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4.1.1 GENERAL

Inspection, testing, and evaluation of a complex electromechanical structure such as a movable bridge usually generates a large amount of information. Evaluators may receive data collected by individuals of differing fields of expertise and with significant variations in focus, experience, and priorities. Individual inspectors, engineers performing rating analyses of structural, mechanical, and electrical components, and testing groups will collect data and formulate theories about the reliability of components and subassemblies based upon the limited information available to them. This wide range of independent data must be evaluated for degree of reliability and relative importance and integrated into a useful picture of the overall condition, safety, and operational reliability of the bridge as a complete assembly.

This chapter addresses the interpretation and assessment of the results of this varied activity and the process of integration into a practical evaluation of condition, reliability, and safety of the bridge.

4.1.2 DATA RELIABILITY

The first consideration in the assessment should be to determine the reliability of the data received. A large volume of information is gathered, and frequently individual items of data appear to conflict. However, movable bridge evaluators are usually dealing with phenomena which are repeatable. A defect or operational problem reported by an inspector should also be evident in a follow-up investigation. Deterioration and physical defects can usually be verified by reviewing supporting photographic documentation or measurement.

A more problematic area for reliability determination is anecdotal information from inspectors, bridge operators and maintainers when describing noises or operational problems. Communication and interpretation are subjective.

Troubleshooting operating problems usually involves sending an experienced maintenance “mechanic” or evaluator to the bridge to conduct performance tests until the reported problem is experienced. Communication and interpretation are no longer a problem, but the diagnostic process can become lengthy. However, the only proven reliable method for determining the cause of an operational problem is methodical diagnostic work by an experienced engineer or maintenance mechanic.

A promising new method is simultaneous long-term monitoring and recording of critical operating parameters, such

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The repeatability of results is one key to reliability. Evaluators should not look at only the most recent inspection, but rather at a number of past inspections. Physical deterioration and distress on bridges is a time-dependent process which should be consistent. The depth of corrosion pitting and concrete or timber deterioration from the original surface should not vary widely from one area to another unless there is a detectable difference in the contributing factors. Horizontal surfaces can deteriorate when moisture and debris accumulate. Vertical surfaces tend to shed water and debris except at a connection to horizontal members. Areas below the bridge gutter lines, scuppers, and deck joints will deteriorate faster if deck moisture runs onto members below.

These facts and others can be used to develop an opinion on the probability of data items being accurate. Improbable data should be deemed to be suspect until confirmed by additional investigation. If data can be confirmed in two successive inspections by as wind speed, temperature, motor circuit amperage, bearing temperature, hydraulic pressure, stresses, and reactions with an electronic data logger that will permit relating unusual readings that have occurred at the same time. Availability of this type of detailed continuous or intermittent "snapshot" time line trace of critical system data can at times help to pinpoint the problem area.

different personnel, reliability is established. Photographs, field verification of critical data by the evaluator discussion with inspectors, and other verification procedures assist in determining reliability of individual data.

An example of the ability to relate unusual instrument readings with a data logger is that if unusually high spikes in motor current (amperage) occurred in the log, investigation might reveal that a spike occurred simultaneously in the wind speed log. Thus no action or further investigation would be necessary. A repetitive spike in motor current that occurred at the same angle of opening without any corresponding reading which explained this event would lead to an investigation to determine the cause. Such an event could result from a number of causes such as machinery binding at a certain point or inadequate clearance at the floor break.

4.1.3 PROBLEM INVESTIGATION

Reliable data should be grouped in a logical order which gathers the facts pertinent to a particular defect or operational problem into a usable format. This information can be used to formulate a preliminary theory about the causes and severity of the problem, and identify any corrective measures which may be needed. Often it is useful to draw a sketch of the assembly being evaluated and annotate it with the available data. Each engineer or maintainer requires a different degree of presentation detail to form a three-dimensional mental image of a complex assembly complete with all data about defects and deterioration, but most personnel who are effective at troubleshooting complex structures and machines find it essential to do so. Once the mental image is formed, it becomes easier to add facts and form a preliminary theory.

The preliminary theory can be used to predict where other problems and supporting evidence may be found, and to focus subsequent inspection efforts. Another critical feature of investigation is to predict what evidence should not be present if the theory is correct, and to investigate whether such conflicting evidence is present. Often a preliminary theory will evolve as confirming data is not found or conflicting data is discovered. The key to problem solving is to continue to refine the general theory until it fits the data and to continue to investigate, field test, make test repairs, and monitor

C4.1.3

There may be a tendency in some investigations to formulate a theory before all the facts are gathered and to continue to advocate the theory in spite of conflicting data. Complex machines such as movable bridges may often contain multiple defects which cause an observed operational problem. The existence of conflicting data is not necessarily conclusive proof that a theory is invalid. Conflicting data does, however, make it necessary to investigate further to prove an existing theory.

performance until the cause of an observed defect can be proven conclusively.

4.1.4 PRIORITIZATION FOR CORRECTIVE ACTION

Having identified the problems, the evaluator should identify potential consequences of each problem and assess the likelihood of occurrence of those consequences.

The desired end result of this assessment is to determine the relative priority of the various observed conditions, defects, and problem areas for action. One method used to rank such items is an occurrence probability and consequence severity priority ranking matrix, as shown in Table 4.1.4-1.

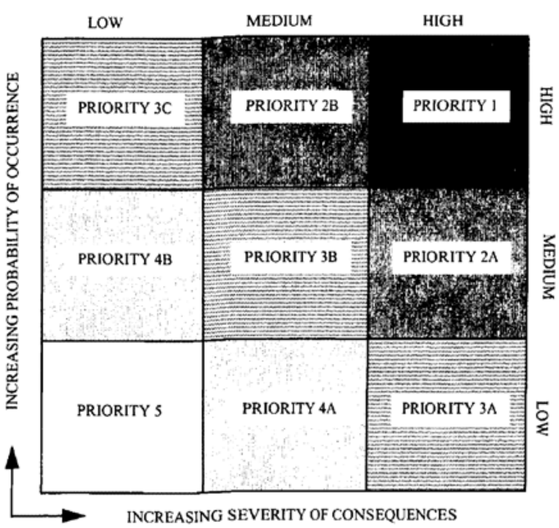

Table 4.1.4-1 – Priority ranking matrix

The matrix is used to rank each defect (or each bridge in a group) by the relative probability of occurrence of an undesirable consequence (such as a failure to operate, structural failure, worker hazard, etc.) versus the severity of the consequences. Each result is assigned “high,” “medium,” or “low” probability of occurrence based on engineering judgment of the available information, and the consequences are ranked by severity. Failure is considered “high” severity, failure to operate varies depending on the bridge, worker hazard is either “high” or “medium,” and so forth.

The defects can then be prioritized for corrective action. A highly probable event with highly severe consequences would be the first priority, shown as Priority 1. Priorities 2, 3, 4, and 5 follow. The relative priority of the A, B, and C items in each

C4.1.4

The method presented is a qualitative means of prioritizing one problem with respect to other problems, based solely upon the likelihood that the problem will occur and the severity of consequences if the problem occurs. There are obviously other considerations, such as but not limited to the importance of the structure and the cost of needed repairs that must also be considered. The matrix method presented can be applied to any prioritization based upon two scales of importance. For example, the results of this matrix could be formatted as a priority scale and then compared by a similar procedure to repair cost and importance of the structure.

diagonal band depends upon a subjective assessment of how quickly an item can progress along each axis with time and also with the particular details of the individual case. The prioritization in Table 4.1.4-1 assumes that a high-probability event with low-severity consequences is less important than a low-probability event with high-severity consequences. The decision about such details is a matter for engineering judgment. Priority decreases from upper right to lower left of the matrix.

4.1.5 DECISION PROCESS

Having established the relative priority of defects requiring corrective action, the evaluator must determine the appropriate action and the urgency of implementation.

This step is a critical stage in the progress of work from problem identification to problem solution. Parts changing or in-kind replacement of damaged or failed components may not be the most reliable way of correcting defects. The most reliable method for selecting appropriate corrective actions is to identify and correct the primary cause of the observed defect. Anything less is equivalent to treating the symptoms, but ignoring the disease.

Movable bridges are complex machines. There are less than a thousand movable highway bridges in the United States, and many of them are unique idiosyncratic structures designed and built many years ago. Replacing worn-out or defective parts is usually a straightforward maintenance activity. However, correcting chronic problems requires thorough investigation and sound engineering judgment.

Often the source of the problem lies with the original design details, or a previous rehabilitation or maintenance decision. Some allowable design stresses in the codes have changed over the years in response to the discovery of chronic problem areas in movable bridges. Examples include rolling-lift bascule line bearing allowable stress on tread plates and swing bridge bronze sleeve bearings at the pivot (Chapter 4.3). The original 1938 version and subsequent versions of the AASHO *Standard Specifications for Movable Highway Bridges* (Reference 8d) is available for purchase from AASHTO.

C4.1.5

Analysis is a necessary step in the decision-making process to determine if original design problems exist and if correction is warranted.

Another source of distress in movable bridges results from the proliferation of recreational marine traffic. Many movable bridges open far more often than their original designers could have anticipated.

Rehabilitation of a movable bridge is an extremely labor intensive, high visibility activity that usually results in inconvenience to navigation and vehicular traffic. Detailed analysis and field testing of an in-service movable bridge are extremely valuable methods to confirm that proposed corrective measures are based upon accurate conclusions and will correct the cause of the problem.

Pressing ahead to develop repairs based upon an unproven theory concerning the cause of existing defects can sometimes cause more problems than it solves. It will prove a theory to be erroneous if repairs are made and the defect reappears. For this reason it is advisable to take a cautious approach to making widespread repairs of a chronic defect when it is not possible to conclusively prove the root cause of the defect. A test repair or other solution that is less complex and costly can be made and monitored for performance prior to full implementation of repairs.

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4.1.6 METHODS OF EVALUATING COMPONENTS

In the decision-making process for rehabilitation, several basic methods can be used to evaluate structural, mechanical, hydraulic, and electrical components on movable bridges.

4.1.6.1 Predicted Life Method

The predicted life method is based upon the concept that all parts have an identifiable in-service useful life. Replacement decisions are simple; owners need only track when they install a part and put a new one in before the existing one reaches the end of its predicted useful life. The problem lies entirely in reliably predicting the useful life. If an owner can obtain reliable life data on purchased components, the predicted life method of scheduling component replacement is extremely useful. A predicted life condition rating method has been recommended for electrical and hydraulic components in Chapter 2.9.

4.1.6.2 Stress Method

The stress method is more complex and requires performing stress calculations on the various components. This method is used for structural components on fixed bridges and is recommended in Chapter 4.3 as the analysis method for movable bridge structural components. It also can be used to evaluate spur gears, some other mechanical components, or electrical components. Because the stress method requires specialized engineering training, it cannot be used to make rapid decisions in the field by technicians without appropriate design experience. It is also problematic on proprietary items such as enclosed reducers, where critical design parameters are established by the manufacturer and are not considered public domain information. When feasible, it is the most reliable method and will often allow extended service life on deteriorated components that were originally over designed. A component that is stressed to only half of the original allowable service load value might not need replacement if it has substantial loss of its original critical design geometry, as long as this loss creates no operational problems of a practical "loose fit" nature.

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4.1.6.3 Percentage Loss Method

The percentage loss or "wear" method is based on the concept that components should be replaced when reduced a certain percentage from their original dimensions. It is common in the gear and machinery industry to use 15 percent wear as a maximum allowable limit beyond which component replacement is recommended. This is a practical requirement developed over time primarily for gears. It is not necessarily stress-based, but is intended to avoid the accumulation of excessive clearances in a gear based drive train that may cause unacceptable shock loads if the drive system is suddenly reversed or stopped without a gradual deceleration/acceleration. This method is also used for condition rating of structural components in the field by technicians, but the percentage of loss requiring replacement can be higher than 15 percent. Replacement of structural components is usually based on the stress method.

C4.1.6.3

See Chapter 2.8.2 for more information on gear tooth measurement and gear tooth wear measurement.

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CHAPTER 4.2 – OPERATING CRITERIA FOR IN-SERVICE MOVABLE BRIDGES

4.2.1 GENERAL

The AASHTO *LRFD Movable Highway Bridge Design Specifications* (Reference 7) prescribes design standards for new movable bridges. The specification does not contain modified criteria for assessment or rehabilitation of in-service bridges, but as a consequence theengineer should make engineering judgments in the selection of rating and rehabilitation criteria for each bridge. Each existing movable bridge is subject to unique conditions of use, site and environmental factors, and existing design limitations that require special consideration in the evaluation process. It is the intention of this chapter to provide guidance to evaluators in making the essential decisions regarding non-action/retrofit/rehabilitation/replace-ment of existing movable bridges and their components in a manner consistent with public safety and good engineering practice.

Reference 7 contains design and operating criteria and includes requirements for operating system controls, interlocking, and numerous other features. Some of these requirements were developed well after the construction of many in-service movable highway bridges that currently provide safe reliable service without meeting current design standards. It is necessary for the evaluator of an existing movable bridge to compare the conditions present on the bridge to the applicable current design criteria to identify the areas of nonconformance. The evaluator must then decide in conjunction with the bridge owner which nonconforming items are to be upgraded to the current design provision and which can be left as is.

The guidance provided herein reflects current preferred practice, and is subject to interpretation and application by evaluating engineers.

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C4.2.1

Sound engineering judgment is critical in the selection of appropriate operating criteria. This chapter provides guidance to assist the decision making process, but should not be interpreted as providing the solution to all of the complex issues which arise during a repair or rehabilitation project. The repair or rehabilitation of any movable bridge is a special study which requires the application of substantial experience and engineering judgment during the evaluation process.

4.2.2 DESIGN STANDARD COMPLIANCE

The assessment of an in-service movable bridge requires considerable engineering judgment related to non-action/-retrofit/rehabilitation/replacement of components, systems, or the entire structure.

The application of the design specification provisions to an in-service bridge must be considered item-by-item based on the site specific conditions. OSHA provisions (Reference 55) that involve major items of worker or public safety should, in general, be carried over to in-service bridges, even if retrofit is required for compliance. AASHTO design standard provisions that apply to reliability, durability, and efficiency of operations can be enforced at the engineer's option based on the performance demands of the facility. Similarly, AASHTO design standard provisions relating to sizing components and allowable stresses provide a standard against which the actual component performance and working stresses can be compared as the basis for engineering judgment on the need for compliance.

In addition to determining whether or not to upgrade individual elements of the in-service movable bridge to current AASHTO design standards, the engineer should determine whether the improvements should be scheduled as an immediate retrofit, part of a scheduled rehabilitation project, or deferred to a future repair, rehabilitation, or maintenance project. This determination usually involves a consideration of the risk of noncompliance or deferred action.

Certain site specific details can be used as the basis for deciding whether to upgrade to comply with specific design standards or whether continued operation under existing conditions is acceptable. Items that should be considered include, but are not limited to:

- Roadway traffic volume (annual/hourly)
- Number of openings (annual/monthly)
- Use of roadway by emergency vehicles
- Mix of roadway traffic (trucks/cars)
- Geometrics of roadway, number of lanes, travel speed, etc.
- Vessels using channel (type, size, commercial, recreational)
- Channel geometrics
- Detour length for vessels/vehicles
- Risk to vessels, vehicles, personnel, or some combination of these in event of component failure
- Probable downtime in the event of component failure

Each current standard for which the existing structure is noncompliant should be assessed individually in light of the above information. If the bridge operation and safety are acceptable and the potential impacts of noncompliance are tolerable, compliance with that particular code provision need not be recommended. If the operational reliability or safety of the facility is at risk and the potential impacts are unacceptable, retrofitting the structure to comply with that particular code provision should be recommended.

The following sections provide discussion of typical AASHTO design standard provisions with which many in-service movable bridges are found to be noncompliant, and offer guidance on making the decision between non-action, retrofitting, rehabilitation, or replacement.

CHAPTER 4.2 – OPERATING CRITERIA FOR IN-SERVICE MOVABLE BRIDGES

4.2.3 STRUCTURAL AND GENERAL PROVISIONS

Contractors are required to supply listed minimum tools and equipment.

During rehabilitation design, evaluators—in coordination with owners—should select tools and equipment to be supplied by the contractor. It is preferred that the existing inventory and those items selected to be supplied during rehabilitation constitute a complete set necessary to fully disassemble and repair critical drive, support, control, and traffic control system components. If, in the assessment, individual components or systems are identified that require frequent repair, and which are not scheduled for rehabilitation, the evaluator should consider recommending the purchase of spares, tools, and equipment to facilitate the maintenance of these items.

Auxiliary power or two independent sources of power are required.

Existing structures that do not at present have auxiliary power, two independent sources of power, or a functional, reliable hand drive system, should be evaluated to determine the consequences of a power outage. For the bridges where highway traffic or vessel traffic make reliable span or leaf operation vital, the consequences of power outage may be unacceptable. Under these circumstances, it is preferred that an auxiliary power system or reliable hand drive system be installed. Some bridges, however, open infrequently or only by advance notice, and the evaluator could reasonably retain the single power source (or consider a hand drive as the second source of power). Evaluators should consider appropriate contingency plans for opening such single power source structures with other means such as winches or mobile cranes if an emergency arose during a power outage.

Air buffers or industrial shock absorbers are required unless controls provide smooth seating capability.

Movable bridge structures should seat smoothly. Installation of air buffers or shock absorbers or a modification of controls should be considered on existing structures where seating is noisy. Banging noises can indicate unacceptable impact forces being imposed during seating. This type of retrofit can be deferred to a scheduled maintenance or rehabilitation activity.

C4.2.3 through C4.2.5

The information presented in these sections is not intended to address all areas of current design specifications that may conflict with existing conditions, but rather to illustrate methods of resolving such conflict through the exercise of engineering judgment.

"Toe heavy" or "span heavy" for a bascule bridge have the same meaning, and are defined as having the center of gravity of the entire bascule leaf located such that the leaf will tend to close If allowed to drift at the lower portion of its range information. Such a "toe heavy" bascule will also tend to stay closed with span locks and brakes released in the closed position. A bascule, which tends to rise under such circumstances, is a potential hazard if the span locks or brakes fracture, malfunction or are temporarily disconnected.

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Under no circumstances should a bascule leaf balance be adjusted to be “heel heavy” or a lift span be adjusted to be “counterweight heavy” to correct a noisy seating problem. All bascules must be balanced to be slightly “toe heavy” when seated. Lift spans should be slightly “span heavy.”

Requirements for span or leaf balance on bascules require small positive dead load reactions at the supports when the bridge is seated.

Evaluators should verify that bascule bridges have small positive dead load reactions at the supports when the bridge is seated. Bascules are required to be slightly toe heavy and lift bridges are to be slightly span or leaf heavy when seated. This Manual recommends in Part 2 that span or leaf balance be tested during each inspection. Evaluators should obtain and review recent historic test data when making any decisions concerning the need for corrective actions at bascule or lift-span bridges. This code provision affects operational safety and, in general, compliance should be considered mandatory.

Span or leaf alignment and locking devices are required.

Span or leaf alignment devices add to operational reliability in seating, are sometimes an integral part of the locking sequence, but generally do not carry load. Span or leaf locks secure the structure in the seated position, and, in the case of double-leaf bascules, may carry live load across the center channel floor break. Existing structures that do not have span or leaf alignment and locking devices should be evaluated based on bridge performance. If span or leaf alignment when seating is difficult or unreliable, addition of a centering device should be considered. If the bridge vibrates considerably under live load, addition of span or leaf locks should be considered. Misalignment or vibration can cause other problems, particularly fatigue. The long-term result could be failure of machinery components with potentially severe consequences. In general, installation of properly interlocked span or leaf alignment and locking devices is recommended on existing bridges, unless the bridge opens infrequently and operates in a satisfactory manner without evidence of misalignment or vibration. The bridge performance record should be used to determine the urgency of installation of alignment and locking devices.

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Operator's and machinery houses must be fireproof construction.

Fireproofing is a personnel safety issue, and existing operator's and machinery houses that are not fireproof construction should be updated to conform to local building codes. Evaluators should consider providing secondary exits, automatic fire suppression systems, smoke detectors, and similar methods to enhance fire safety.

On critical structures that appear likely to experience significant downtime in the event of a fire, the installation of an appropriate type automatic fire suppression system in critical control and machinery spaces should be considered.

In areas susceptible to storm surge or hurricane winds, windows should be load rated to resist increased winds. Also, houses should be elevated for storm surge issues.

Specific requirements for traffic gates and physical resistance gates are specified.

The requirements for traffic and physical resistance gates are discussed in Chapter 4.6.

4.2.4 MECHANICAL PROVISIONS

Safe access ladders, platforms, railings, and in some cases, safety cages are required.

Existing structures that do not presently conform to the requirements of OSHA (Reference 55) for safe access ladders, platforms, railing, and safety cages should be upgraded during the next scheduled rehabilitation. Aging bridges require more frequent maintenance and repair requiring more frequent presence of maintainers on the site. For these reasons it is important to have convenient, safe access to critical areas of the bridge.

The existing machinery for existing moving the spans shall also be designed for the stress caused by the greater of the starting torque or the breakdown torque of electric motors, using unit stresses 50 percent greater than the normal allowable stress.

Existing structures that do not meet this provision should be evaluated for signs of machinery distress. In the absence of visible evidence of distress in the components of a functioning drive system that has a satisfactory performance history, it may

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not be necessary to replace the nonconforming components. When an existing nonconforming drive system is left in place, consideration should be given to addition of electrical monitoring and control measures to reduce actual applied motor torque or to trip a relay and disable the motor circuit in an over-torque condition. Replacement drive systems should be designed to meet this provision.

Gear tooth design shall meet AGMA standards for surface durability (pitting resistance) and bending strength.

Existing gears should be evaluated based on condition and performance, and should not be replaced solely based on this current specification provision. Replacement gears should be designed to meet current specifications.

Two sets of brakes, motor and span or leaf holding, are required for bridge operation.

Existing bridges that do not at present have two sets of brakes (motor and span or leaf holding), should be evaluated based on the site specific criteria. Many existing spans have only motor brakes. For a bascule bridge with a small positive toe reaction, brake failure may result in some difficulty holding the span or leaf in the open position, and might cause uncontrolled closing motion if the operator does not hold the span open with the span motor. If the structure is heel heavy when seated and the brakes fail, then only the locks can prevent uncontrolled span or leaf motion. If locks are nonexistent or inoperable, brake failure could be a hazard. Based on the level of potential hazard the evaluator can determine the need for the second set of brakes. In general, compliance with this code provision is preferred.

4.2.5 ELECTRICAL PROVISIONS

Testing of replacement motors and generators must be done in accordance with the latest requirements of the NEMA standards for motor/generators.

It is required that replacement span or leaf drive motors be tested in accordance with the latest requirements of NEMA standards for motor/generators. It is also required that all other replacement electric motors that are not for span or leaf drive be given a short commercial test in conformance with NEMA requirements.

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All motors must be of the totally enclosed, fan cooled type and be constructed as nearly waterproof as possible.

Existing span or leaf drive motors, span or leaf lock motors, and other motors vital to movable span or leaf operation that are not totally enclosed fan cooled type motors should be evaluated for exposure to the intrusion of runoff water or other environmental conditions that can cause rapid motor deterioration and shorting of the motor electrical system. If deterioration or shorting is deemed likely or has been a problem in the past, conforming replacement motors would be preferred. For installations without problem conditions, the evaluator should consider corrective action, such as construction of a protective machinery enclosure or other measures to increase motor protection.

Limit switches are required to stop motors and set brakes automatically at each end of travel.

Existing movable bridges that are not equipped with limit switches to stop span or leaf motors and set brakes automatically at each end of travel should be evaluated to determine whether structural or machinery overstress is likely due to result from over travel during span or leaf motion. In addition, the existing procedures for manually setting the brakes at each end of travel should be evaluated during rehabilitation studies. It should be determined whether overstress is likely or if there is a record of incident reports relating to problems caused by the operator's failure to set the brakes at each end of travel. If so, then corrective action should be taken to revise procedures and install air buffers or other corrective measures. In general, installation of limit switches to stop motors and set brakes automatically is preferred.

An interlocking sequence of steps in order to open and close the bridge is required.

Existing bridge control systems that do not provide an interlocking sequence of steps in order to open and close the movable structure should be evaluated for the efficacy of current procedures in use by operators to ensure public safety. Existence of any incident reports that show damage or accidents resulting from out of sequence bridge operation should require that immediate corrective action be taken to improve operational procedures. Printed operation checklists or computerized checklists that require the operator to read and respond to a set sequence of steps before proceeding to the next may prove effective in avoiding out of sequence operation due to operator error. On structures where incidents resulting from out of sequence operation cannot be entirely eliminated by procedural improvements, installation of an interlocking system that prevents out of sequence operation is preferred during the next scheduled rehabilitation.

Indicator lights are required to show various positions of the bridge at operator's console.

Installation of voltmeters and ammeters on the control panel indicator lights and span or leaf motor switches, bypass switches and seating switches in conformance with current specifications are preferred during any control panel rehabilitation.

4.2.6 IMPLEMENTATION OF CORRECTIVE MEASURES

The criteria used to decide whether specific provisions of current specifications should be applied and whether other corrective measures should be taken immediately or during subsequent rehabilitations should be based upon assessment of the degree of potential hazard to workers or the public if no action is taken and upon the severity of potential consequences and feasibility of any proposed retrofit upgrading. Prioritization of repairs is discussed in Chapter 4.1.

4.2.7 ANALYSIS OF IN-SERVICE MOVABLE BRIDGES

The above discussions are typical of the evaluation process used in applying provisions of current design specifications to in-service movable bridges. It is not mandatory that existing bridges meet every provision of the current specifications,

The quantitative analysis of existing movable bridges and their components is covered in Chapter 4.3 of this Manual.

CHAPTER 4.3 – ANALYSIS OF IN-SERVICE MOVABLE BRIDGES

4.3.1 GENERAL

The purpose of this chapter is to provide guidance for the basic analysis of an in-service movable bridge under actual operating conditions. The goal of such analysis is to verify that the functional systems of the movable bridge are capable of operating safely under imposed loads.

It is intended that this analysis be based on the methods presented in the AASHTO *LRFD Movable Highway Bridge Design Specifications* (Reference 7) and the discussion in Chapter 4.2. This chapter provides additional guidance for adapting the Reference 7 criteria for new bridges to the analysis of in-service bridges. The analysis should evaluate the primary structural, mechanical, hydraulic and electrical components that together provide operational reliability and safety of the bridge in the closed position carrying traffic and in the open, operating position.

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

- Live load capacity (Inventory/Operating rating)
- Performance checks
- Systems analysis

The live load capacity can be determined using procedures described in Reference 9. The movable bridge in the closed position is treated similarly to a fixed bridge. Consideration must be given in the analysis to the effects of the counterweight, mechanical end lifts, shear locks and other support devices that modify support conditions in accordance with Reference 7.

A qualitative review of the performance characteristics of the movable bridge during operation can identify deficiencies. The intent of this performance check is to determine if the bridge is adequately providing its intended service. The evaluator should review the bridge logs and other operating and maintenance records to establish that the bridge operates satisfactorily under the existing range of in-service conditions.

A quantitative systems analysis should be performed on the primary structural, mechanical, hydraulic, and electrical components using the procedures, loads and load combinations specified in Reference 7. To realistically analyze an in-service bridge, consideration should be given to the age of the structure and the codes under which it was originally designed. This chapter provides guidance for establishing allowable stress and operating parameters based on historic code data. The strict application of Reference 7 design criteria is not uniformly appropriate to such analysis. Engineering judgment is required

C4.3.1

The type of movable span and the particular details used in the construction of that type are key components in the evaluation process. The support details and condition of locks, stops, etc. can affect the distribution of dead and live load reactions. For a swing span, the type of live load shoes or wedges, continuity of main members, and substructure support conditions should be considered in the analysis. The type of bascule span affects the analysis. A rolling lift (Scherzer type) bascule span has different concerns than a fixed trunnion bascule span. Both types use gear locks, heel stops, live load shoes, counterweights, and counterweight stops, however, the rolling-lift bascule spans have track girders, segmental girders and tread plates that should be analyzed. The fixed trunnion bascule span uses trunnion pin bearings and support framing that should be analyzed. For other types of movable bridges, the bridge type and details used should be determined and evaluated/or support conditions in the field investigation and analysis.

The presence of a skew angle that creates torque or unusual loadings on any load carrying member should also be determined and evaluated for its effects on the structure analysis.

The connections of any primary load carrying members should be evaluated. The use of riveted or bolted connections may have a higher resistance to fracture and fatigue than the use of welded connections. Blocked flanges, coped webs and other reentrant cuts in steel members are susceptible to fatigue cracking.

in the determination of procedures and acceptance criteria for the analysis.

4.3.2 DEAD LOAD EFFECTS

Accurate determination of the magnitude and distribution of dead loads is a critical requirement in the analysis of movable bridges.

Detailed calculations should be performed to quantify the amount and location of existing dead loads. Detailed calculations require a thorough review of as-built plans, shop drawings, maintenance and repair records, inspection reports and related documentation. Site visits should be made to verify available information and obtain additional data. Basic structural configuration and typical primary and secondary member sizes should be field verified and any undocumented alterations to the bridge should be field measured as necessary to provide engineering assurance that the dead load calculations will be accurate. Thicknesses of elements such as deck, sidewalk, machinery floor overlay and paint can vary substantially from plan values and should be verified. Inspection and maintenance records of previous repairs, balance tests, and addition of adjustment weights should be field verified.

If the current state-of-balance, location of center of gravity, rotational moment of inertia, gross weight, and other necessary machinery design parameters of the bridge cannot be reliably established by calculations or if operational problems or excessive wear of machinery components have been reported, these bridge characteristics should be determined by strain gauge, load cell jacking to measure reactions, or other field test methods. Accurate determination of these critical bridge parameters is vital to reliable analysis of structural, mechanical and electrical performance.

4.3.3 LOAD RATING

Bridge structural load rating calculations should be performed to determine the safe load capacity when the movable spans are in the closed position and carrying normal vehicular traffic. Procedures for load rating of fixed bridges provided in Reference 9 also apply to movable bridges.

Load ratings should be calculated at the inventory and operating levels considering the effects of dead, live, and impact loads only. Various standard live loads and known overload trucks may be used for analysis based on owner needs.

Analysis methodology, allowable stresses and other

C4.3.3

Reference 9 contains recommended allowable stresses for aged structural steel members. The relationship between structure age and yield strength is presented in Reference 9 and should be maintained for use in related formulas contained in Reference 7.

necessary rating procedures should be based on the requirements of References 7 and 9.

Analysis of swing-span bridges in the closed position with the wedges driven should consider the measured end lifts in the stress calculations when the spans are of continuous or partially continuous construction.

4.3.4 PERFORMANCE CHECKS

An existing movable bridge should be evaluated based on its ability to meet user needs in a safe and reasonably efficient manner. The objective is to qualitatively evaluate the structure's performance related to needs rather than to compare an aged but functioning design to current AASHTO design standards. To this end, the evaluator should review available information from plans, calculations, inspection data, logs, operator interviews, maintenance records and other pertinent documents in order to determine how well the bridge operates under service conditions.

The primary performance check is to establish that a complete operating system exists. The evaluator should review each functional system (see Chapter 2.9) to determine whether it is complete, operational, and performing adequately.

If all functional systems satisfy the performance checks, then their adequacy for long term service should be assessed. Section 4.3.5 discusses procedures for a quantitative analysis of the system components. In the event that one or more functional systems do not satisfy the performance check, the evaluator should determine the necessary corrective action and its priority for implementation. The procedures in Reference 7 as amended by Section 4.3.5 present an analytical approach to provide the basis for selecting proposed corrective actions.

In general, the design of replacement systems should be governed by the requirements of Reference 7 as discussed in Chapter 4.2. The design criteria selected from Reference 7 must result in components that are compatible with the existing systems that are to remain. Caution and engineering judgment are required to adapt code provisions to confirm that new components do not cause overstress in existing elements.

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

The performance check should include an assessment of the adequacy of existing bridge opening times under both normal and severe service conditions. This assessment should be a

C4.3.4

An example of a potential cause of overstress would be an electric drive motor replaced with a new motor that generates a higher starting torque that exceeds the capacity a/the existing machinery that is to remain. The torque and speed characteristics of electric motors are subject to a wide degree of variation between manufacturers and also between different motors from the same manufacturer.

practical determination of whether the bridge operating times meet user needs. If adequate, the opening time under normal service should be used to set the "normal time for opening" in the systems analysis. If the opening time is found inadequate for user needs, a systems analysis should be performed to determine if improvement is feasible.

4.3.5 SYSTEMS ANALYSIS

The systems analysis determines stress or other vital load effects on the existing components. These effects are computed using the current design standard (Reference 7) loads and load combinations applied to the existing systems. The results are then compared to allowable values that consider the age and condition of the element.

C4.3.5

Evaluators will seldom find an existing movable bridge that meets all the criteria presented in Reference 7. It is important for evaluators to recognize many existing bridges were designed and built under outdated codes and will not satisfy the current AASHTO design standards in many areas. For this reason, the performance check is significant. The primary criterion for an existing bridge is that it should provide functional, safe, reliable service. Compliance with current design standards should be used to identify potential safety hazards or possible future breakdowns due to overstress. These components can then be scheduled for monitoring during subsequent inspections or upgraded as needed.

4.3.5.1 Structural Analysis

In order to determine whether an in-service movable bridge can safely operate under the applied loading conditions, analysis prescribed for the bridge type in Reference 7 should be performed. This should become part of the bridge inventory file and should serve as a baseline analysis for future comparisons as conditions change.

The analysis should consider dead load, wind load, ice load and other loads, load cases and effects as per Reference 7 based upon the engineering judgment of the designer and the needs of the bridge owner. The maximum combined stresses in the structural members under any loading case or load group should not exceed the allowable stresses at operating level provided in Reference 9.

Operating conditions that result in member stresses exceeding the operating level allowable stresses are potentially hazardous. The evaluator should determine the need to impose operating restrictions or implement other corrective actions.

As part of future inspections, the analysis of safe operating conditions should be reviewed and updated to reflect any relevant changes in condition or loading.

4.3.5.1.1 Wire Rope Analysis

The design of new wire ropes for movable bridges is covered in Reference 7. Allowable stresses in wire rope are expressed as a fraction of their ultimate strength. For many existing movable bridges, information on the ultimate strength of existing wire rope is unavailable. The following data is taken from Reference 8, which was published in 1927. This information is based upon properties of wire rope manufactured in the early 1900's and provides a reasonable lower bound for determining allowable stresses for wire rope on bridges of that era. It is probable that a wire rope placed in the 1920's has been replaced. However, if a wire rope in-service on an existing structure is of indeterminate age, it is reasonable and conservative to use the presented values in the absence of better information.

The direct tension in counterweight and operating wire ropes should not exceed the appropriate fraction, as per Reference 7 of the minimum specified ultimate strength, given in Tables 4.3.5.1.1-1 and 4.3.5.1.1-2, less the equivalent tension due to bending as specified in the commentary. For wire ropes of unknown age, but placed after 1988, the ultimate strength should be determined according to Reference 7.

C4.3.5.1.1

Bending stresses in wire ropes: *When a wire rope is bent over a sheave or drum, the bending stress and equivalent tension on the rope should be calculated as follows:*

$$S = E_R d / D$$

$$T = Sa.$$

a = Area of metal (sq. in.)
d = the diameter of the wires in the rope (in.)
D = the diameter of the sheave to the center of the rope (in.)
S = the unit stress in the wires making up the rope (psi)
T = the equivalent total tension stress in the rope due to bending it around the sheave (lbs.)
The values of a and d are given in Tables 4.3.5.1.1-1 and 4.3.5.1.1-2.

For the types of rope in Tables 4.3.5.1.1-1 and 4.3.5.1.1-2, the maximum value of E_R should be taken as 12,000,000 psi (82, 737 MPa).

Dimension and Construction				Minimum Ultimate Strength in Pounds		
Diameter of Rope, In.	Construction	Approx. Area of Metal Section, Sq. In. a	Approx Average Diam. of wire, In. d	A Extra Strong Crucible Cast Steel	B Plow Steel	C Monitor Steel (Improved Plow Steel)
1/2	6 x 19	0.108	.032	18,000	19,000	20,000
5/8	6 x 19	0.166	.041	28,000	30,000	32,000
3/4	6 x 19	0.229	.050	38,000	42,000	46,000
7/8	6 x 19	0.314	.058	50,000	56,000	62,000
1	6 x 19	0.405	.065	66,000	73,000	80,000
1 1/8	6 x 19	0.505	.074	83,000	90,000	100,000
1 1/4	6 x 19	0.612	.082	102,000	110,000	120,000
1 3/8	6 x 19	0.753	.090	123,000	135,000	148,000
1 1/2	6 x 19	0.909	.098	142,000	158,000	178,000
1 5/8	6 x 37	1.010	.074	160,000	180,000	200,000
1 3/4	6 x 37	1.155	.079	185,000	205,000	225,000
1 7/8	6 x 37	1.324	.085	212,000	235,000	255,000
2	6 x 37	1.520	.091	242,000	270,000	290,000
2 1/8	6 x 37	1.695	.096	270,000	300,000	325,000
2 1/4	6 x 61	1.912	.079	298,000	330,000	360,000
2 3/8	6 x 61	2.084	.083	324,000	360,000	400,000
2 1/2	6 x 61	2.370	.088	360,000	390,000	445,000

Table 4.3.5.1.1-1 – Dimensions and minimum ultimate strengths of fiber core wire ropes in customary U.S. units

Dimension and Construction				Minimum Ultimate Strength in kN		
Diameter of Rope, mm	Construction	Approx. Area of Metal Section, Sq. mm a	Approx Average Diam. of wire, mm d	A Extra Strong Crucible Cast Steel	B Plow Steel	C Monitor Steel (Improved Plow Steel)
12.70	6 x 19	69.68	0.81	80.07	84.52	88.96
15.88	6 x 19	107.09	1.04	124.55	133.45	142.34
19.05	6 x 19	147.74	1.27	169.03	186.83	204.62
22.23	6 x 19	202.58	1.47	222.41	249.10	275.79
25.40	6 x 19	261.29	1.65	293.58	324.72	355.86
28.58	6 x 19	325.80	1.88	369.20	400.34	444.82
31.75	6 x 19	394.83	2.08	453.72	489.30	533.79
34.93	6 x 19	485.80	2.29	547.13	600.51	658.34
38.10	6 x 19	586.44	2.49	631.65	702.82	791.78
41.28	6 x 37	651.60	1.88	711.72	800.68	889.64
44.45	6 x 37	745.15	2.01	822.92	911.89	1,000.85
47.63	6 x 37	854.18	2.16	943.02	1,045.33	1,134.30
50.80	6 x 37	980.63	2.31	1,076.47	1,201.02	1,289.98
53.98	6 x 37	1,093.53	2.44	1,201.02	1,334.47	1,445.67
57.15	6 x 61	1,233.53	2.01	1,325.57	1,467.91	1,601.36
60.33	6 x 61	1,344.49	2.11	1,441.22	1,601.36	1,779.29
63.50	6 x 61	1,529.01	2.24	1,601.36	1,734.81	1,979.46

Table 4.3.5.1.1-2 – Dimensions and minimum ultimate strengths of fiber core wire ropes in SI units

CHAPTER 4.3 – ANALYSIS OF IN-SERVICE MOVABLE BRIDGES

4.3.5.2 Analysis of Power Requirements

In cases where bridge operators encounter operational difficulty in high wind or other extreme operating conditions, the evaluator should analyze the power requirements for the bridge. The power requirements should also be evaluated if the main drive machinery exhibits signs of distress such as cracks or plastic flow.

The power rating of the bridge operating motor or engine should be compared to the calculated power requirements for the starting, accelerating, and constant velocity conditions as found in *LRFD Movable Highway Bridge Design Specifications*, Reference 7. The normal time for opening should be based upon actual bridge operating time, as discussed in Section 4.3.4.

In cases where calculations indicate that the bridge is underpowered and operators encounter operational difficulty in high wind or other extreme operating conditions, rehabilitation should be considered.

If calculations show a bridge to be overpowered, the evaluator should investigate whether the existing drive machinery is capable of withstanding the applied torque over the long term. When the calculations and motor performance data show the motor to be unnecessarily strong, the system may not require replacement if there is a history of trouble free operation with no visible signs of distress. A motor that is a recent replacement having no established history should be a source of concern, and may require testing to verify that machinery is not being overstressed.

4.3.5.3 Machinery Analysis

All mechanical components from the primary span drive to the span brake should be analyzed for the operating conditions specified in the *LRFD Movable Highway Bridge Design Specifications*, Reference 7 and as per Chapter 4.4 herein.

As the operating machinery of some in-service movable bridges is proprietary, sufficient information may be lacking to permit a detailed quantitative analysis. To this end the evaluator should make reasonable efforts to locate the necessary information by reviewing available bridge drawings and specifications, manufacturer's literature and other pertinent publications. Where possible, information should be solicited directly from the manufacturer. Hardness testing may be used to approximate the yield stress of unknown quality metallic materials.

CHAPTER 4.3 – ANALYSIS OF IN-SERVICE MOVABLE BRIDGES

AASHTO's original movable bridge design specification was published in 1938 (Reference 8d), with subsequent versions published in 1953, 1970, 1978, 1988, and 2007 (Reference 7). *Movable Bridges, Volume II—Machinery* by Hovey (Reference 102) was published in 1927 and contained allowable stress tables for machinery design. The allowable stresses in the 1927 Hovey and 1938 AASHTO are quite similar. The 1938 AASHTO *Standard Specifications for Movable Highway Bridges* is included in the Appendix to allow comparison with current Reference 7 requirements.

A summary of allowable unit stresses for machinery parts given in these references is shown in Table 4.3.5.3-1. For movable bridges built after 1930, the 1938 AASHTO (Reference 8d) allowable stresses could be conservatively applied. For movable bridges that pre-date 1930, a 10 percent reduction in allowable stresses from the 1938 values is preferred unless documentation of materials allows using higher values. For movable bridges that pre-date 1900, a 20 percent reduction in allowable stresses from the 1938 values is preferred unless documentation of materials allows using higher values.

If the calculated stresses in the machinery parts under any load combination exceed the Table 4.3.5.3-1 allowable stresses by more than 50 percent, the mechanical component should be investigated further in the field for condition and performance. The components should be monitored for progressive distress. Components with excessive calculated stresses that show ongoing distress should be considered to have a high probability of failure and should be scheduled for replacement.

4.3.5.4 Hydraulic Analysis

Hydraulic systems should be analyzed by the methods contained in Reference 7. Systems that exhibit working pressures over 3,000 psi (20600 kPa) under severe loading conditions (such as holding against maximum wind loads) should be considered subject to early failure unless all affected components have clearly documented allowable working pressure ratings that exceed 3,000 psi (20600 kPa).

Flexible hoses and hose fittings should be considered subject to early failure unless their allowable working pressure ratings exceed 1.66 times the actual system pressures. The safety factors and other details of analysis used to evaluate hydraulic systems should be based upon the requirements of Reference 7, *LRFD Movable Highway Bridge Design Specifications*.

Older hydraulic systems that are designed with pressures which do not conform to Reference 7 should be considered as

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Flexible hoses and hose fittings for high pressure lines should be rated for 5,000 psi (34333 kPa) as required by Reference 7, or should be noted as not conforming to current practice in the inspection report.

likely to experience early failure unless the maximum working pressure rating of all components (as defined in Reference 7) exceeds the maximum actual system pressures imposed on the components during use.

Flare fittings on tubing or threaded fittings on pipe should generally be considered subject to early failure and should generally be scheduled for early replacement. These types of fittings should not be permitted for replacement lines.

Material	1970 THRU 1988 AASHTO Reference 3	1953 AASHTO Reference 4e	1938 AASHTO Reference 4f	1927 Hovey Reference 8
Pivots of Swing Bridges* Hardened Steel/Alloy Bronze (Alloy 913)	3,000	(Alloy A) 3,000	3,000 (Alloy A) 2,000 (Alloy B)	(Alloy unknown) 3,500
Pivots of Swing Bridges* Hardened Steel/Alloy Bronze (Alloy 911)	2,500			
Trunnion Bearings and Counterweight Sheave Bearings Rolled or Forged Steel/Bronze (Alloy 911)	1,500* 2,000 (at rest)	(Alloy B) 1,500* 2,000 (at rest)	1,500*	2,000* (phosphor-bronze)
Shaft Journals	1,000 (steel/bronze alloy 937) 600** (steel/bronze alloy 937) 250,000/Nd (steel/bronze) 400** (steel/babbit or cast iron)	300,000/Nd**	750* (steel/bronze) 600* (steel/cast iron) 600* (steel/babbit) 500* (cast iron/cast iron) 300,000/Nd**	750* (steel/bronze) 600* (steel/cast iron) 600* (steel/babbit) 400* (cast iron/cast iron) 300,000/Nd**
Wedges* Cast Steel/Cast Steel or Cast Steel/Structural Steel	1,500*	1,500* 16,000 (at rest)	1,500* (any material) 16,000 (at rest, cast steel) 12,000 (at rest, cast iron)	1,500* 16,000 (at rest)
Acme Screw (transmitting motion) Rolled or Forged Steel/Bronze	(Alloy 905) 1,500* 220,000/Nd**	350,000/Nd up to 2,500 maximum	262,500/Nd (steel/steel) 350,000/Nd (steel/bronze)	
Axles of Balance Wheels*	1,000 (shaft journals steel/ bronze alloy 937)	1,500 (steel/bronze alloy C) 2,000 (steel/bronze alloy B)	1,500 (steel/cast iron or steel)	1,500 (steel/cast iron or steel)
Bearings** (at high speeds)	250,000/Nd (steel/bronze sleeve bearings) 60,000/Nd (hardened/balance step bearings)	80,000/Nd (steel/bronze)	60,000/Nd (steel/cast iron) 60,000/Nd (cast iron/cast iron) 80,000/Nd (steel/bronze)	60,000/Nd (steel/cast iron) 60,000/Nd (cast iron/cast iron) 80,000/Nd (steel/bronze) 20,000/Nd (steel/steel)
Pivot or Step Bearings **	1,200* (hardened steel/bronze alloy 911) 600* (hardened steel/bronze alloy 937) 60,000/Nd** (hardened steel/bronze)	100,000/Nd (steel/bronze)	100,000/Nd (steel/cast iron) 300,000/Nd (steel/bronze journals)	100,000/Nd
Thrust Collars** Rolled or Forged Steel/Bronze (Alloy 905)	200 but < 50,000/Nd			
Cross-head Slides (speeds < 600 ft./min)	50			

Notes:

* Speeds not exceeding 50 feet per minute

** Speeds exceeding 50 feet per minute

Bronze Alloy (Class) B is roughly equivalent to Alloy 911

Bronze Alloy (Class) C is roughly equivalent to Alloy 937

N = rpm

d = diameter of pivot, journal, step bearing or mean diameter of collar or screw in inches

AASHTO Standard Specifications for Movable Highway Bridges published in 1970, 1978, and 1988 have identical allowable stresses for these items

Table 4.3.5.2-1 – Allowable stresses in machinery parts in U.S. customary units; all stresses are psi

1988 AASHTO
Reference 3

-*Strength of Gear Teeth*

In the design of spur gears, bevel gears, and helical gears, the load shall be taken as applied to only one tooth.

The tooth profile for spur, bevel and helical gears shall be the 20 deg., full depth involute or stub involute and shall be of the proportions stated in Art. 2.6.11. (Reference 3)

The allowable load on gear teeth shall conform to the following formulas:

(A) Spur gears and Bevel gears

For full-depth involute teeth

$$W = fsp\,(0.154 - \frac{0.912}{n})\ \frac{600}{600+V}$$

or

$$\left(fsp\,(0.154 - \frac{0.912}{n})\ \frac{183}{183+V}\right)$$

For stub involute teeth

$$W = fsp\,(0.178 - \frac{1.033}{n})\ \frac{600}{600+V}$$

or

$$\left(fsp\,(0.178 - \frac{1.033}{n})\ \frac{183}{183+V}\right)$$

In the above formulas:

W = allowable tooth load, in pounds (MN)
p = circular pitch, in inches (m)
s = allowable unit stress, in pounds per square inch (MPa)
f = effective face width, in inches (m)
n = number of teeth in gear
V = velocity of pitch, in feet per minute (m/min.)

The effective face width for spur and bevel gears shall be the full face width up to 3 times the circular pitch; for greater face widths, the effective width shall be 3 times the circular pitch but not less than 1/2 the full width.

The effective face width for helical gears shall be the net active width of face measured parallel to the axis of the bore.

For calculating the strength of bevel gear teeth, the middle section of the tooth shall be taken. The number of teeth "n" in the above formulas for bevel gear teeth shall be the formative number which, for the pitch is determined as follows:

$$n = np\sqrt{1+\left(\frac{np}{ng}\right)^2}$$

where np = actual number of teeth in pitch
ng = actual number of teeth in gear

Allowable stresses in PSI (MPa) for cut gear teeth:

Bronze	9,000	(62.053)
Cast steel	16,000	(110.316)
Class C forged carbon steel AASHTO M102 (ASTM A668 Class C)	20,000	(137.895)
Class D forged carbon steel AASHTO M102 (ASTM A668 Class D)	22,500	(155.131)
Forged alloy steels	60 percent of yield point in tensions, but not more than 1/3 of ultimate strength in tension	

The allowable stress in pounds per square inch (MPa) for machine molded teeth shall be:

Cast steel	8,000	(55.158)

For racks and their pinions and all other mating gears and pinions which are not supported in, and shop-assembled in, a common frame the allowable unit stresses shall be decreased 20 percent.

1938 AASHTO
Reference 4f

-*Design of Spur gears*

The permissible tooth load shall be determined from the formula:

$$W = S\,p\,f\,y$$

In this formula:
W = the permissible tooth load in pounds (MN)
S = the permissible fiber stress in pounds per square inch (MPa)
p = the circular pitch in inches (m)
f = the face width of the gear in inches (m)
y = a factor depending upon the number and form of the teeth

The values of S shall be determined from the formula:

$$S = S\left[1-\frac{1}{4200}\sqrt{6200V-V^2}\right] \qquad S = S\left[1-\frac{1}{21.34}\sqrt{31.5V-V^2}\right]$$

In which
V = the velocity at the pitch of a gear in feet per minute (m/sec)
S = the permissible fiber stress on a gear tooth when running at a velocity of V at the pitch in PSI (MPa)

S_n shall have the following values in pounds per square inch (MPa):

		Values of S_n
Class C forged steel gears		22,000 (151.685)
Cast steel gears	20,000	(137.895)
Phosphor-bronze gears		10,000 (68.948)
Cast iron gears	8,000	(55.158)

The values of y shall be determined as follows:

Form of gear teeth	Values of y
For 20 deg. involute stub teeth (Nuttall system)*	$0.178 - \frac{1.033}{N}$
For 20 deg. involute teeth	$0.154 - \frac{0.912}{N}$
For 14½ deg. involute teeth	$0.124 - \frac{0.684}{N}$
For radial flank teeth	$0.075 - \frac{0.276}{N}$

* Use no pitch with less than 14 teeth

For these formulas N is the number of teeth on the gears.

-*Design of Bevel Gears*

Bevel gears shall be designed in the same manner as spur gears with the following modifications:

$$W_1 = S\,p\,f\,y_1\frac{d}{D}$$

In which
W_1 = the permissible tooth load at the outside pitch in pounds (MN)
d = the pitch at the inside end of the teeth in inches (m)
D = the pitch at the outside end of the teeth in inches (m)

The value used for y_1 shall be that corresponding to the number of teeth, N.

The value of N shall be determined from the formula:

$$N = n\sqrt{1+\left(\frac{n}{n_1}\right)^2}$$

In which
n = the number of teeth on the pitch
n_1 = the number of teeth on the mating gear

Bevel gears shall be designed so that $\frac{d}{D}$ shall not be less than $^2/_3$.

1927 Hovey
Reference 8

Teeth of spur gears - The entire load shall be assumed to be carried by one tooth. The permissible tooth load shall be determined from the formula:

$$W = S\,p\,f\,y$$

In this formula:
W = the permissible tooth load, in pounds (MN);
S = the permissible fiber stress, in pounds per square inch (MPa);
p = the circular pitch, in inches (m);
f = the face of the gear, in inches (m);
y = a factor depending upon the number and form of the teeth.

The values of S shall be determined from the formula:

$$S = S\left\{1-\frac{1}{4200}\sqrt{6200V-V^2}\right\} \qquad S = S\left\{1-\frac{1}{21.34}\sqrt{31.5V-V^2}\right\}$$

in which V = the velocity at the pitch of a gear, in feet per minute (m/sec);
S = the permissible fiber stress on a gear tooth when running at a velocity of V at the pitch in PSI (MPa)

S_n shall have the following values in pounds per square inch (MPa):

		Values of S_n
Class C forged steel gears	22,000	(151.685)
Cast steel gears	20,000	(137.895)
Phosphor-bronze gears	10,000	(68.948)
Cast iron gears	8,000	(55.158)

The values of y shall be determined as follows:

Form of gear teeth	Values of y
For 20 degree involute stub teeth (Nuttall system)[1]	$0.178 - \frac{1.033}{N}$
For 20 degree involute teeth	$0.154 - \frac{0.912}{N}$
For 14½ degree involute teeth	$0.124 - \frac{0.684}{N}$
For radial-flank teeth	$0.075 - \frac{0.276}{N}$

For these formulas N is the number of teeth on the gears.

[1] Use no pitch with less than 14 teeth

Bevel gears - Bevel gears shall be designed in the same manner as spur gears with the following modifications:

$$W_s = S\,p\,f\,y_1\frac{d}{D}$$

In which
W_s = the permissible tooth load at the outside pitch, in pounds (MN);
d = the pitch at the inside end of the teeth in inches (m);
D = the pitch at the outside end of the teeth in inches (m).

The value used for y_1 shall be that corresponding to the number of teeth, N.

The value of N shall be determined from the formula:

$$N = n\sqrt{1+\left(\frac{n}{n_1}\right)^2}$$

In which
n = the number of teeth on the pitch;
n_1 = the number of teeth on the mating gear.

Bevel gears shall be designed so that $\frac{d}{D}$ shall not be less than $^2/_3$.

Table 4.3.5.3-2 – Allowable stresses in machinery parts in SI units; all stresses are MPa

Material	1970 THRU 1988 AASHTO Reference 3	1953 AASHTO Reference 4e	1938 AASHTO Reference 4f	1927 Hovey Reference 8
Pivots of Swing Bridges* Hardened Steel/Alloy Bronze (Alloy 913)	20.684	(Alloy A) 20.684	20.684 (Alloy A) 13.790 (Alloy B)	(Alloy unknown) 24.132
Pivots of Swing Bridges* Hardened Steel/Alloy Bronze (Alloy 911)	17.237			
Trunnion Bearings and Counterweight Sheave Bearings Rolled or Forged Steel/Bronze (Alloy 911)	10.342* 13.790 (at rest)	(Alloy B) 10.342* 13.790 (at rest)	10.342*	13.790* (phosphor-bronze)
Shaft Journals	6.895 (steel/bronze alloy 937) 4.137** (steel/bronze alloy 937) 43.788/Nd (steel/bronze) 2.758** (steel/babbit or cast iron)	52.546/Nd**	5.171* (steel/bronze) 4.137* (steel/cast iron) 4.137* (steel/babbit) 3.447* (cast iron/cast iron) 52.546/Nd**	5.171* (steel/bronze) 4.137* (steel/cast iron) 4.137* (steel/babbit) 2.758* (cast iron/cast iron) 52.546/Nd**
Wedges* Cast Steel/Cast Steel or Cast Steel/Structural Steel	10.342*	10.342* 110.316 (at rest)	10.342* (any material) 110.316 (at rest, cast steel) 82.737 (at rest, cast iron)	10.342* 110.316 (at rest)
Acme Screw (transmitting motion) Rolled or Forged Steel/Bronze	(Alloy 905) 10.342* 38.533/Nd**	61.303/Nd up to 17.237 maximum	45.977/Nd (steel/steel) 61.303/Nd (steel/bronze)	
Axles of Balance Wheels*	6.895 (shaft journals steel/ bronze alloy 937)	10.342 (steel/bronze alloy C) 13.790 (steel/bronze alloy B)	10.342 (steel/cast iron or steel)	10.342 (steel/cast iron or steel)
Bearings** (at high speeds)	43.788/Nd (steel/bronze sleeve bearings) 10.509/Nd (hardened/balance step bearings)	14.012/Nd (steel/bronze)	10.509/Nd (steel/cast iron) 10.509/Nd (cast iron/cast iron) 14.012/Nd (steel/bronze)	10.509/Nd (steel/cast iron) 10.509/Nd (cast iron/cast iron) 14.012/Nd (steel/bronze) 3.503/Nd (steel/steel)
Pivot or Step Bearings **	8.274* (hardened steel/bronze alloy 911) 4.137* (hardened steel/bronze alloy 937) 10.509/Nd** (hardened steel/bronze)	17.515/Nd (steel/bronze)	17.515/Nd (steel/cast iron) 52.546/Nd (steel/bronze journals)	17.515/Nd
Thrust Collars** Rolled or Forged Steel/Bronze (Alloy 905)	1.379 but < 8.758/Nd			
Cross-head Slides (speeds < 3.048 m/s)	0.345			

Notes:

* Speeds not exceeding 0.254 m/s

** Speeds exceeding 0.254 m/s

Bronze Alloy (Class) B is roughly equivalent to Alloy 911

Bronze Alloy (Class) C is roughly equivalent to Alloy 937

N = rpm

d = diameter of pivot, journal, step bearing or mean diameter of collar or screw in meters

AASHTO <u>Standard Specifications for Movable Highway Bridges</u> published in 1970, 1978, and 1988 have identical allowable stresses for these items

Table 4.3.5.3-2 – Allowable stresses in machinery parts (continued)

CHAPTER 4.4 – VULNERABILITY TO EXTREME EVENTS

4.4.1 GENERAL

Vulnerability analysis and assessment of an existing movable bridge to extreme events is a process of identifying potential modes of sudden collapse, evaluating the level of risk and the likelihood of the failure. This chapter provides minimum guidelines for vulnerability studies.

Many failure risks identified for fixed highway bridges also apply to movable bridges such as: scour, vessel impact, vehicle overload, seismic events, brittle fracture and fatigue cracking. In addition, movable bridges are subject to additional risks resulting from the failure of mechanical, hydraulic, and electrical components and/or the failure of the bridge operator to control the span properly. Any of these events may not result in collapse, but could render the bridge inoperable. Where the level of risk of collapse or inoperability is deemed to be unacceptable to the owner, rehabilitation or retrofit should be considered and the priority of the work established.

Vulnerability assessment is performed for the purpose of identifying risks and developing mitigation measures to reduce or eliminate risks that the owner deems to be unacceptable. This chapter focuses on the risks of collapse, but there are also risks associated with failure to operate, risks to workers or the public and others that owners may also wish to access during the evaluation of the risk of structural collapse. Evaluators should determine if identified risks require immediate action or can await a later retrofit project. The evaluators performing vulnerability assessments must apply engineering judgment and require a high degree of judgment and expertise in the evaluation of movable bridges. Vulnerability assessment should be performed by an engineer with substantial experience in movable bridge design and operation. Each movable bridge presents unique potential vulnerabilities with outcomes that vary in degree of possible hazard based upon circumstances at the specific bridge site.

C4.4.1

Vulnerability is a complex issue on movable bridges and there are numerous scenarios that may have potentially hazardous outcomes. A discussion of possible failure causes in this chapter will provide a background for the engineer/evaluator to develop a vulnerability assessment. However, in view of the unique nature of many movable bridges it is noted that this chapter is limited primarily to a general discussion of the topic. Special studies may be necessary to develop the vulnerability study for an individual bridge.

Guidance on rehabilitation/retrofit of vulnerable bridges can be found in the references cited in Section 4.4.2. The probability of occurrence, and the severity of potential consequences, as described in Chapter 4.1, can be used to assist in prioritizing rehabilitation/retrofit decisions and in determining whether immediate or deferred action is appropriate.

4.4.2 FAILURE MODES

The identification of potential failure modes is the critical first step in any vulnerability analysis. Potential causes of bridge failures with suggested references for evaluation methodology include:

- Scour (Reference 70, 133, 157)
- Collision: Truck, train or navigational vessel

(Reference 4, 131, 152)
- Overload: Open or closed positions (Reference 134)
- Seismic: Open or closed positions (Reference 8b, 11, 135, 160b)
- Fracture: Due to fatigue or brittle fracture (Reference 42, 71, 82, 83, 136)
- Operational failure
- Wave/storm surge forces (Reference 5, 131)

4.4.2.1 Scour

The vulnerability of a movable bridge to scour damage should be evaluated on the basis of hydraulic, subsurface, and foundation conditions. The evaluation should include both a hydraulic assessment and a foundation assessment.

Movable bridge piers, especially bascule counterweight pit piers and swing-span pivot piers, tend to be wider than common fixed bridge piers and can create unique scour conditions. In addition, Scherzer-type bascule spans upon opening create a condition where the dead load reactions translate from one side of the pier to the other resulting in unique variations of bearing pressures in the foundation. Special studies may be required.

C4. 4. 2.1

The current state-of-the art procedures for the evaluation and inspection of bridges for scour can be found in the FHWA Technical Advisories commonly known as HEC-18 and HEC20 (References 70 and 157). These documents should be used by the engineer/evaluator to assess the movable bridge's vulnerability due to scour.

Channel constriction may affect the potential for scour. Tug boats passing very close to piers can scour the soil cover on a pier footing while maneuvering a vessel through the channel, and specific tug operations at the site should be considered. The potential effects of scour are more severe at movable bridges due to the span's sensitivity to bearing support changes. Bridges with problems such as jamming, fit-related difficulties, or misalignments should be evaluated for support settlement due to scour.

In addition to scour, flooding can be a direct hazard to the superstructure if the quantity of water exceeds the capacity of the bridge opening during a flood. Movable bridge structures that show evidence that flood water elevation has exceeded the structure freeboard (the water has risen above the bottom of the superstructure during a flood) should be scheduled for a special evaluation to determine the frequency of such floods and the potential consequences of such events.

4.4.2.2 Vehicle or Vessel Impact

The vulnerability of a movable bridge to sudden collapse as a result of impact should be assessed for train, truck, and navigational vessel impacts. Truck or train impacts in general may occur on through trusses, pony trusses, and through girder type movable spans in the closed position only, but may occur on substructure members at any time. Vessel impacts may occur at any part of the substructure or superstructure accessible from deep water in either the open or closed position.

The same parameters used to assess the potential for truck impacts on the superstructure of fixed bridges should be used in assessing movable bridges, including:

- ADTT
- Percentage of overloaded trucks
- Number and width of lanes on or under structure
- Vertical and horizontal clearances
- Location and type of barriers
- Type of wearing surface
- Bridge lighting and reflectors
- Posting-load limits and speed limits

Evidence of previous impact damage suggests the superstructure may be hit again. However, the probability of sudden collapse depends on the number and type of superstructure components exposed to a single impact and the consequences of the failure of those components. Structural redundancy of the damaged member(s) also affects the probability of collapse.

The evaluation of vessel impact with the movable span in the closed position is essentially the same as for a fixed bridge. The point of impact can occur at either the substructure or superstructure and may involve initial damage to pier protection systems.

The movable bridge superstructure in the closed position is generally more vulnerable to vessel impact than a fixed bridge due to its close vertical proximity to the water. Evaluation of vessel impact risks should include a determination of the most probable impact points and probability of superstructure failure due to such impacts. The movable bridge superstructure in the open position can be exposed to collision when the structure does not move completely out of the navigation clearance envelope or when the structure fails to open for a vessel that has committed itself to the navigation channel and cannot stop. An evaluation of the pier protection system should be performed to determine:

- If the system can safely redirect an errant vessel through the channel.

C4.4.2.2

The channel layout, approach geometry, water depths, winds and currents should be analyzed to develop navigational impact scenarios and possible consequences. Bridge and vessel characteristics should also become part of the analysis in order to determine the vulnerability to collapse (Reference 4).

- That the fender deflection does not allow the vessel to impact the retracted superstructure or the adjacent substructure.

The bridge components and pier protection systems should be analyzed for vessel impact forces as specified in the AASHTO *Guide Specification and Commentary for Vessel Collision Design of Highway Bridges* (Reference 4), as well as Section 3.14 of the AASHTO *LRFD Bridge Design Specifications, (Reference 7)*. The analysis should be based upon actual vessels that use the navigation channel. The analysis should consider the following cases, as appropriate, with the movable spans in either the open or closed position:

CASE I: No pier protection system exists. Structure to resist vessel impact.
CASE II: Existing pier protection system alone to resist vessel impact.
CASE III: If Case II fails then consider the vessel impact to be resisted jointly by the pier protection system and structure.

The performance goals for each bridge category under vessel impact forces should be similar to that for seismic loading (see Figure 4.4.2.2-1).

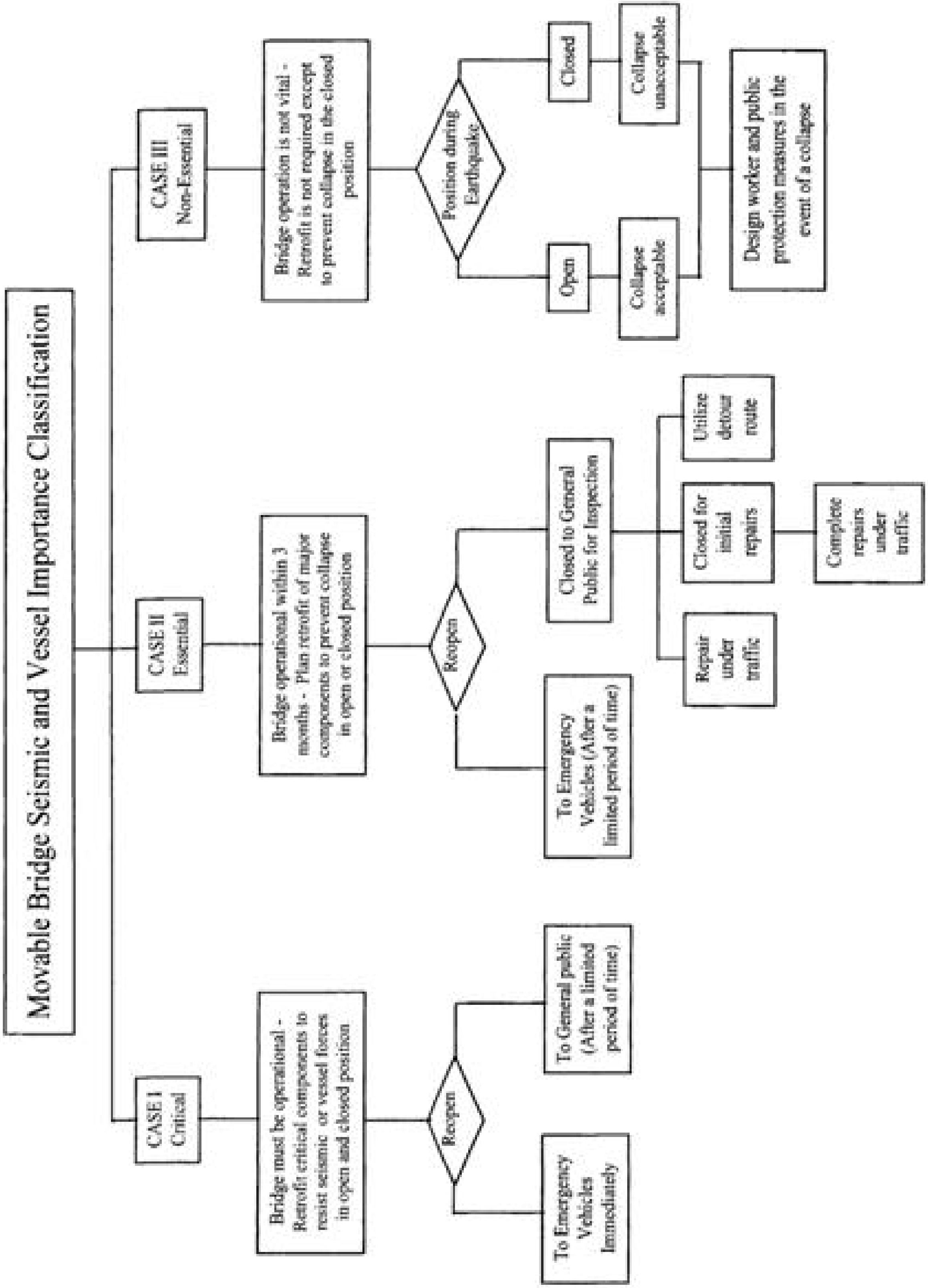

Figure 4.4.2.2-1 – Movable bridge seismic and vessel impact categories

CHAPTER 4.4 – VULNERABILITY TO EXTREME EVENTS

4.4.2.3 Overload

The vulnerability assessment for failure of a movable bridge due to overload should include a determination of the probability of an overloaded truck crossing the movable bridge and resulting in a collapse of the span. The probability of occurrence of a train of lighter trucks resulting in a lane load that is excessive should also be evaluated based upon the frequency of passage of typical overloads. This assessment should include a comparison of the probable overload with the ultimate structural resistance of the primary structural members.

The analysis to determine the probability that one overloaded truck or a group of trucks will cross the span should include the estimated ADTT, size and weight of the trucks observed during traffic counts and as allowed by overload permits, the total number of special overload permits allowed to cross the subject bridge, and predicted number of yearly overload permits. Additional considerations include the presence and amount of restrictive live load posting limits, operating rating of the critical members, and the availability and length of any detour used by trucks.

The ultimate structural resistance of the movable span shall be determined by a quantitative engineering analysis as described in Section 4.3.3. The ultimate structural resistance should be determined by considering the collapse mechanism of the movable span where the overloaded vehicle causes a stress level in a critical member or members that exceeds the yield point of the structural material. In some cases, a more detailed evaluation may be warranted including the use of physical load tests.

This assessment should result in the identification of the known types of vehicles that could cause sudden collapse of the span, the conditions required to cause such a collapse, and a determination of the probability of such an extreme event given the types of overloaded vehicles likely to be present.

C4.4.2.3

An analysis of the traffic records supported by local experience can assist in the determination of the probability that an overloaded truck will cross the movable bridge. It is obvious that at higher restrictive live load posting levels of a restricted bridge, the total population of trucks that could cause a sudden collapse of the structure decreases, resulting in less vulnerability to sudden collapse due to fatigue and overload (Reference 134).

Assessment of the local conditions at a movable bridge site should be done to identify the presence of unique conditions which may affect the probability of an overloaded vehicle crossing the span (Reference 134). Some of these conditions may include: posting of adjacent bridges near the movable bridge under consideration; the proximity of industries which routinely generate heavy trucks such as landfills, concrete plants, sand and gravel pits etc.

The determination of the structural resistance of the span should include identification of the critical members, potential collapse mechanisms, and structural redundancy inherent in the design. Increased redundancy of primary members results in an increased resistance to failure by overload since the load can redistribute and the structure may not fail as quickly, or may not fail at all. In certain cases on redundant structures it is possible for an individual member to fail without collapse of the span. Bridges where a large portion of the total stress in the critical members is from dead loads tend to have higher operating level rating factors and therefore have more reserve ultimate structural capacity.

4.4.2.4 Seismic

In active seismic regions the vulnerability assessment of movable bridges needs special attention because many of these bridges were originally designed for little or no lateral load.

C4.4.2.4

The seismic retrofit of an existing movable bridge to withstand the design seismic event in the open position is not always practical. For

Many existing movable bridges were constructed prior to the adoption of the AASHTO seismic design specifications. The design of new movable bridges is governed by the current AASHTO *LRFD Movable Highway Bridge Design Specifications* (Reference 7) which now refers to the seismic loads contained in the AASHTO *Standard Specification for Highway Bridges* (Reference 11) and specifies the movable span be designed for seismic loads in both the open and closed positions. Seismic loads and analysis procedures for the vulnerability study should be as presented in References 7 and 11 and as described below. References 74 to 78 provide additional guidance for seismic evaluation of bridges.

Movable bridges are more vulnerable when the bridge is in the open to marine traffic position than in the closed position.

Movable bridges should be analyzed with the movable spans in both the open and closed position. When the movable spans are in one position (open or closed) over 90 percent of the time, one-half the seismic load may be used for evaluation for the other position, unless a more detailed analysis is conducted per Abrahams, *Seismic Performance of Movable Bridges* (Reference 15).

Critical bridge components should be evaluated by the capacity/ demand ratio method for each potential mode of failure during a seismic event (Reference 74, 78). The component capacity is the ultimate force or displacement capacity. For the allowable stress method a 50 percent increase in inventory stresses for steel or timber and 33 percent increase in inventory stresses for concrete is permitted (References 7 and 11).

Analysis by the load factor methods or LRFD should be done with appropriate beta factors for steel, timber, and concrete to provide similarly calibrated safety factors as given for the working stress method.

Performance goals for in-service movable bridges under seismic loading are a function of the importance of the structure as determined by the bridge owner. Three categories are recommended to describe the importance of a bridge:

- Critical
- Essential
- Nonessential

The performance goal for each category is as follows (see Figure 4.4.2.2-1):

Critical Bridge: Should be designed to be functional for emergency vehicles and navigation immediately after a seismic event. Local failure of noncritical components may be permitted.

Essential Bridge: Should be designed against collapse in the fully open or closed positions. May be closed for a limited period of time for repairs after a seismic event. If it is not feasible to retrofit the structure to withstand the design seismic event while the structure is in motion, a risk analysis should be

critical or essential bridges, this may necessitate major rehabilitation.

Pedestrians and vehicles are not generally on the structure during operation, and vessels normally are not allowed to proceed through the channel until the span is fully open. In some cases, it may be possible to provide seismic restraints for the fully open and fully closed positions only, without the risk to mariners, vehicles and pedestrians. Providing seismic restraints during the bridge operation can be the most difficult and costly part of a seismic retrofit program. Since the amount of time that the structure is actually moving is typically a small percentage of each calendar day, the risk that a seismic event will occur during motion is reduced. If a bridge is not considered to be critical, the risk of failure due to a seismic event during operation may be tolerable.

considered to prioritize necessary rehabilitation work.

Nonessential Bridge: Might be allowed to collapse during span motion provided the structure is modified to provide ductile behavior during collapse or other measures are taken that are designed to protect workers, vessels and the public in the event of such a collapse. The structure should be designed against collapse in the closed position and in the fully open position during vessel transit of the navigational channel.

4.4.2.5 Fracture and Fatigue

The evaluation of a movable bridge for its vulnerability to failure by brittle fracture and fatigue should include an assessment of the structure's steel details and stresses considering the current level of deterioration (Reference 9, 71).

The probability of failure due to brittle fracture or fatigue depends upon the following factors:

- **Redundancy:** ability to redistribute loads (Reference 9, 71)
- **Fatigue resistance:** type of details and fatigue category (Reference 8b, 22, 42, 82, 83)
- **Number of cycles:** ADTT and navigation openings (Reference 42, 82)
- **Material toughness:** Charpy V-Notch resistance of material (Reference 42)
- **Temperature:** bridge location and minimum service temperature (Reference 42)
- **Rate of applied load:** impact considerations at floor beams and upon closing (Reference 42)
- **Secondary stresses:** evaluate out-of-plane movements.
- **Main member type:** internal load paths within member configuration (Reference 69)
- **Bridge type:** movable span type and details (Reference 7, 69)
- **Skew angle:** tendency to creep (Reference 83)
- **Connections:** type and condition (Reference 22)
- **Corrosion:** condition and rating evaluation (Reference 9)

Evaluation of these factors should include an assessment of the likelihood of each failure type and the severity of consequences for a particular failure.

C4.4.2.5

One important parameter affecting the vulnerability of a structure to sudden failure due to fracture is structural redundancy. In the event of fracture of a primary member, redundancy allows the load to be transferred to other members. Many movable spans contain only two main members and are structurally non redundant.

It is noted that a structure with retrofitted details that conform to AASHTO fatigue categories D, E, E', and F may not be as vulnerable to fracture and fatigue if the work was designed after 1973, and conforms to the revised Charpy V-Notch material toughness and revised welding and fabrication methodology specifications developed to control brittle fractures.

A movable span in the closed position, with all bearing components functioning and seated properly, behaves essentially as a fixed span and shares the same fatigue and brittle fracture related concerns. However, operating the span introduces special concerns. While the normal operating stresses are not usually experienced over a large number of cycles, other considerations such as vibration, oscillation of components, rough opening motion or chatter may in effect multiply the total number of cycles experienced over the life of the structure resulting in reduced fatigue life.

Movable bridges have a number of bearing components that must function within a narrow range of performance characteristics in order for the bridge to operate with dead and live load reactions as designed. These components include span locks, live load shoes, live load wedges, shear locks, heel stops, and substructure supports. In addition, some of these bearing components are mechanisms that move in and out of position in conjunction *with span operation. If any of these components do not function properly the span support conditions change. This can result in overstress of the main structural members and an increase in the structure's vulnerability to failure by fatigue and brittle fracture. If significant vertical movement occurs at these support locations under the passage of live load, an analysis is warranted to determine the effects on the structural components. Particular emphasis should be placed upon any fracture critical components.*

Finally, it is noted that vulnerability to failure by fracture increases when the bridge experiences a stress increase due to an increase in dead load or, in the case of a vertical-lift, movement of the towers.

4.4.2.6 Operational Failure

Operational failure is the inability of a movable bridge span (or leaf) to move on demand. Potential causes of operational failure, other than described in Section 4.4.2.1 through 4.4.2.5, are numerous and may be identified based on the specific details of structural design, maintenance practices, operating procedures, site and use conditions. Typical causes of operational failure are mechanical failure, electrical failure, or operator error.

Electrical components power the span movement, the control and interlocking logic and position detection limit switches of most movable bridges. Temporary power loss can lead to operational failures. Mechanical and structural damage can result from unreliable, maladjusted or improperly repaired electrical components. Limit switches are particularly critical to the continued operational reliability of bridge systems.

Mechanical failures such as failures of the span drive components and brakes during operation can result in uncontrolled span motion. Uncontrolled span motion may also occur from the closed position without warning, and before activation of traffic control signals or safety devices.

Failure of mechanical components such as shear locks can result in changed structural support conditions. This condition can lead to structural overload and the potential hazard of a structural collapse if the bridge remains open with inoperative or maladjusted shear locks, wedges or live load shoes.

Operator errors can damage system components such that the span becomes inoperable. The vulnerability assessment should include an evaluation of the bridge opening and closing procedures with identification of the potential risks associated with each step in the procedure.

Evaluators should review controls, interlocking and operating

C4.4.2.6

Operational failures also vary in the severity and type of consequences resulting from such failure. Tripping of the span drive electrical motor circuit breaker is an example of a relatively minor operational failure that may result from mechanical or electrical problems. Failure of a bascule main drive component due to severe overstress caused by major leaf imbalance is an example of a major operational failure caused by a machinery problem

An example of a limit switch problem is the case of a span lock limit switch that indicates lock withdrawn when, in fact, the lock bar is still partially engaged in the receiver. This event would permit operation of the main drive and could result in the mechanical damage of the span lock and structural damage to the span lock supporting members and might also overstress the main span drive components.

procedures and assess the following:

- Is interlocking present and functional?
- Does the system allow the operator to bypass the interlocking and defeat the safety interlocking features? Has it happened in the past?
- Based upon the above information, is it possible that an operator action could lead to potentially hazardous consequences such as opening the bridge with span locks engaged or without first stopping traffic?
- Are any of the scenarios developed above likely to lead to structural, mechanical, hydraulic or electrical failure resulting in collapse of the movable span?

Fire that occurs during span operation can cause electrical or mechanical failure resulting in uncontrolled motion of the span and other hazards to vessels and the structure.

The presence of flammable fluids and grease combined with improper maintenance of the storage area increases the risk of fire and its potential consequences.

Structural problems may also exist that can contribute to operational failure. One area of particular concern should be the condition of structural and mechanical components that support the counterweight. Counterweights have detached from movable bridges due to corrosion or damage to counterweight support pins or structural framing. The consequences of a counterweight support failure during span operation are potentially catastrophic.

4.4.2.7 Wave/storm surge forces

In 2008, AASHTO published the *Guide Specifications for Bridges Vulnerable to Coastal Storms* (Reference 5). These specifications give owners an opportunity to apply coastal loads, including storm surge and wave loading, during the design of new bridges, including movable bridges. Prior to 2008, coastal loads were not considered. These issues take on extra importance if an existing movable bridge is included in a designated evacuation or rescue/recovery route. The *Guide Specifications for Bridges Vulnerable to Coastal Storms* indicates that “Wherever practical, the vertical clearance of highway bridges should be sufficient to provide at least 1 foot of clearance over the 100-year design wave crest elevations, which includes the design storm water elevation. . . . No effect of anticipated climate change has been accounted for herein. Individual Owners may include this feature depending on their jurisdiction’s policy in this regard.”

CHAPTER 4.5 – NAVIGATIONAL GUIDANCE

4.5.1 GENERAL

This chapter provides an overview of existing navigational related regulations set forth by U.S. Coast Guard (USCG), U.S Army Corps of Engineers (USACOE), Federal Aviation Administration (FAA), Federal Communications Commission (FCC), and other federal agencies.

The needs of both recreational and commercial traffic carry equal weight. It is important to realize that vessels, unlike land based vehicles, do not stay in one place when they come to a stop. The wind, current, wakes from other vessels, or other outside effects from any source can cause a vessel to move. All bridges are obstructions to navigation and are tolerated only as long as they serve the needs of land transportation while allowing for the reasonable needs of navigation. Movable bridges that obstruct navigation are permitted only if they are capable of being opened at all times in a prompt and timely fashion or when an exception has been approved by USCG and is listed (or is slated to be listed) in 33 CFR (Reference 56) for the individual bridge. When a vessel is underway, meaning not moored to a pier or at anchor, it maintains its ability to maneuver primarily by maintaining forward motion. A vessel that is not moving with some specific minimum velocity, forward or reverse loses the steerage control of the rudder and is adrift at the mercy of currents and wind. Additionally, when moving in reverse, vessel control is less predictable because the vessel has less available power and the wind and currents can affect a vessel differently each time. Thus, if a movable bridge does not open and a vessel cannot circle or stem the tide, both the bridge and the vessel are susceptible to impact. Generally channels are not wide enough for larger vessels to circle because of inadequate water depth or obstructions.

4.5.2 BACKGROUND

In the inspection, maintenance, or evaluation of movable bridges and pier protection systems the following items should be considered:

- Direction and velocity of currents, cross currents, and tidal flow.
- Prevailing wind conditions.
- The size, configuration, and type of vessel and any vessel in tow.
- The alignment and configuration of bridge piers with the waterway, particularly the effect of piers on eddy or cross currents, vessel sight distance and maneuverability.
- Impact of docks and wharves in the immediate vicinity of the bridge, and vessels moored to them on the ability of

C4.5.2

For many inspectors, maintainers and evaluators the marine environment and the size and configuration of vessels may be hard to understand or envision unless they observe the different vessels transiting. Figure C4.5.2-1 shows a 1000 ft. (305m) long, 105 ft. (32m) beam container ship transiting a vertical-lift bridge. The figure shows how the vessel crabs (transits on angle) when transiting the bridge due to wind and current effects.

transiting vessels to maneuver while waiting for an opening or for a vessel departing the dock to align with the movable bridge navigational channel, Figure 4.5.2-1.

- The proximity and alignment of the main navigation channel upstream and downstream of bridges and anchorages, Figure 4.5.2-2.
- Bends in the navigational channel and obstructions such as shoals, rocks, riprap, or fill placed around piers to control scour cause constrictions that increase water velocity, cause vessel shear and can limit the navigable opening if riprap or fill protrude beyond the pier protection system.

Figure 4.5.2-1 – Problems related to facilities near a movable bridge

Figure 4.5.2-2 – Navigation problems created by movable span location

Figure C4.5.2-1 – *Large ship transiting a bascule bridge*

4.5.3 APPLICABLE LAWS AND REGULATIONS

Several federal and state agencies regulate various aspects of maintenance, repair, operation, equipment, and safety with regard to movable bridges.

C4.5.3

The intent of Congress in the enactment of the bridge statutes was to retain exclusive jurisdiction over navigable waters in the United States. In order to preserve the public right of navigation and to prevent interference with interstate and foreign commerce, federal laws and regulations control the construction, alteration, repair, maintenance and operation of bridges built across "Navigable Waters of the United States."

Note: *A Navigable Water is not limited to ones that physically have known vessel transits. "Permitted" bridges are considered by law to be obstructions or interferences to navigation. They are allowed, once permitted by the federal regulatory agency, only so long as they serve the needs of land transportation and so long as the bridge's vertical and horizontal clearances provide for the reasonable needs of navigation.*

A bridge that does not fully comply with or conform to its operating permit and permit drawings is considered an unlawful bridge. For example, if a bridge is permitted with a pier protection system, the owner cannot decide to remove the pier protection system and not replace it, permanently close the bridge or not maintain the auxiliary machinery because of lack of funds, ability, or manpower. Such actions would result in invalidation of the bridge permit.

There may be some confusion regarding primary jurisdiction for bridge administration matters. In April 1967, in conjunction with the establishment of the U.S. Department of Transportation, the USACOE relinquished to the USCG the primary responsibility for permitting, enforcing and regulating the major aspects of bridges built across navigable waters of the United States. The USACOE retained responsibility for construction of marine piers, locks, dams and overhead power transmission lines not connected to a bridge or its operation. They also operate and maintain some locks, canals and movable bridges. Movable bridges over such waterways as the C & D Canal and Cape Cod Canal require careful attention for complete coordination with all regulatory bodies.

4.5.3.1 General Navigational Regulations

It is important that the bridge is operated and maintained in full accordance with its bridge permit and any subsequent amendments, whether originally issued by the USACOE or the USCG. USCG approved lighting plans and pier protection system drawings should be implemented and maintained at all times. An inspector or evaluator should not assume that limit switches that control the height or angle of bridge opening, the location or thickness of counterweight stop blocks, or other repairs or alterations, continue to guarantee the bridge is in compliance and is capable of opening to the required horizontal distances or vertical heights above mean high water.

For bascule bridges, unlimited vertical clearance for the full horizontal distance between pier protection devices should be provided unless the permit, its amendments or its attached drawings state or show a reduced vertical clearance is authorized.

Drawbridge Operation Regulations, 33 CFR 117, requires movable bridges over navigable waters to be opened and operated in accordance with 33 U.S.C. 499, "Regulations for Drawbridges" (Section 5 of the Rivers and Harbors Appropriations Act of 1894).

When planning an inspection of a movable bridge, the inspector should verify the current operating regulations as established by the USCG in 33 CFR 117. Operating procedures or regulations implemented by a bridge owner or local government that are contrary to federal regulations may cause owners to incur fines, and should be noted by inspectors.

In performing an inspection of a movable bridge, it may be necessary for an inspector to open bearings or place equipment on or under the bridge that may delay an opening or reduce approved vertical clearances, if the bridge is required to open. Regulations require the responsible party to request approval from the USCG for a temporary variance in the operating regulations or advance notice from the mariners for prompt and timely openings during the inspection.

C4.5.3.1

Bridge Permit Laws: *Most bridges built over navigable waters that exist today were permitted under one of five bridge laws: The Rivers and Harbors Act of 1899 (33 CFR 401 et. seq. (and the appropriated sections that follow)); the Bridge Act of 1906 (33 CFR. 491 et. seq.); the General Bridge Act of 1946 (33 CFR 525 et. seq.) and the International Bridge Act of 1972.*

Under the applicable bridge acts, the Commandant (USCG) has the authority to approve the clearances required for navigation through or under bridges. It is understood that this duty and authority extends to and may be exercised in connection with the construction, repair, alteration, operation, maintenance, and removal of bridges, and includes the power to authorize the temporary restriction of passage through or under a bridge by use of false work, piling, floating equipment, closure of movable bridges, or any works or activities that temporarily reduce the navigational clearances and design flood flows, including closure of any or all spans of the bridge whether in or out of the marked deep water navigational channel.

Under 33 CFR 499 statute, the USCG issues regulations for movable bridges and regulates their operation. These regulations have the force of law. The law states that it shall be the duty of all persons owning, operating, and tending the movable bridges built prior to August 18, 1894 or that may thereafter be built, to open or cause to be opened, under the rules and regulations established or published by the USCG.

4.5.3.2 Closure of Waterways and Restriction of Navigational Passage

The Ports and Waterway Safety Act of 1972 gives the USCG the ability to control vessel traffic when hazardous conditions exist.

C4.5.3.2

The Ports and Waterways Safety Act of 1972 (Public Law 92-340, 33 U.S.C. 1221 et seq.) gives the USCG the authority to exercise broad powers in waterways to control vessel traffic in

In the event that an inspection, accident, construction, alteration, or repair of a movable bridge is of such a nature that for the protection of life and property, navigation through or in the vicinity of the bridge must be temporarily prohibited, the USCG may close that part of the affected waterway while the situation is being stabilized or the inspection or work is being performed. However, it is also clear that the Secretary of the Army and the Chief of Engineers have the authority, under Section 4 of the Act of August 18, 1894, as amended, 33 CFR 1, to prescribe rules for the use, administration, and navigation of the navigable waters of the United States. In recognition of that authority, and pursuant to Section I02(c) of the Ports and Waterways Safety Act, 33 CFR 1222(c), the USCG must consult with the USACOE when any significant restriction of passage through or under a bridge is contemplated to be authorized or if a waterway is to be temporarily closed. The bridge owner, inspector and contractor must demonstrate the restrictions are necessary and the work will be performed on an expedited basis.

areas the USCG determines to be especially hazardous. It provides the authority to establish safety and security zones or other measures to limit or conditionally control access and activity when necessary to prevent damage to or the destruction or loss of, any vessel, bridge or other structure on or in the navigable waters of the United States.

4.5.3.3 Other Navigation and Navigable Water Laws

Deposit of Refuse in Navigable Waters 33 CFR 407:

- Maintainers, inspectors, and evaluators are cautioned that discharge of any material is prohibited except for potable water and an extremely limited list of specific material such as fish parts.
- The Federal Water Pollution Control Act prohibits the discharge of oil or oil based materials into navigable waters. Inland and Great Lakes Navigation Rules:
- Any marine equipment used to assist in an inspection or to perform maintenance work must be in full compliance with the appropriate navigation rules of the road.

C4.5.3.3

The law states it shall not be lawful to throw, discharge, deposit, or cause to be deposited from shore, a vessel or a structure into any navigable water of the United States or on the bank where shall be liable to be washed into such navigable water by ordinary or high tides, storms, floods, or otherwise. This law can be enforced by both the USCG and the USACOE. Refuse matter under the law does not limit itself to such refuse matter as would impede navigation. For example, a member of a pile-driving crew who cut off the ends of piles that were too long and discarded the unwanted pieces into the river violated the law.

4.5.3.4 FCC Regulations

The Federal Communications Commission controls all radio communications in the U.S. Radio telephones and two way radios on movable bridges are therefore subject to FCC regulations.

- To enhance the safety of navigation and to minimize delays to both land and marine traffic, the USCG in 1970 encouraged bridge owners of movable bridges to voluntarily install radiotelephones.

C4.5.3.4

A VHF-FM Limited Coast Station license is issued by the FCC to a person, corporation, or agency that is responsible for the operation of bridges that are a part of or directly related to a port or waterway when the operation of such facilities requires radio communications with vessels for safety or navigation. Each Limited Coast Station installed on a bridge must be capable of operation on both channel 16 (156.8 MHz) and a working frequency,

- The FCC in an amendment of 47 CFR 81 authorized the operation of VHF-PM Limited Coast Stations by persons responsible for the operation of bridges. These stations must be licensed and the equipment must meet FCC requirements and be on the approved equipment list.
- The station license or a photocopy is required to be posted at the station. If a photocopy is posted, the location of the original must be stated on the photocopy. The inspector should verify that a copy of the license is posted and that it has not expired.
- Under no circumstances should the output power exceed 10 watts.
- Each station is required to have a copy of Part 81 of the FCC rules and regulations.
- A station radio log is required to be kept by the FCC rules.

generally channel 13 or 14. All stations are required to monitor both channels 16 and 13 during the hours of operation. Channel 16 is a calling and distress channel.

Limited Coast Station operations on movable bridges are primarily to communicate with vessels with respect to the operation of the movable bridge. The working frequency, generally channels 12, 13, or 14, is used for that purpose. Since channel 16 is a calling and distress frequency, it should not be used to conduct business.

4.5.3.5 FAA Regulations

The major concern of the FAA relating to bridges is the marking and lighting of them as obstructions to aviation. Generally, any temporary or permanent object, including all appurtenances, that exceed an overall height of 200 ft. (61 m) above ground level or measured above low water level when over water would normally be marked and lighted. Outside commercial lighting is not considered sufficient reason to omit recommended marking and lighting. The FAA may also recommend marking and/or lighting a structure that does not exceed 200 ft. (61 m) above ground level because of its particular location near a public use airport, heliport, visually marked seaplane base or an airport operated by the military.

4.5.3.6 USCG Regulations

USCG regulations for movable bridges are contained in the Code of Federal Regulations as follows:

- 33 CFR Subchapter E: Inland navigation rules
- 33 CFR Subchapter J: Bridges
- 33 CFR 114 General
- 33 CFR 115 Bridge location and clearance; administrative procedures
- 33 CFR 116 Alteration of obstructive bridges
- 33 CFR 117 Drawbridge operation regulations
- 33 CFR 118 Bridge lighting and other signals
- 33 CFR Subchapter P: Ports and Waterways Safety

4.5.3.7 USACOE Regulations

CHAPTER 4.5 – NAVIGATIONAL GUIDANCE

The USACOE regulations pertaining to movable bridges are contained in the following *Code of Federal Regulations*:

- 33 CFR 207 Navigation regulations
- 33 CFR 277 Navigation policy; cost apportionment of bridge alterations
- 33 CFR 322 Permits for structure or work in or affecting navigable waters of the United States
- 33 CFR 323 Permits for discharge of dredge or fill material into waters of the United States
- 33 CFR 389 Permits for ocean dumping of dredged material
- 33 CFR 330 Nationwide permit program

4.5.4 PENALTIES FOR VIOLATION OF LAWS AND REGULATIONS

The purpose of "civil penalties relating to bridges" is to facilitate the safe passage of vessels through bridges by deterring inconvenience or impediment to navigation that may result from the location, construction, modification, maintenance, and operation of bridges across navigable waters of the United States. Inspectors, operators, owners, evaluators, maintainers, and contractors performing work on movable bridges should realize that their actions and activities that affect navigation can result in civil or criminal penalties if proper approvals are not obtained in advance of their activities.

4.5.5 BRIDGE LIGHTING, MARKING AND OTHER SIGNALS

Bridges across waterways that support nighttime navigation are required to display navigational lights at all times in accordance with 33 CFR 118. It is the responsibility of an owner, operator, and maintainer to maintain proper navigational lighting and other such markings as may be prescribed for the bridge.

Lights required or authorized by the USCG regulations must be securely attached to the structure and of sufficient candlepower as to be visible against the background lighting at a minimum distance of 6,000 ft. (1830 m), 90 percent of the nights of the year.

Requirements for the number, location, color, and arcs of visibility of navigational lights on bridges are dependent on the type and configuration of the bridge itself. Guidance in this aspect is provided in 33 CFR 118.

Several other means of marking and warning mariners that a bridge obstructs their passage are fog signals, racons (radar

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Approval of navigational lights and other signals is normally obtained prior to construction from the USCG District Commander of the area in which the structure is situated.

The District Commander may modify the requirements for the display of lights and other signals on any bridge when a change in local conditions warrants the modification. Application/or modification of lighting may be made by the bridge owner by letter accompanied by duplicate sets of drawings showing (a) plan and elevation views of the structure showing the lights and signals proposed and (b) a small vicinity chart showing the bridge and other bridges within 1000 FT (305m) above or below the bridge. It beacon), radar reflectors, and painting the piers and upper wales of pier protection systems. Based on an inspector's observation of the effectiveness of the bridge lighting or evidence of collisions with the bridge, evaluators and inspectors can supplement the existing lighting systems with one or more of the following discussed briefly below:

- **Fog signals:** On waterways where visibility is frequently reduced due to fog or other causes, the local USCG District Bridge Office may require or authorize the installation of one or more fog signals to warn navigators of the presence of the bridge. The fog signals must conform to the installation, range, and sound frequencies specified in 33 CFR.
- **RACONs and Radar Reflectors:** Aboard commercial vessels and large recreational and sailing vessel radars are required and considered an indispensable aid to navigation. Bridges provide an excellent radar target, appearing as a thick, bright stripe on the mariner's radar. Unfortunately, the support piers and pier protection systems that flank the navigable channel are obscured. RACONs provide an unmistakable radar mark. The USCG may require or authorize the installation of radar reflectors and RACONs on bridge structures, stakes and buoys. Radar reflectors are sometimes used to mark the location of the edge of the navigable channel, bridge channel piers, or centerline of the channel.

is important for evaluators to be aware that there is a difference in the design of equipment for occasional use as a signaling device versus a fog signal. Fog signal devices should be rugged, low-maintenance horns specifically designed for long-term continuous operation during adverse weather conditions.

4.5.6 REQUIREMENT TO LOWER APPURTENANCE UNESSENTIAL TO NAVIGATION

The regulations state, “No vessel owner or operator shall signal a drawbridge to open for any nonstructural vessel appurtenance which is not essential to navigation or which is easily lowered.” Mariners are responsible for knowing the actual vertical clearance required for their vessels and for checking the clearance gauges at movable bridges before requesting an opening. The inspector, owner, and maintainer should ensure that the clearance gauges are present, legible, correct and in good repair.

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Appurtenances not essential to navigation include but are not limited to radio, television and loran antennas, collapsible bimini tops, booms, flag masts for ornamental purposes, false stacks and fishing outriggers. They do not include fixed flying bridges, sailboat masts, pile driver leads, and radars.

4.5.6.1 Clearance Gauges

The basic requirements for the installation, configuration and location of clearance gauges are found in 33 CFR 118.160. Clearance gauges are often misunderstood. This is the same type of information as the bridge overhead clearance, which is provided to truckers. However, in the marine environment, the

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The owner or operator of the bridge is required to maintain each gauge in good repair and legible condition.

relative elevation of the bridge and roadway is constantly changing. Clearance gauges are primarily a navigational safety item intended to convey real-time height or vertical clearance information to the mariner. Thus, there is the need for a gauge that shows the minimum vertical clearance between "low steel" and the constantly changing level of the water due to wind, tide and current effects. The amount of change varies greatly based on the location of a waterway or river. For example, in New York Harbor there is a 5.0 to 6.0 ft. (1.5-2.0 m) range of tide; in Boston Harbor, a 9.0 to 10.0 ft. (2.7-3.0 m), and in Great South Bay, Islip NY and Snake Creek, Islamorada, FL a 1.0 ft. (0.3 m) range. “Low steel” is often, but not always, found at the inner (channel ward) edge of the pier protection system. Bridges that are not symmetrical to the channel often will have one edge of the channel lower than the other. Additionally, bridges that have a haunch or curve in the girders often provide additional clearance for some specific distance at the center of the channel. All of this information can be valuable to the mariner if it is posted and able to be read before the mariner signals for or arrives at the bridge.

4.5.7 DRAW BRIDGE OPERATIONS UNDER EMERGENCY SITUATIONS

33 CFR 117.31 requires bridge owners and operators to take all reasonable measures to have the bridge opened, regardless of its operating schedule, provided this opening does not conflict with local emergency management procedures that have been approved by the cognizant USCG Captain of the Port for the passage of federal, state and local government vessels used for public safety, vessels in distress, vessels seeking shelter from severe weather, or commercial vessels engaged in rescue or emergency salvage operations. Upon receiving notification that an emergency vehicle is responding to an emergency situation, a drawtender must make all reasonable efforts to have the drawspan closed at the time the emergency vehicle arrives. When the drawtender receives notice, or a proper signal as provided in 33 CFR 117.15 of this part, the drawtender shall take all reasonable measures to have the draw opened, regardless of the operating schedule of the draw, for passage of the following, provided this opening does not conflict with local emergency management procedures which have been approved by the cognizant Coast Guard Captain of the Port:

1. Federal, state, and local government vessels used for public safety
2. Vessels in distress where a delay would endanger life or property

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3. Commercial vessels engaged in rescue or emergency salvage operations
4. Vessels seeking shelter from severe weather

4.5.7.1 High Winds

High winds may make a movable bridge inoperable or subject it to damage. It is a typical safety measure with bridge owners that movable bridges will not operate at wind speeds in excess of 64 knots (33 m/s) except in an emergency. Hurricane force winds are defined as wind speeds exceeding 64 knots (l knot = 1.15 mph). Evaluators may recommend that operation at wind speeds less than 60 knots (31 m/s) be restricted in the case that operational problems are discovered that affect the ability to operate the movable structure safely. Requests to eliminate bridge openings at specific wind speeds of less than 60 knots (31 m/s) to prevent damage are considered by the USCG on an individual basis while steps are being taken to restore the bridge to full operation. Such requests should be accompanied by an engineering analysis showing the maximum wind the bridge could experience without damage while in a partial and full open position. Additionally, the bridge owner is required to show the corrective action being taken to permit the bridge to operate at all normal weather conditions for the area. Any time a movable bridge must be removed from service whether because of high winds or otherwise, it must be reported to the USCG immediately.

In addition to inconvenience and impediment, penalties from USCG can arise from inoperable navigation lighting, and illegible or missing clearance gauges.

Federal regulations authorize movable bridges to remain closed during extreme weather events such as a hurricane, unless the USCG specifically directs otherwise. Authorities desiring to temporarily cease or restrict movable bridge openings to facilitate evacuation of land traffic before the arrival of a hurricane or other major storm must obtain authorization from the Bridge Administration Office of the appropriate USCG District Commander. Temporary closures are approved on a case by case basis if the operation of the bridge would impede evacuation.

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High winds affect each type of movable bridge differently. Often the wind direction is a key factor in the operation of the bridge, as is whether the bridge is operating on primary or emergency (backup) power or mechanical means. On swing bridges, excessive wear in the pinion bearings, between the pinion and the rack, or nonoperational centering devices can cause problems in opening, closing. and controlling the swing-span against wind gusts. On vertical-lift bridges, especially on span-drives, if the up haul and down haul cables are not kept properly adjusted wind can cause the cables to whip or move horizontally and come off the sheaves. This problem can be corrected by partially protecting the cables from the wind effects or maintaining proper adjustment of the cables to eliminate excessive slack when changing the direction of the bridge's motion.

Wind pressure is proportional to wind speed squared to the wind pressure at 40 knots (21 m/s) is approximately 44 percent of the pressure at 60 knots (31 m/s).

CHAPTER 4.6 – TRAFFIC CONTROL

4.6.1 GENERAL

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CHAPTER 4.6 – TRAFFIC CONTROL

Some traffic control measures are unique to existing movable highway bridges. The design of traffic control for new movable bridges is covered in Reference 7 and its references to the FHWA Manual on Uniform Traffic Control Devices (Reference 72). Reference 72 specifically addresses signals and traffic gates for movable bridges with other traffic control devices covered under the general MUTCD provisions. Resistance gates are considered a design feature, not a traffic control device, and design requirements for same are covered in Reference 7. The application of these design specifications to in-service movable bridges requires engineering judgment to accommodate site specific conditions and usage. Strict application of the code provisions may be impractical or unnecessary in some cases. The code permits exceptions in certain cases.

Reference 72, the FHWA Manual on Uniform Traffic Control Devices is a national standard for the design and usage of signs, signals, markings, and other devices placed on public roads to regulate, warn, or guide traffic. In virtually all states, traffic control devices are required by statute to conform to the FHWA MUTCD or a state manual that is in substantial conformance with the MUTCD. The individual state manuals may contain additional requirements or enhancements to the MUTCD and should also be consulted by the engineer when evaluating the traffic control measures at an individual bridge site.

Evaluation of the in-place traffic control measures present at a movable bridge site should consider the overall effectiveness of the system and the adequacy of the components. Existing movable bridges present many different site and use variables that impact performance of the traffic control system. Traffic volume and frequency of bridge openings are the primary criteria for consideration in analyzing the adequacy of an existing traffic control system. The combination of high traffic volumes with a large number of bridge openings warrants traffic control measures in general conformance with the code requirements for new bridges, and such structures should be evaluated on this basis. Existing movable bridges carrying low volume or requiring infrequent or off-peak scheduled openings may not be subject to strict compliance with code provisions.

4.6.2 TRAFFIC CONTROL DEVICES

The traffic control system at a movable highway bridge serves two basic purposes:

- Warns drivers and pedestrians of the bridge operator's intent to close the roadway prior to a bridge opening.
- Safely halts and stores vehicular, pedestrian and other traffic during a bridge opening. The traffic control devices may be supplemented with resistance gates that serve as a barrier to errant vehicles and pedestrians.

The following traffic control devices are used to accomplish the above purposes:

- **Warning Signs:** Warning signs at movable bridges include “Drawbridge Ahead” or “Swing Bridge Ahead,” among others. In general, the use of warning signs is mandated in new design. Basic design requirements, exceptions, and supplemental requirements for special conditions are given in the MUTCD.

- Warning signs may be supplemented with hazard identification beacons, high level warning devices, additional signs, or variable message signs. Existing sign locations and placement should be evaluated based upon visibility and adequacy to provide sufficient driver recognition and reaction time.
- **Traffic Signals:** Highway traffic is commonly notified to stop before a bridge opening at locations in advance of existing movable bridges by one of the following means: the standard three color traffic signal, a "STOP HERE ON RED" sign with a red signal indication mounted above and below the sign, or manual flagging. Requirements for placement and design of traffic signals for new movable bridge design are given in Reference 7 and the MUTCD (Reference 72). Traffic signals or alternate means to stop traffic at an existing movable bridge should be evaluated based upon specific site and use conditions and traffic volumes.
- **Traffic/Warning Gates:** Traffic/warning gates work in conjunction with traffic signals in notifying drivers to stop. Traffic gates are generally required for new movable bridge design. The number, placement, size, and marking requirements of traffic gates, as well as conditions that allow exclusion from the warning gate requirement for new design are given in References 7 and 72. Exceptions are allowed on an individual basis upon evaluation of specific site and use conditions.
- **Warning Bells:** Warning bells or sirens are sometimes used to supplement traffic signals. Their use, per Reference 7 is permitted subject to engineering judgment. Use of warning bells or sirens may be advantageous at bridges with poor sight distance due to roadway geometry or in locations where heavy fog or other obstructions to driver visibility are common.
- **Interconnect/Interlocking:** Interconnect/Interlocking of powered traffic control devices and bridge span-drive machinery is required so that the roadway is closed to traffic before the spans are opened and that the spans are closed before reopening the roadway to traffic. While generally required for new design, there are some exceptions for the interlocking of power equipment on existing movable bridges. The decision to provide interlocking on an existing movable bridge should be based on an engineering evaluation of accident history and potential consequences of

an improper opening sequence.

4.6.3 RESISTANCE GATES

Resistance gates are designed to halt vehicles and prevent them from entering the bridge opening. There are two types of resistance gates: resistance barriers that contain the errant vehicle, and energy absorbing barriers. Energy absorbing resistance gates decelerate the vehicle at a specified rate and absorb a portion of the energy of the impact. Energy absorbing barriers include the net assembly type Dragnet Crash Cushion (Reference 10), foam filled crushable cartridge type, collapsible water-filled type, or other resistance barrier or truck mounted attenuators. As with traffic gates, resistance gates are generally required for new design, with exceptions allowed based upon type of movable bridge and specific site conditions.

Refer to the current AASHTO *LRFD Movable Highway Bridge Design Specifications* (Reference 7), Section 1.4.4.4 Traffic Gates and Barriers for additional information.

4.6.4 EVALUATION

Reference 72 specifies that traffic control at movable bridges should include both signals and traffic gates. Certain exceptions are allowed, including low volume roadways (less than 400 ADT). Reference 7 specifies that a physical resistance barrier be provided, except when open bascule leaves effectively block the roadway. Other traffic control devices are described and specified in both References 7 and 72.

These provisions should be used as guidelines in the assessment of the traffic control system at existing movable bridges. Each site should be reviewed for compliance with References 7 and 72. Where deficiencies are noted, a detailed engineering evaluation of the site conditions should be made. Based on the engineering evaluation, movable bridges may not warrant installation of all elements of a complete traffic control system.

The engineering evaluation should consist of: collecting, reviewing, and analyzing available relevant traffic and accident data; performing a field study to observe and evaluate the effectiveness of the in-place system for the existing site and use conditions; and evaluation of the record of safety performance of in-place controls. The study should determine the extent of rehabilitation needed to meet design code requirements versus a reduced or non-action alternate.

The following items should be considered:

Accident History and Projection: The performance record of the existing traffic control should be evaluated with respect to accident history. The probability and possible consequences of vehicles penetrating the traffic controls and entering the hazard area should be evaluated.

Special Traffic Use: Although the ADT is used as the primary means to exclude movable bridges from the requirement of having both signals and traffic gates, additional factors may exist that deserve consideration. One example would be if the bridge carries a large volume of commuter traffic with heavy use restricted to a few early morning and late afternoon hours, do bridge openings occur at these times? If so, this situation might indicate a need for compliance or a need for restricted hours of opening.

Significant Truck Use or High Speed Locations: In conjunction with study of accident history, the existing traffic control placement and spacing in terms of adequacy to provide the deceleration distance needed by trucks should be evaluated. If the existing traffic controls are not in compliance with the design code and the existing conditions result in insufficient deceleration distance to safely warn, slow down, and halt truck traffic; the study should evaluate upgrading the traffic control as specified in References 7 and 72 (including supplemental warning signs, hazard identification beacons, and interlocking).

Bridge Openings During Night Time Hours or Subject to Other Poor Visibility Conditions:

- Under the existing worst case lighting conditions, the approaching vehicle and pedestrian traffic as well as any traffic on the spans should be adequately visible to the bridge operator. Similarly, the traffic control devices should be clearly visible to vehicles, pedestrians and to the bridge operator. The study should evaluate the adequacy of the in-place lighting on the effective performance of the traffic control. If additional lighting is needed, it may be provided by permanent electrical installation or powered during bridge operation. Warning bells may be used to supplement the existing traffic control to inform motorists and pedestrians of a bridge opening.
- Existing signs, traffic gates and resistance gates should include reflective materials and marked in accordance with the MUTCD (Reference 72) requirements.

Presence of Intersecting Streets or Driveways in Close Proximity to the Movable Span: The MUTCD (Reference 72) waives the traffic control requirements for traffic gates and the "Drawbridge Ahead" warning signs in dense urban areas where intersecting streets or driveways make these traffic control features ineffective. The warning and stop controls at such locations are typically provided by traffic signals. Existing bridges of this type should be evaluated based upon the past and projected safety performance. If the study determines a need for safety improvements, the following measures may be considered and evaluated based upon engineering judgment:

- If advance warning signs are not currently in place, evaluate their placement on the intersecting streets approaching the bridge and the primary street on which the bridge is located:
  - Determine if sufficient space is available for signs. Proposed sign placement should provide adequate warning and reaction time for drivers. Sufficient lateral clearance is needed for sign placement to be clear of road and sidewalk traffic, etc.
  - Determine if signs would be adequately visible to approaching traffic.
- Traffic signals within the nearby grid of streets could be interconnected with the existing bridge traffic controls to favor traffic leading away from the bridge during a bridge opening.
- If traffic gates are not currently in place, evaluate their placement based upon existing available clearance (it may not be practical or possible to locate traffic gates exactly as specified in Reference 72).

Bridge Sites With Compromised Approach Stopping Site Distance: The MUTCD (Reference 72) specifies the use of either a supplemental traffic signal or addition of hazard identification beacon where conditions prevent a driver from having a continuous view of at least one signal indication for a specified duration before reaching the stop line. In addition, driver recognition and reaction to movable bridge traffic control devices may be enhanced through implementation of warning bells, sirens, or larger diameter traffic signal lenses as given in the MUTCD (Reference 72).

Barriers: The study should also evaluate the effectiveness of existing traffic controls and barriers in preventing vehicles from entering the hazard area created by movable bridge operation. The barrier component of movable bridge traffic control is intended to serve one of the following functions:

- To prevent the vehicle from entering the channel. (Swing-spans, vertical-lift spans, toe end of single-leaf bascule).
- To prevent the vehicle from impacting the open structure or entering the pit created by the bridge operation (heel end of bascule, vertical-lift span during the open/close cycle).

The barriers may be either resistance barriers or energy absorbing barriers designed for the particular location, speed, vehicle, and hazard.

CHAPTER 4.7 – OPERATION AND MAINTENANCE MANUALS

4.7.1 GENERAL

Concise, complete guides to the operation and maintenance of movable bridges should be assembled in individual, separately-bound volumes.

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The AASHTO LRFD Movable Highway Bridge Design Specifications *(Reference 7) specifies that wire diagrams, operator's instruction, electrical and mechanical data booklets and lubrication charts be supplied with a new bridge. For existing bridges, evaluators should determine if operations or maintenance manuals exist, and if so whether they conform to current specifications.*

4.7.2 BRIDGE OPERATIONS MANUALS

A bridge specific operations manual is currently recommended for use by bridge operators. This manual should cover all aspects of normal bridge operation and emergency procedures. The following topics are suggested for inclusion:

Normal Operation:

- A step-by-step detailed written procedure of the bridge specific complete opening and closing cycle including the function of all limit switches and operator console controls and displays.
- Clear definition of the bridge operator's communication procedures required for radio, visual, and audible contact with inbound and outbound shipping, USCG, and local public safety officials.

Emergency Action Procedures to Respond to:

- Vehicular or marine accidents or other possible site specific emergencies that may prevent bridge openings or closures.
- List of anticipated possible equipment malfunctions and a complete description of any emergency procedures related to bypassing or immediately deactivating the equipment if necessary for the following:
    - Traffic signals, traffic gates or barriers, audio devices, etc.
    - Main drive motor, brake motor, centering device, locks, etc.
    - Utility power failure or interruption
    - Emergency operation procedures
    - Utility contact telephone numbers
    - Vessel impact
    - Notifications to authorities: contact telephone numbers
    - Required documentation: sample forms
    - Damage assessment procedure: contact telephone numbers
    - Bridge closure authority: contact telephone numbers

C4.7.2

Operations manuals should be prepared as part of any rehabilitation of a movable bridge. If no project is scheduled, evaluators should assess whether the operators and maintainers are properly informed on normal and emergency procedures. The evaluators should also investigate the operational history of the structure to determine whether the record shows frequent operational difficulties that appear to result from lack of formalized normal and emergency operating procedures. If the need exists, consideration should be given to preparation of a full operations manual or at least a formal detailed set of operating procedures for normal and emergency conditions.

Training of bridge operator supervisors should include extensive bridge operator experience plus evidence of adequate supervisory experience and should include operation training for all bridges under their jurisdiction.

Training of bridge operators should include several days of on-site training on the operation of the bridge, the bridge operations manual and USCG regulations. Training should also include classroom instruction and should require the successful completion of written and operational tests.

- Non-functioning navigation lights

Nighttime, Low Visibility, Inclement Weather Operation:

- List of recommended changes in normal operating procedure, if any
- List of weather related restrictions (if any) on movable span operation (e.g., maximum wind speed permitted during bridge operation)
- Changes in timing sequence, if any
- Changes in lighting requirements, if any
- Requirements for assisted ship passage (tug boats)

Procedure for Crossing Oversized/Overweight Vehicles:

- Required documentation and authorization
- Required traffic control
- Required post crossing inspections

Operating Personnel Duties and Responsibilities:

- Bridge operator duties and responsibilities should be clearly defined in the manual and should also be posted conspicuously in the operator's control house.
- Supervisor responsibilities

Sample copies of bridge records, or current logs on appropriate owner approved forms should be maintained. Each owner should develop standard forms as require for uses that include but are not limited to the following topics:

- Vessel passage
- Bridge openings
- Malfunctions
- Accident: vessel, vehicular, personnel
- Bridge logs
- Maintenance logs
- Inspection logs

The manual should designate the person(s) responsible to complete each type of form and the frequency of preparation and submission data.

A sample table of contents for a typical operations manual is included at the end of the chapter.

4.7.3 BRIDGE MAINTENANCE MANUALS

A bridge specific maintenance manual should be developed for use by maintainers to accomplish both corrective and preventive maintenance tasks. Documentation should include written, graphical, and pictorial data that defines the necessary maintenance actions, component specific procedures, and repair policies for the systems or components. The manual should provide information on the various tools and testing equipment required, acceptable tolerances, safety procedures,

C4.7.3

Most bridge owners assign some routine maintenance chores to the on-site bridge operator. The bridge maintenance manual should clearly state items for which the bridge operator is responsible and those activities that are the responsibility of the maintainers. Any tasks that are the responsibility of the bridge operator(s) should be included in the repair/replacement parts and a step by step sequence required to complete the maintenance or repair work for each major component. The document should be detailed and factual, avoiding discussion on theory of operation or any design features. In general, the documentation should be a complete package with the following information:

- A full copy of all material present in the Operator's Manual
- Details of the bridge systems, including:
  - Wiring diagrams
  - Hydraulic schematics
  - Machinery layout and components
  - Control and interlocking logic systems
  - Traffic control system drawings and sequence of operation
  - Navigation control system drawings and procedures
  - Bridge systems trouble-shooting procedures including full details of control and interlocking logic hardware and software settings and field access/adjustment procedures for:
    - Structural, electrical, hydraulic and mechanical components
    - Lighting, signals and warning devices
    - Emergency procedures
- Include concise detailed procedures for maintenance inspection, preventive maintenance, testing, failure detection, component trouble shooting, fault isolation, parts repair and component replacement. Also include equipment components manufacturer's specifications and detailed procedures for disassembly, adjustment, repairs, and reassembly of individual components wherever maintenance requires disassembly.
- List the tools (name and size) required for maintenance of mechanical, hydraulic and electrical systems, andprocedures for gaskets, brake shoe pads, DC motor brushes, lubricating fluids, etc. The intent is that any internal parts that require periodic replacement by maintainers should have detailed “shop manual” type procedures supplied by the component manufacturer or if not available from the manufacturer, by the designer.
- The maintenance manual should also generally include any other data required by the current version of Reference 7.

A sample table of contents for a typical bridge maintenance manual is provided at the end of this chapter.

operator's manual as well as the maintenance manual. The maintenance manual will typically contain all of the information present in the operator's manual and will also contain additional material that should be restricted to qualified maintainers only. It is not usual for owners to allow operators to gain access to information that might allow unauthorized access or modifications to critical control and interlocking component adjustments and logic settings. Only properly trained and authorized personnel should be permitted to reset control or interlocking switches and sensors.

SAMPLE TABLE OF CONTENTS
BRIDGE OPERATIONS MANUAL
SWING SPAN BRIDGE

SAMPLE TABLE OF CONTENTS
BRIDGE MAINTENANCE MANUAL
SWING SPAN BRIDGE
FOR MAINTENANCE USE ONLY

SAMPLE TABLE OF CONTENTS (CONT.)
BRIDGE MAINTENANCE MANUAL