased use of new "smart" structure monitoring technologies with electronic data collection and storage. For example, transducers can now be used to record real-time measurements of vibration, strain, temperature, acoustic emissions, chemical properties, imaging, and more.
- Increased scrutiny of gusset plates and fracture critical members as a result of the FHWA's *Clarification of Requirements for Fracture Critical Members* (June 20, 2012), and its introduction of the term "system redundant members."
- Technological changes in electrical control systems, including sophisticated motor-drive technologies, network-based and wireless control systems, and improved security practices for electronic and wireless control systems.
- Changes in materials, fabrication, and construction processes including reduced use of open-grid decks and greater use of types of solid decks. Other innovations include new types of steel materials, changes in welding processes, advances in concrete technology, increased use of large pre-fabricated elements, fiber-reinforced polymer (FRP), and new foundation types with drilled shafts and advanced

ground improvement methods. AASHTO material specifications lag behind industry standards, sometimes requiring no-longer-common materials, which cost extra time and money. For example, fiber-core wire ropes with zinc socketing as opposed to more common internal wire-rope-core type with polymer socketing.

- Substantial advances in engineering analyses including finite element analysis with non-linear material properties and fracture analysis, and Bridge Inspection Manual (BIM) processes. Seismic analysis for movable bridges has developed well beyond the simplified method allowed in the earlier specifications and now allows the consideration of providing equal risk for the open and closed span positions. Ship collision analysis has evolved substantially.
- Advances to bridge machinery, including the span-lock research currently conducted by the AASHTO T-8 Movable Bridge Committee, and advancements within the realm of industrial hydraulics, including hydraulic cylinders with integral buffer orifices at the end-of-stroke.
- Widespread use of new bridge access methods such as industrial rope access and the increase in patented specialty bridge access vehicles.
- Emphasis on bridge security provisions, creating additional access considerations for bridge inspectors, as well as design or retrofit issues such as blast analysis and electronic surveillance systems.
- Increased focus on worker safety and the application of the Occupational Safety and Health Administration (OSHA) provisions for both access and protection. For example, lockout/tagout procedures for electrical and mechanical inspections. NFPA 70E *Standard for Electrical Safety in the Workplace* provides guidance with respect to lockout/tagout procedures, arc flash/shock hazards, and the required personal protective equipment for electrical inspections and measurements.
- More stringent training requirements for certified bridge inspectors, including the National Bridge Inspection Standards (NBIS) inspection qualification requirements.
- Increased focus on environmental preservation and protection, as well as the concepts of climate change, sustainability, and resiliency.
- Increased restrictions on the performance of movable bridge test openings during inspections, due to owner concerns about vehicular traffic disruptions and to a lesser extent, potential failures.
- Advances in non-destructive testing methods. For example, phased-array ultrasonic testing, wet fluorescent magnetic particle testing, and thermal imaging acoustic emission testing.

3.4 Title and Organization of the 2015 Manual

The research team prepared the *2015 Manual* to reflect findings from the literature review, current best practices, and comments from the NCHRP Project Panel and other industry professionals. The *2015 Manual* omitted subject matter that was inconsistent with current best practices.

The *2015 Manual* contains an outline that was organized to be compatible with the format and terminology of the most recent relevant AASHTO publications for existing fixed bridges, including the *Manual for Bridge Evaluation* (MBE), published in 2011, and the *Manual for Bridge Element Inspection* (MBEI), published in 2013.

In May 2014, the NCHRP Project Panel approved the following outline, which appears in the *2015 Manual*:

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PART 1 – INTRODUCTION

Chapter 1.1 – Purpose
Chapter 1.2 – Scope
Chapter 1.3 – Movable Bridge Types
Chapter 1.4 – Bridge Functional Systems
Chapter 1.5 – Quality Measures

Chapter 1.6 – Recent Trends – Sustainability, Security, and Resiliency

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Chapter 2.1 – General
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Chapter 3.9 – Movable Bridge Interlocking System – Mechanical
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PART 4 – EVALUATION

Chapter 4.1 – Assessment of Inspection, Testing, and Evaluation Results
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PART 5 – MAINTENANCE

Chapter 5.1 – Movable Bridge Maintenance
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APPENDIX A – SUGGESTED INSPECTION FORMS

APPENDIX B – GEAR MECHANICS

APPENDIX C – REFERENCES

APPENDIX D – GLOSSARY

3.5 Highlights of the 2015 Manual

Exhibit 4 presents highlights of the *2015 Manual*, including comparisons with the *1998 Manual* and the *2011 MBE*, where appropriate. The information describes the manner in which the *2015 Manual* addresses identified gaps, developments, and redundancies.

3.6 Summary of Additions and Modifications between the 1998 Manual and the 2015 Manual

The *2015 Manual* includes the following topics, which the *1998 Manual* did not address:

- Definitions for new movable bridge elements and defects.
- Suggestions for movable bridge inspection forms.
- Suggestions for acceptable span balance conditions.
- Medium voltage (above 600 V to 50 kV) circuits and equipment.
- Advancements in non-destructive testing technology (e.g., the use of partial discharge testing to determine insulation integrity of medium voltage cables and equipment).
- Resiliency, security, and sustainability.

The *2015 Manual* modifies the following topics, which previously appeared in the *1998 Manual*:

- Removes dozens of existing very-poor-quality photo images (scans of Xeroxed images) and replaces them with high resolution photos.
- Clarifies recommended type and scope of movable bridge inspections, frequency, and inspector qualifications.
- Updates movable bridge inspection procedures including: wire-rope retirement criteria, acceptable span-balance conditions, and electrical insulation (Megger) testing with normalization for temperture.

Finally, unlike the *1998 Manual*, the *2015 Manual* is an electronic-native document that includes search, bookmark, and embedded “hot-link” capabilities.

Exhibit 4. Highlights of the 2015 Manual

Manual Section and Heading	2015 Manual*
1. Introduction	Establishes the purpose, scope, and applicability of the manual, and provides background information for the special topics related to inspection, evaluation, and maintenance of existing movable bridges.
1.3 Movable Bridge Types	Briefly describes and provides illustrations of the four types of movable bridges: bascule, swing, vertical lift, and other. Addresses the following: – "The varied scope of structures and inspection expectations. For example, some bridges are hand-operated very infrequently, while others are now very complex systems requiring and relying on expertise from out of state jurisdictions."
1.4 Bridge Functional Systems	Provides an overview of the seven distinct functional systems into which a movable bridge can be separated. Addresses the following: – "Emphasis on the highly specialized structures and required coordination between trades, specialties, and professions."
1.6 Recent Industry Trends	Addresses recent industry trends as they apply to existing movable bridges. Addresses the following gap: "Increased focus on environmental preservation and protection, as well as the concepts of sustainability and resiliency."
1.6.1 Sustainability	Provides a brief overview describing the applicability of sustainability to existing movable bridges. It introduces the topics of triple-bottom-line and life cycle cost analysis and mentions sustainability rating systems, such as Envision.
1.6.2 Security	Provides a brief overview describing the ramifications of heighted security concerns since the publication of the *1998 Manual*. For instance, movable bridge inspectors often require background checks before being approved to access field sites, inspectors may also expect local law enforcement to question their activities. Existing movable bridges may have retrofit projects designed to address security concerns not present during the original design.
1.6.3 Resiliency	Provides a brief overview describing the applicability of resiliency to existing movable bridges. Low-level movable bridges may be more susceptible to rising sea levels or rising temperatures than typical fixed bridges.
2. Inspection	Addresses the following gap: – Element-level condition assessment methods have been adopted by FHWA along with associated software, such as AASHTO BridgeWare (formerly Pontis). Element-level inspections collect information in a format that is focused on bridge management. This supersedes the previous safety focused inspections for the National Bridge Inventory.
2.1 General	Addresses the following: – "The importance of inspections in verifying systems correctness and consistency." – "Awareness of the *Code of Federal Regulations* (CFR) 'Title 33 Navigation and Navigable Waterways' law relevant to inspectors and possible significant fines due to improper operation. "

Manual Section and Heading	2015 Manual*
2.2 Types and Scopes of Inspection	Provides the recommended minimum types and descriptions of movable bridge inspections. Provides a checklist for routine and in-depth movable bridge inspection for each discipline: structural, mechanical, and electrical. Addresses the following gaps: – Consistency for electrical and mechanical inspection methods and scopes. – Discusses emergency inspections after an extreme event. – Clarifies requirements regarding when drive machinery should be load rated for motor sizing, brake settings, and machinery torque capacity. – Defines the various types of inspections and the recommended scope and frequency associated with each. – Recommends number of movable span test operations for the various levels of inspection and types of bridges. – Increases restrictions on the performance of movable bridge test openings during inspections, due to owner concerns about vehicular traffic disruptions and to a lesser extent, potential failures. Also addresses the following: – "Adding deficiency, time importance, safety analysis and system load testing as part of inspections (similar to load ratings). The effect of electro-mechanical performance on the overall structural inspection rating. Clarify when major deficiencies in the reliability of positioning and seating the bridge will decrease the overall bridge rating to 'structurally deficient'." – "The varied scope of structures and inspection expectations. For example, some bridges are hand operated very infrequently, while others are now very complex systems requiring and relying on expertise from out of state jurisdictions."
2.2.1 Routine Inspections	Provides a one-page checklist presenting the minimum suggested scope for routine movable bridge inspections for each discipline: structural, mechanical, and electrical. New checklist reflects guidance from Section 2.1.5.2 In-Depth Inspections from the *1998 Manual* and Section 4.2.2 In-Depth Inspections from the *2011 MBE*.
2.2.2 In-Depth Inspections	Provides a one-page checklist presenting the minimum suggested scope for routine movable bridge inspections for each discipline: structural, mechanical, and electrical. New checklist reflects guidance from Section 2.1.5.4 In-Depth Inspections from the *1998 Manual* and Section 4.2.4 In-Depth Inspections from the *2011 MBE*.
2.2.3 Special Inspections	Addresses initial, damage, emergency, non-destructive examination and other special inspection types and scopes.
2.3 Frequency	Recommends the frequency for each type of inspection, similar to Section 2.1 of the *1998 Manual* and Section 4.3 of the *2011 MBE*.

Manual Section and Heading	2015 Manual*
2.4 Qualifications and Responsibilities of Inspection Personnel	Addresses the following gap: – More stringent training requirements for certified bridge inspectors, including the NBIS inspection qualification requirements. Also addresses the following: – "Qualifications of the inspectors to ensure safety, welfare, and the public's implied consent." – "Emphasis on the highly specialized structures and required coordination between trades, specialties, and professions."
2.5 Safety	Highlights safety issues particular to movable bridges and not found on fixed bridges. Addresses the following gap: – Increased focus on worker safety and the application of the OSHA and PE OSHA provisions to both access and protection considerations. For example, lockout/tagout procedures for electrical and mechanical inspections. NFPA 70E Standard for Electrical Safety in the Workplace provides guidance with respect to lockout/tagout procedures, arc flash/shock hazards, and the required personal protective equipment for electrical inspections and measurements.
2.6 Planning, Scheduling, Equipment and Mobilization	Addresses the following gaps: – New bridge access methods have gained widespread use, such as industrial rope access and the increase in patented specialty bridge access vehicles. – Bridge security provisions are now a vital consideration, creating additional access considerations for bridge inspectors, as well as design or retrofit issues such as blast analysis and electronic surveillance systems.
2.7 Inspection Forms and Reports	Does not include the sample forms found in Section 2.11 Inspection Records and Reporting of the *1998 Manual* since thet have not been widely adopted by the industry. Provides updated sample forms in Appendix A - Suggested Inspection Forms. In general, the best practice is for each movable bridge to have a set of inspection forms included in its bridge-specific Operation, Inspection and Maintenance Manual. Addresses the following: – "Overall industry standardized forms to allow quick assessment of the condition while understanding the importance of a site specific data and inspection plan." – "Developing a reporting format to be quickly understood by decision-makers." – "Importance of record-keeping for maintenance, especially for mechanical and electrical equipment. Trends are more important in determining condition of equipment than instantaneous bad (or good) readings or measurements. Historical recordkeeping (megger readings, thermal imaging, tripped circuit breakers, blown fuses, clearance measurements, etc) is something that should be addressed."
2.8 Procedures	Addresses the following: – "Emphasis on the highly specialized structures and required coordination between trades, specialties, and professions."

Manual Section and Heading	2015 Manual*
2.8.1 Structural Inspection Procedures	Does not include inspection procedures for typical structural components (girders, trusses, floorbeams, stringers, pier protection fenders, etc.), which are similar to fixed bridges contained in Section 4.8 Procedures from the *2011 MBE*. Addresses specific movable bridge topics including: machinery access areas, operator's house, and counterweights – including pits and linkage members. Addresses the following gap: – Gusset plates and Fracture Critical Members now receive increased scrutiny, with the June 20, 2012 FHWA *Clarification of Requirements for Fracture Critical Members*, and its introduction of the term System Redundant Members.
2.8.2 Mechanical Inspection Procedures	Addresses the following gap: – At the beginning of this section, it will be explained how a mechanical component, such as a gear reducer, can be applicable to several movable bridge elements, such as the drive system, interlocking system, traffic guidance system, and span support system (such as wedges). For this reason, the general component-oriented organizational approach (as opposed to an element-oriented organizational approach) used in the 1998 manual will be carried over herein. Addresses the following: – In order to determine open gear tooth wear, mechanical inspectors typically have to calculate chordal addendums, chordal tooth thickness, and tooth span measurements. The 1998 manual devotes several sub-sections to discussing gear tooth measurement and wear. However, the 1998 manual does not provide the formulas required to translate gear tooth wear measurements into a meaningful calculated percent wear. – Clarify wire rope retirement criteria, similar to found in ANSI elevator specifications and the CFR for mining equipment. Clarify retirement criteria for other mechanical or electrical elements, such as bearings, gearing, limit switches, etc. Addresses the following gaps: – Bridge owners and inspectors have to decide if and when span balance is acceptable. While Section 2.2.2.2 Balance System of the *1998 Manual* discusses span balance in general terms, the manual lacks clear guidance regarding acceptable conditions of balance, both while closed and over the full range of motion of the movable span. The design standard specification also provides some guidance on balance but only in the closed position. – Increased use of hydraulic machinery for movable bridge operations. Advances with regards to bridge machinery include the Span Lock Research currently being conducted by AASHTO T-8 Movable Bridge Committee, as well as advancements within the realm of industrial hydraulics, including hydraulic cylinders with integral buffer orifices at the end-of-stroke.

Manual Section and Heading	2015 Manual*
2.8.3 Electrical Inspection Procedures	Addresses the following gap: – The beginning of this section explains how an electrical component, such as a motor, can be applicable to several movable bridge elements, such as the drive system, interlocking system, traffic guidance system, and span support system. For this reason, the section maintains the general component-oriented organizational approach used in the *1998 Manual* (as opposed to an element-oriented organizational approach). Addresses the following gaps: – Incorporate the NETA maintenance testing standards for electrical insulation resistance testing of conductors and windings – Electrical testing methods should be expanded to provide motor winding polarization indexes (PI) and dielectric absorption rations (DAR), per the NETA maintenance testing specification. – The current manual addresses the need to track electrical insulation resistance trending, but does not address normalization of values for ambient temperatures. Normalization is important when evaluating the trending.
2.9 Predicted Component Life	Incorporates the tables of predicted hydraulic and electrical component life found in Section 2.3.3 of the *1998 Manual*.
2.10 Testing, Monitoring, and Advanced Inspection Methods	Includes recent developments in health monitoring based on Section 2.10 Testing and Advanced Inspection Methods from the *1998 Manual*. Addresses the following: – New remote operations and monitoring systems to improve or change current practice. How have the new systems been changed over what we did before? – New “smart” structure monitoring technologies with electronic data collection and storage have seen increased usage. For example, transducers can now be used to record real-time measurements of vibration, strain, temperature, acoustic emissions, chemical properties, imaging, and more.
3. Movable Bridge Element Descriptions	Complements movable bridge element descriptions in the 2013 *Manual for Bridge Element Inspection*, which does not currently include movable bridge specific elements.
4. Evaluation	Replaces AASHTO Standard Specifications for bridge structures with Load Resistance Factor Design (LRFD). This development has included the publication of the AASHTO *LRFD Movable Highway Bridge Design Specifications*, 2nd Edition, with 2008, 2010, 2011, and 2012 Interim Revisions.

Manual Section and Heading	2015 Manual*
4 .2 Operating Criteria for In-Service Movable Bridges	Addresses the following: – Add deficiency, time importance, safety analysis and system load testing as part of inspections (similar to load ratings). The effect of electro-mechanical performance on the overall structural inspection rating. Clarify when major deficiencies in the reliability of positioning and seating the bridge will decrease the overall bridge rating, to “structurally deficient”, for example. – An overall movable bridge rating based on a systemic approach, including movable superstructure, mechanical operating system, and electrical control system. The superstructure rating should match the current practices on fixed bridges. – Provide recommended course of action for a particular rating, i.e., reduced inspection interval, load posting, etc. – Engineering analysis has seen significant advances including: finite element analysis with non-linear material properties and fracture analysis, BIM, ship collision analysis, and seismic analysis for movable bridges (has moved well beyond the simplified method allowed in the earlier specifications and now allows the consideration of providing equal risk for the open and closed span positions).
4.2.4 Mechanical Provisions	Addresses the following gap: – Clarify requirements regarding when drive machinery should be load rated for motor sizing, brake settings, and machinery torque capacity.
4.3 Analysis of In-Service Movable Bridges	Addresses the following: – Clarify wire rope retirement criteria, similar to found in ANSI elevator specifications and the CFR for mining equipment. Clarify retirement criteria for other mechanical or electrical elements, such as bearings, gearing, limit switches, etc.
4.4 Vulnerability to Extreme Events	Addresses the following gaps: – Engineering analysis has seen substantial advances, including: finite element analysis with non-linear material properties and fracture analysis, BIM, seismic analysis for movable bridges has moved well beyond the simplified method allowed in the earlier specifications and now allow the consideration of providing equal risk for the open and closed span positions, and ship collision analysis has evolved substantially. – Bridge security provisions are now a vital consideration, creating additional access considerations for bridge inspectors, as well as design or retrofit issues such as blast analysis and electronic surveillance systems.
4.7.2 Bridge Operations Manuals	Updates the example outline for a bridge-specific operation manual to reflect previous discussions with the NCHRP Project Panel.
4.7.3 Bridge Maintenance Manuals	Updates the bridge-specific maintenance manual to reflect previous discussions with the NCHRP Project Panel.
Appendix A – Suggested Inspection Forms	Addresses the following gaps: – Overall industry standardized forms to allow quick assessment of the condition while understanding the importance of site-specific data and an inspection plan. – Developing a clear reporting format for decision-makers.
Appendix B – References	Updates references from Chapter 1.2 Codes and Standards in the *1998 Manual*.

*Note: The *2015 Manual* pertains to movable bridges and includes only those requirements that are beyond what is specifically required for fixed bridges.

CHAPTER 4

Conclusions and Suggested Research

The *2015 Manual* addresses many of the topics that the *1998 Manual* did not include. The *2015 Manual* also reflects current industry best practices, new technological innovations, and comments from the NCHRP Project Panel and other professionals.

4.1 Issues Not Addressed in the 2015 Manual

The *2015 Manual* does not address torsional vibration resonance problems in drive machinery, which have occurred on at least one new movable bridge—the floating concrete pontoon retractile-type. Torsional vibration of drive machinery is not common and is a design issue; therefore, the *2015 Manual* does not address this issue.

4.2 Potential Impacts of Revising the 1998 Manual

The revisions included in the *2015 Manual* will affect public safety, inspection procedures, and allocation of resources needed for implementation. In order to be justified, the revisions contained in the *2015 Manual* should increase public safety, clarify and standardize inspection procedures, and/or reduce the resources necessary to inspect, evaluate, and maintain movable highway bridges.

Public Safety

The following revisions in the *2015 Manual* will greatly improve public safety. In general, movable bridge inspection is critical to properly scheduling bridge maintenance activities and bridge rehabilitation or replacement, in order to maintain public safety and to efficiently allocate maintenance resources. Users of highway movable bridges include not only vehicular traffic, but also marine traffic (navigable vessels), pedestrians, cyclists, and transit including heavy rail, in some instances.

- Part 3, Movable Bridge Element Descriptions, in the *2015 Manual* will improve public safety, inspection procedures, and allocation of resources by providing an asset management approach for improved identification and qualification of movable bridge elements.
- The *2015 Manual* clarifies minimum suggested requirements for movable bridge mechanical and electrical inspections with revisions to Section 2.2, Types and Scopes of Inspection; Section 2.3, Frequency; and Section 2.4, Inspector Qualifications. These clarifications improve public safety, inspection procedures, and allocation of resources by clearly communicating the minimum suggested "who, when, and what" of movable bridge inspections to owner agencies.
- Appendix A - Suggested Inspection Forms, in the *2015 Manual* will improve public safety, inspection procedures, and allocation of resources by serving both as a checklist for use by movable bridge inspectors in the field, as well as reporting a concise summary of inspection findings for reference by decision-makers.
- The *2015 Manual* eliminates dozens of very-poor-quality photo images (scans of Xeroxed images) and replaces them with high-resolution photos, primarily in Part 1 and Part 2 of the manual.

The improved clarity of the *2015 Manual* will facilitate the training of movable bridge inspectors, leading to a higher quality of work within the industry.

- The *2015 Manual* is available in an electronic .pdf format, including “hot-link” capabilities, to speed navigation within the document. The *2015 Manual* contains a comprehensive Table of Contents at the beginning of the document and a Glossary at the end. The improved clarity of the *2015 Manual* will facilitate the training of movable bridge inspectors, leading to a higher quality of work within the industry.
- Updated movable bridge inspection procedures, discussed below, will improve public safety, inspection procedures, and allocation of resources by documenting and implementing inspection best practices.

Inspection Procedures

In general, the *2015 Manual* contains similar movable bridge inspection procedures and subject matter as the *1998 Manual*. The largest change regards the type and form of documentation following the inspection.

In order to gain the asset-management-related benefits of the new element-level inspection definitions, movable bridge owners will need to update the format of their inspection reports. While element-level definitions have been adopted for fixed bridges, currently, there is no national standard for movable bridge inspection reports. Owners have discretion to develop unique report templates. The *2015 Manual* contains Appendix A - Suggested Inspection Forms, which provides a template for concisely reporting element-level inspection data.

The *2015 Manual* contains the following examples of new, or substantially revised, inspection procedures:

- New sections incorporating recent industry practices related to sustainability, security, and resiliency.
- New suggestions for wire-rope retirement criteria, including associated measurements.
- New suggestions for acceptable span-balance conditions.
- Updates for electrical inspection of medium-voltage equipment.
- New standards for normalizing the data associated with electrical insulation (Megger) testing.

Recommendations for Resources Needed for Implementation

The research team recommends the following resources for implementing the *2015 Manual*:

- A pilot project to field-test the newly proposed element-level definitions on a trial basis. This will maximize the chances for successful adoption of the new element-level definitions and minimize misunderstandings among movable bridge owners. A pilot project will also provide valuable feedback and inform future revisions to the element-level definitions, if necessary.
- A nationwide training class to qualify movable bridge inspectors, similar to fracture critical bridge inspection training.
- Internal procedures regarding how each movable bridge owner would archive element-level condition ratings and how the ratings would be used to inform decisionmaking for asset management.

4.3 Standardized Descriptions for Inventory and Inspection Based on Element-Level Condition Assessment

Movable bridges provide a critical link in the nation’s infrastructure system. These complex structures serve both navigation and highway traffic. Therefore, high importance is placed on their reliable operation. The *Manual for Bridge Element Inspection* (MBEI) forms a basis for the inspection of fixed bridges. However, the MBEI does not define inspection elements for movable bridges. Proper assessment of the condition of bridge elements is the cornerstone of sound bridge management.

This research project included the development of standardized descriptions for inventory and inspection based on the element-level condition assessment methods for movable bridges. In addition, the research team proposed new movable bridge elements and defects—which were submitted to the AASHTO SCOBS T-18 Bridge Management, Evaluation, and Rehabilitation technical committee on June 5, 2015—with a request that numbers be assigned.

The proposed elements for condition assessment of movable bridges are based on the functional systems presented in the *AASHTO Movable Bridge Inspection, Evaluation, and Maintenance Manual*. The 16 newly proposed movable bridge elements include:

- Movable Bridge Support System – Structural.
- Movable Bridge Support System – Mechanical.
- Movable Bridge Balance System – Structural.
- Movable Bridge Balance System – Mechanical.
- Movable Bridge Drive System – Mechanical.
- Movable Bridge Drive System – Electrical.
- Movable Bridge Control System – Mechanical.
- Movable Bridge Control System – Electrical.
- Movable Bridge Interlocking System – Mechanical.
- Movable Bridge Interlocking System – Electrical.
- Movable Bridge Navigation Guidance System – Structural.
- Movable Bridge Navigation Guidance System – Electrical.
- Movable Bridge Power System – Electrical.
- Movable Bridge Traffic Control System – Mechanical.
- Movable Bridge Traffic Control System – Electrical.
- Movable Bridge House.

The 14 proposed movable bridge defects include:

- Operation.
- Lubrication.
- Wear (Machinery).
- Alignment (Mechanical).
- Housekeeping.
- Accessibility and Labeling.
- Support and Electrical Terminations.
- Wear (Electrical).
- Functional Obsolescence.
- Accessibility and Labeling.
- Support and Electrical Terminations.
- Weatherproofing.
- House Mechanical Defect.
- House Electrical Defect.

Detailed definitions for each of the proposed inspection elements, including detailed defect descriptions, are included in the ballot item version of the *2015 Manual*.

4.4 Suggested Research (Continued Enhancements to Manual)

Although NCHRP Project 14-32 accomplished its purpose of revising the *1998 Manual* to reflect current industry practices, it did not address some issues because they were beyond the scope of the project. Therefore, the research team recommends further research regarding the following issues:

- Shepherd the ballot item version of the *2015 Manual* through the AASHTO SCOBS committee voting procedure, including a presentation to the SCOBS group, at its annual meeting in 2016.
- Develop inspection practices for remote bridge operation systems.
- Expand the component coding guidelines in Part 2, with pictures and examples, to ensure consistency with the element rating system.
- Develop an index to take component-level data and provide ratings for each major system.
- Develop maintenance recommendations that correspond to component coding guidelines and the most recent NHI bridge maintenance manual.
- Add a new figure for hydraulic-operated swing bridge to Section 2.6.2.1.
- Provide additional information regarding aviation lighting.
- Change the order of appearance in Figure 2.6.1.3-1 to bascule, swing, vertical lift.
- Add a definition and discussion of kinematic pier protection systems to Section 2.8.1.5.5.
- Add more detail on different types of gates, barriers, and their functions to Section 2.8.1.7.1.
- Discuss the different types of wire-rope-end terminations in Section 2.8.
- Discuss band brakes in Section 2.8.3.5.
- Prepare a new section to be titled Dynamic “Drift” Test to Section 2.10.
- Add discussion of balance for types of bridges other than bascule and vertical lift, such as swing bridges with sidewalks on one side or unequal spans (bob-tail).
- Incorporate data from the white paper “Fatigue Life Extension of Main Counterweight Sheave Trunnions” by Peter Roody which was presented at the Heavy Movable Structures Symposium in 2002. Specifically, discuss bearing length to diameter ratios and fillet radii that raise concerns. Please note that, due to rotating-bending stress reversals, trunnions on vertical lift bridges are substantially more vulnerable to fracture and fatige failures, when compared with bascule trunnions.
- Reconfigure the element definitions using a new master chart of defects that would apply to all of the movable bridge elements. The new chart should indicate which defects are relevent to each element.
- Create a risk matrix for how component ratings roll-up to element/system ratings. The worst-rated component should not control the element/system rating.
- Prepare a new section within Part 4 to discuss the benefits of programmable logic controller (PLC) data logging.
- Add “extra-extra improved plow steel“ and internal wire rope core data to Part 4.
- Add a new section on bridge management to Part 5.
- Perform pilot testing of the element-level inspection for a movable bridge. The state of Michigan has volunteered to participate in the pilot testing.

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Abbreviations, Acronyms, Initialisms, and Symbols

AASHTO	American Association of State Highway Transportation Officials
ADE	Agency Developed Elements
ANSI	American National Standards Institute
AREMA	American Railway Engineering and Maintenance of Way Association
BIRM	Bridge Inspector’s Reference Manual
BME	Bridge Management Elements
CCAA	Crane Certification Association of America
CoRe	Commonly Recognized Elements
CSA	Canadian Standards Association
FDOT	Florida Department of Transportation
FHWA	Federal Highway Administration
FRP	Fiber-Reinforced Polymer
GIS	Geographical Information Systems
GIS-T	GIS for Transportation
GISTAM	Geographical Information Systems Theory, Applications and Management
HMI	Hoist Manufacturers Institute
HMS	Heavy Movable Structures
INDOT	Indiana Department of Transportation
LADOTD	Louisiana Department of Transportation and Development
LRFD	Load and Resistance Factor Design
LRFR	Load and Resistance Factor Rating
MAP-21	Moving Ahead for Progress in the 21st Century (Law)
MBE	Manual for Bridge Evaluation
MBEI	Manual for Bridge Element Inspection
MDSHA	Maryland State Highway Administration
MUTCD	Manual on Uniform Traffic Control Devices for Streets and Highways (MUTCD)
NBE	National Bridge Elements
NBI	National Bridge Inventory
NBIS	National Bridge Inspection Standards
NCHRP	National Cooperative Highway Research Program
NETA	International Electrical Testing Association
NFPA	National Fire Protection Association
NHI	National Highway Institute
NYSDOT	New York State Department of Transportation
ODOT	Oregon Department of Transportation

OSHA	Occupational Safety and Health Administration
PLC	Programmable Logic Controller
SCOBS	Subcommittee on Bridges and Structures
TRID	Transportation Research International Documentation
URISA	Urban and Regional Information Systems Association
WIDOT	Wisconsis Department of Transportation
WRTB	Wire Rope Technical Board
WSDOT	Washington State Department of Transportation