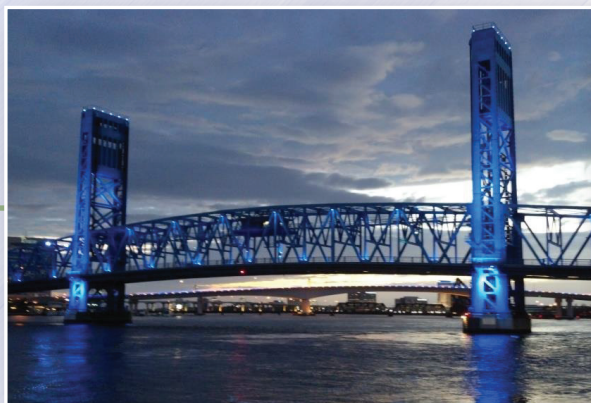




AMERICAN ASSOCIATION
OF STATE HIGHWAY AND
TRANSPORTATION OFFICIALS
AASHTO

Movable Bridge Inspection, Evaluation, and Maintenance Manual





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Cover photos:

Upper Left: John T. Alsop Jr. Bridge, also known as the Main Street Bridge, crossing the St. Johns River in Jacksonville, Florida. Photo courtesy of Florida DOT, provided by Parsons Brinckerhoff.

Upper Right: Stoney Creek Bridge, Riviera Beach, Maryland. Photo courtesy of Maryland State Highway Administration; photo provided by Parsons Brinckerhoff archives.

Lower Right: William A. Bugge Bridge, also known as the Hood Canal Bridge, a floating bridge in Washington State that carries Washington State Route 104 across Hood Canal and connects the Olympic and Kitsap Peninsulas. This photo was taken prior to 2001 and shows a Trident nuclear sub, the SSGN Ohio since converted to SSGN Ohio, from the Bangor Naval base south of the bridge. The east half of this bridge no longer exists (design with roadway “wishbone bulge”) and was replaced by the newer east half design in 2006–2010. Photo courtesy of Washington State DOT; provided by the U.S. Navy.

Lower Left: George P. Coleman Memorial Bridge, Gloucester Point and Yorktown, Virginia. Photo courtesy of Virginia DOT; photo provided by Parsons Brinckerhoff archives.

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CHAPTER 1.1—PURPOSE

The intent of this Manual is to present uniform guidelines and procedures for the inspection, evaluation, and maintenance of the nation's existing movable bridge inventory. The Manual provides information pertaining to the unique structural, mechanical, and electrical components and operational characteristics of a movable highway bridge.

The Manual was developed for bridge engineers, inspectors, and maintainers charged with operational and maintenance responsibility for these complex structures. Therefore, the content of each part is intended for a specific group within the industry. Commentary adjacent to the text on the same page provides suggestions on implementing the guidelines and procedures of this Manual and directs the reader to additional sources of information.

C1.1

This Manual was prepared under NCHRP Project 14-32, Proposed Revisions to Movable Bridge Inspection, Evaluation, and Maintenance. The full final report describing the research effort is filed with the National Cooperative Highway Research Program, which is administered by the Transportation Research Board.



CHAPTER 1.2—SCOPE

The provisions of this Manual apply to highway structures that qualify as movable bridges in accordance with the AASHTO standard definition of a movable bridge. This Manual has been developed to assist bridge owners, engineers, and inspectors by describing procedures and guidelines specific to movable highway bridges and to assist in meeting the requirements of the National Bridge Inspection Standards. The intent of this Manual is to provide a single-source document to address industry needs, not to supplant proper training or the exercise of sound engineering judgment.

Information on safety aspects of movable bridges has been provided to the fullest practical extent, but a structure of unique or advanced design may require a level of sophistication higher than the minimum guidelines and procedures described in this Manual. Bridge owners should evaluate the specific needs of their bridge inventory and organizational structure, exercise judgment, and apply this Manual accordingly.

The National Bridge Inventory data of 2014 indicates that there are 831 movable bridges in the United States. This total includes 184 vertical-lift bridges, 451 bascule bridges, and 196 swing-span bridges.

C1.2

Why a movable versus a fixed bridge? In some cases, the bridge owner and the regulatory agency choose to meet the vertical clearance requirements of the mariner by providing a movable or drawbridge that is able to pass, while in the closed position, an agreed upon percentage of the vessels, while opening for the taller vessels. This compromise is often done to reduce construction costs, adverse environmental impacts, or both. Federal authorization of a drawbridge, however, does not constitute permission to restrict or obstruct navigation beyond the limits of the original permit. When a bridge owner chooses to build a movable bridge, the owner and, by law, all subsequent bridge owners and operators, have legally acknowledged that interruptions to land traffic will be required to allow passage of vessels and that they have a responsibility to budget for continuing maintenance, repair, and operational costs for the life of the bridge. The owner of a bridge that has been closed to vehicular traffic is held responsible by navigation regulatory agencies for ongoing maintenance and operating costs. The term "life of the bridge" is interpreted to mean until the owner removes or replaces the bridge.

CHAPTER 1.3—MOVABLE BRIDGE TYPES

Numerous factors determine the evolution of a movable bridge design. As a result, many types of movable span bridges have evolved to fit specific needs. The design requirements for a short rural bridge spanning a narrow tidal canal are quite different from those for a large urban four-lane bridge that must span a wide, active channel. Movable bridges are classified into four general groups: bascule, swing-span, vertical-lift, and other bridges. This chapter describes the typical design and operational characteristics of each of these three types.

1.3.1—BASCULE BRIDGES

Bascule bridges open by rotating a leaf (or leaves) from the normal horizontal position to a point that is typically nearly vertical, providing an open channel of unlimited height for marine traffic. The width of the channel is limited by the length of the leaf.

If the channel is narrow, one leaf may be sufficient. This design is called a single-leaf bascule bridge. For wider channels, two leaves are used, one on each side of the channel. When the leaves are in the lowered position, they meet at the center of the channel. This design is known as a double-leaf bascule bridge (Figure 1.3.1-1).

There are three basic types of bascule bridges: trunnion, rolling-lift, and heel-trunnion. The trunnion bascule is by far the most common of the three. Some other unique types of bascule bridges are the cable bascule and the overhead counterweight-type multi-trunnion bascule. A more complete listing and description of other types of bascule bridges can be found in References 83, 85, and 154.

1.3.1.1—Design and Operation

Trunnion Bridges: The leaf of a trunnion bascule rotates about a horizontal axis on trunnion shafts attached to each side of the span (Figures 1.3.1.1-1 and 1.3.1.1-2). The trunnion shafts are on a common center line, and mounted in trunnion bearings fastened to the piers. The forward end of the bascule leaf extends over the water and is much longer than the opposite end, referred to as the tail end.

Power to operate a trunnion bascule is transmitted to pinions located on each side of the span. The pinions engage curved racks on the bottom of the leaf. The pinions

C1.3.1.1

Some of the bascule bridge types discussed in this section are also known by alternate names. Typically these alternate names are based on the name of the patent holder for the particular design, or by the region where the design was most prevalent.

The simple trunnion bridges are usually referred to as Chicago type bascules, and the rolling-lift bridges are usually of the Scherzer or Rall type designs. The heel-trunnion and the overhead counterweight bridges are typical Strauss type designs.

rotate in one direction to open the leaf. Reversing the rotation of the pinions closes the leaf.

A few trunnion bascule bridges have machinery mounted on the counterweight end of the movable leaf, with curved racks fixed on the pier. As the pinions rotate, they move along the racks to open and close the span.

Some of the smaller trunnion bascules make use of a single curved rack located under the center of the leaf between the trunnion shafts. The counterweight is positioned so as to balance the weight of the leaf (Figure 1.3.1.1-4).



Figure 1.3.1.1-1 – Double-leaf bascule bridge

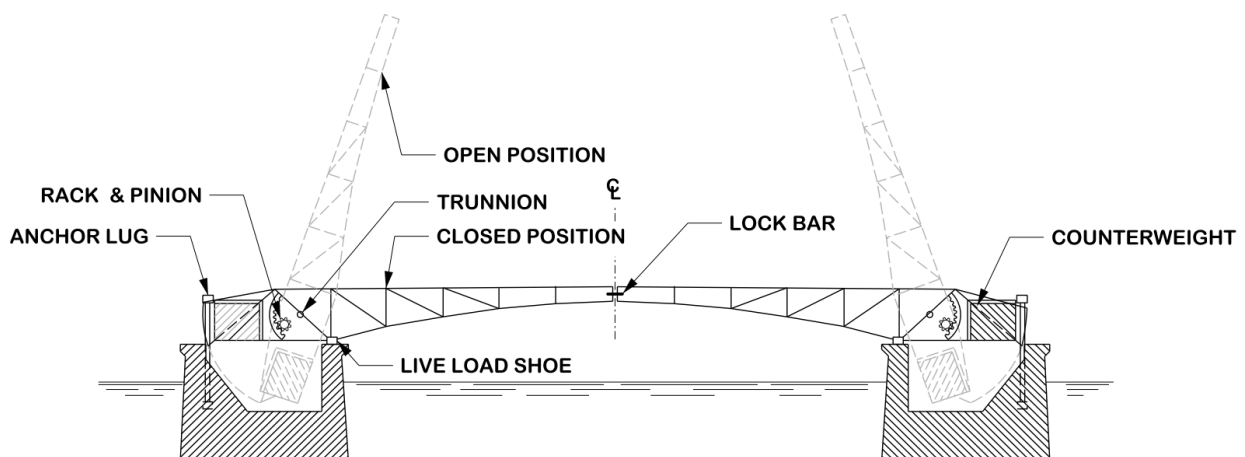


Figure 1.3.1.1-2 – Operating components of a double-leaf trunnion bascule bridge

Rolling-lift Bridges: On this type of bridge (Figure 1.3.1.1-3), curved tracks are attached to each side of the tail end of the leaf. The curved treads, which have square or oblong holes machined into them, roll on flat, horizontal tracks mounted on the pier. The horizontal tracks typically have lugs (or teeth) to mesh with the holes, preventing slippage as the leaf rolls back and forth on the track.

The weight of the leaf, including the superstructure and counterweight, is supported by the curved treads resting on the horizontal tracks.

Drive machinery is most frequently mounted on the leaf above the roadway when the span is a through truss, and most frequently mounted on the leaf below the roadway when the span is a welded or riveted deck girder. Power is transmitted to pinions, which engage straight racks mounted on the pier (Figures 1.3.1.1-5 and 1.3.1.1-6). The pinion is located at the center of rotation of the curved treads; as it rotates away from the channel, the span rolls back.



Figure 1.3.1.1-3 – Rolling-lift single-leaf bascule

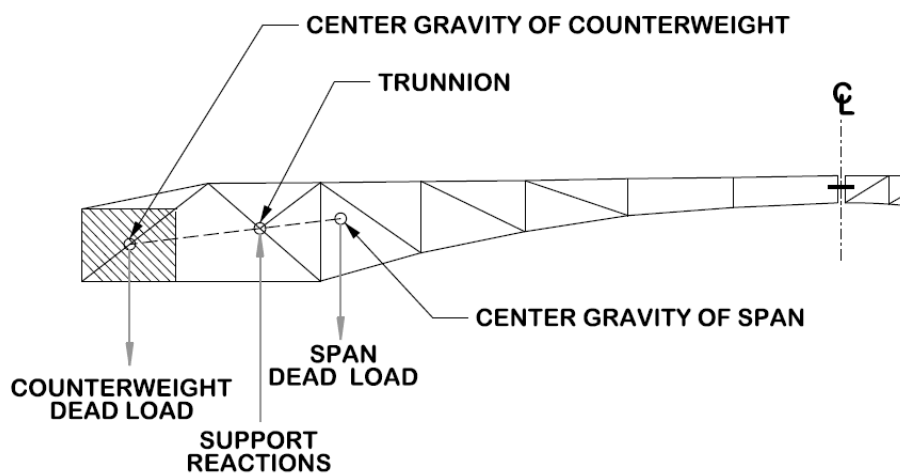


Figure 1.3.1.1-4 – Load distribution on trunnion type bascule bridge

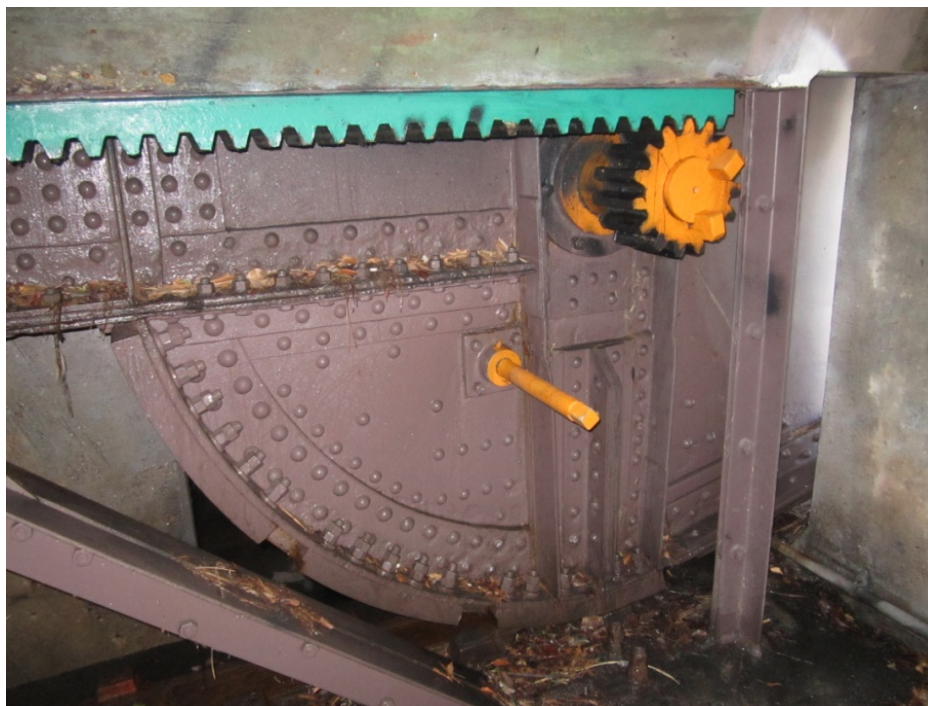


Figure 1.3.1.1-5 – Rolling leaf rack, pinion, and curved tread

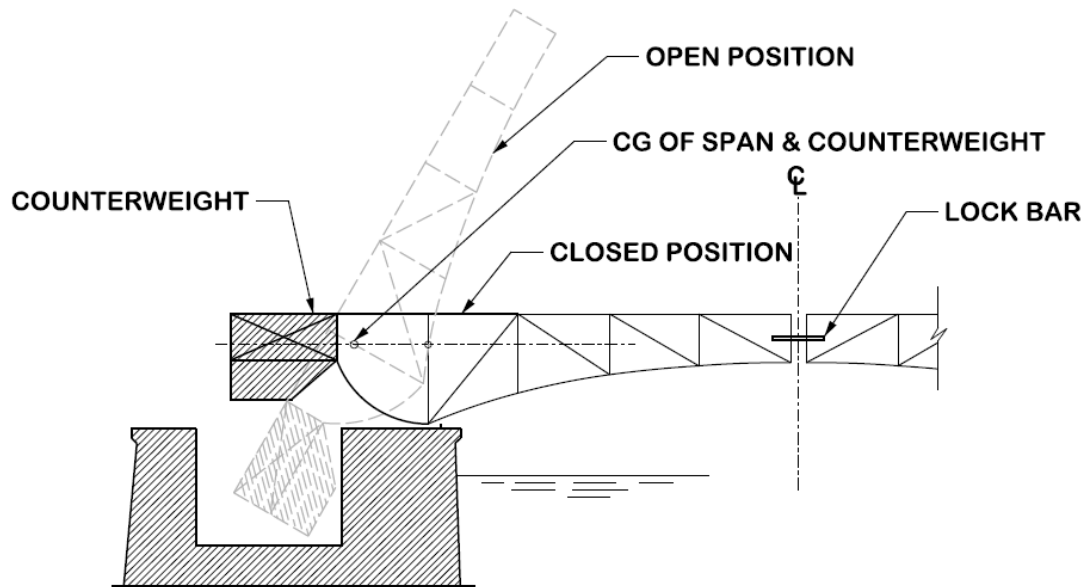


Figure 1.3.1.1-6 – Rolling-lift double-leaf bascule

Heel-trunnion Bridges: This type of bridge (Figures 1.3.1.1-7 and 1.3.1.1-8) rotates about trunnions, similar to a trunnion bascule. The difference lies in the counterweight mounting and drive mechanism. The counterweight is mounted on a rotating framework, not on the leaf itself (Figure 1.3.1.1-8). The leaf rotates about the heel-trunnions mounted on the pier and the counterweight frame rotates about two other trunnions mounted on a rigid rear panel that is fixed to the pier. Connecting arms link the leaf and counterweight frame together.

The drive machinery is usually mounted on the rear panel (Figure 1.3.1.1-8), but may be span mounted on some bridges. In Figure 1.3.1.1-8, two racks are attached to the leaf. Pinions engage these racks and pull the leaf to raise it. As the leaf rotates to open, the counterweights swing down past the rear panel, keeping the system in balance. The rotation of the pinions is reversed to lower the span.



Figure 1.3.1.1-7 – Heel-trunnion (Strauss) type bascule bridge

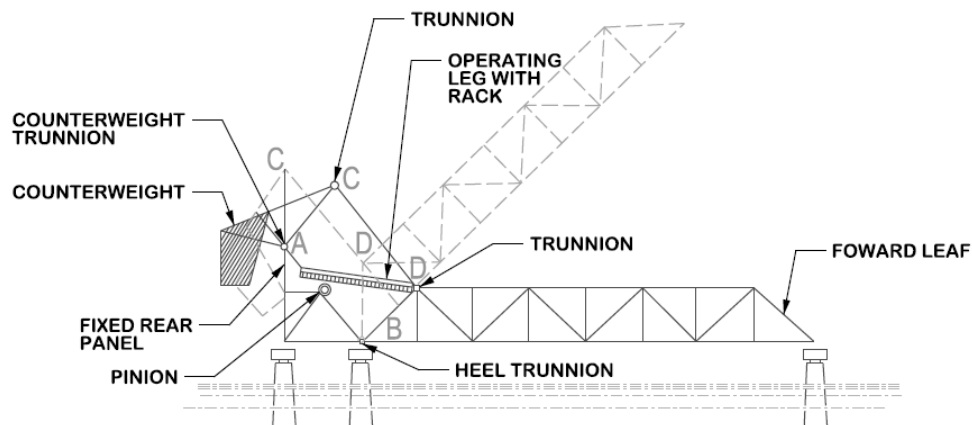


Figure 1.3.1.1-8 – A heel-trunnion bridge has two fixed trunnions, A and B. The leaf rotates about B, and the counter weight rotates around A. Link Pins C and D move as the leaf is raised.

Overhead Counterweight Bridges: The schematic of this type of bascule bridge is shown in Figure 1.3.1.1-9. This bridge is also a multi-trunnion bascule, similar to the heel-trunnion bascule described above. The difference is in the counterweight mounting and the mechanism used for the movement of the counterweight.

The main features of the overhead counterweight type of bascule bridge are the four trunnions T1, T2, T3, and T4, so arranged as to form a parallelogram (Figure 1.3.1.1-9). The bridge rotates about the main trunnion T1, while the counterweight is attached to the diagonally opposite trunnion T3.

On another common design, the counterweight is suspended underneath the roadway and the counterweight mechanism is basically identical to that in the overhead counterweight bridge. The bridge with the counterweight mechanism underneath the roadway is generally called the Strauss underneath counterweight type bridge. Since gravity maintains vertical alignment of the

counterweight, the extraneous horizontal lower link was eliminated in some versions of this design.

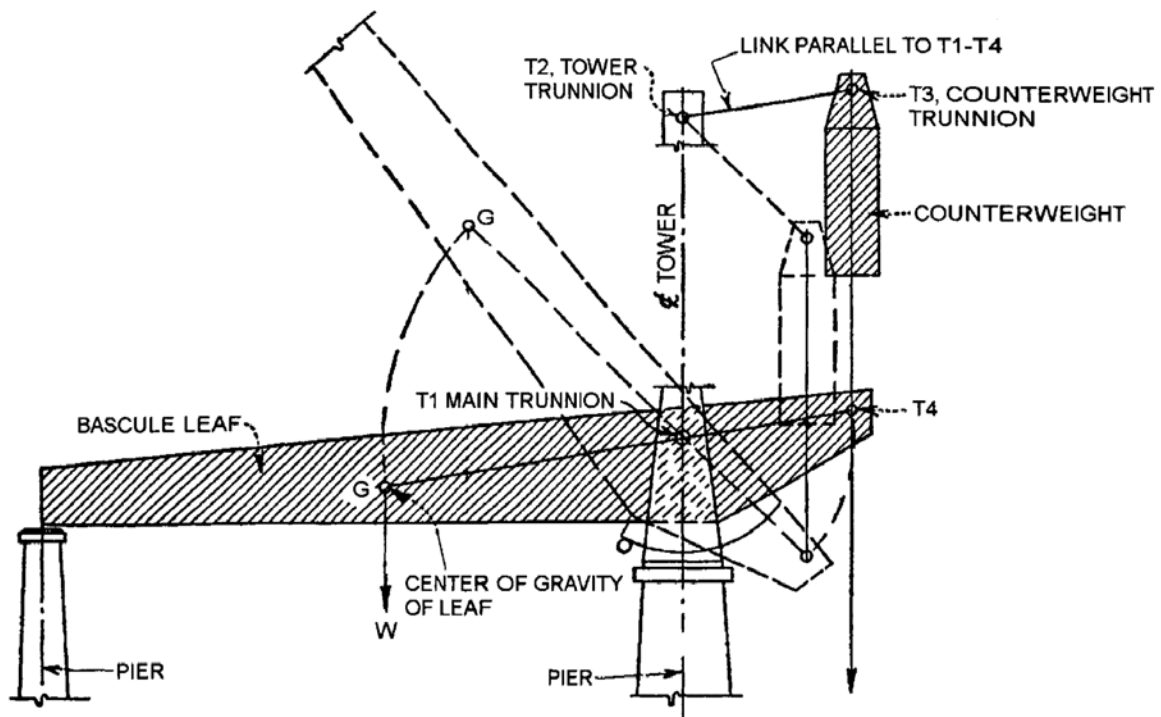


Figure 1.3.1.1-9 – Overhead counterweight-type multi-trunnion bascule

Cable Bascule Bridges: This type of bridge is the most elementary type of bascule bridge. The simplest example of this type of bascule bridge is the entrance to a medieval castle across the moat, where the bridge is raised or lowered by a pair of cables running from the end of the bridge to the top of the castle. A more complex design (Figure 1.3.1.1-10) for a cable bascule bridge consists of two pairs of cables, one pair attached to a set of counterweights, and the other pair used for raising and lowering the bascule leaf. The provision of the counterweight minimizes the effort needed to raise or lower the span.

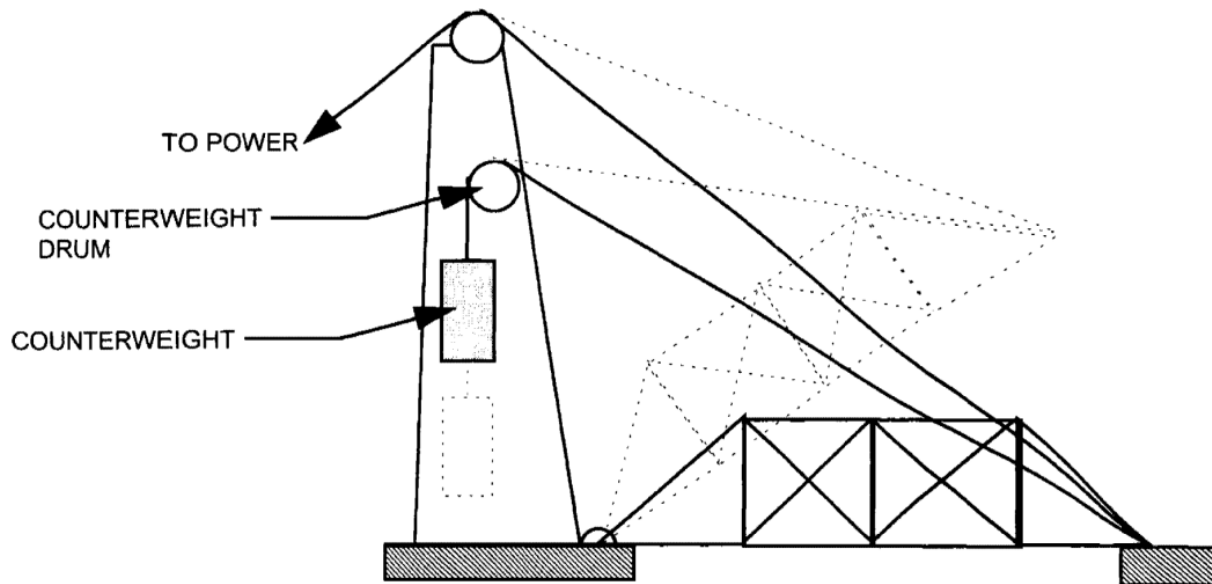


Figure 1.3.1.1-10 – Cable bascule with counterweight

1.3.2—SWING-SPAN BRIDGES

Swing-span bridges open by rotating the movable span so that it is aligned with the channel (Figure 1.3.2-1). In the closed position (closed to marine traffic) the span is supported by three piers. The pivot pier supports the dead load weight of the span itself, while the end or rest piers carry sufficient dead load to stabilize the span. When the span is closed, the rest piers join with the pivot pier in carrying the live load. When the span is not completely closed, its entire weight rests on the pivot pier.

Most swing-span bridges are symmetrical about the center of the span. However, on some occasions non-symmetrical counterweighted spans have been installed in locations where space is limited. These are referred to as bob-tail spans (Figure 1.3.2-2).

Swing-span bridges can be made with different structural systems such as steel plate girder or steel truss.



Figure 1.3.2-1 – Swing-span bridge



Figure 1.3.2-2 – Bob-tail swing-span bridge

1.3.2.1—Design and Operation

There are two types of swing-span bridges: the center bearing design and the rim bearing design.

C1.3.2.1

Balance wheels are typically designed for forces generated by wind loads that tend to create an “overtopping” moment with the span open. Since many swing-spans are not perfectly balanced and since center bearings can become misaligned due to pier or bearing settlement or wear, balance wheels will sometimes also carry a small percentage of the span dead load due to wobble or imbalance. As long as the percentage remains small, this phenomenon may not be a problem. Inspectors should monitor the

performance of balance wheel assemblies during span motion and file a deficiency report if vertical motion or deflection of the balance wheel assembly is observed to be excessive.

Center Bearing Bridges: The center bearing type shown in Figures 1.3.2.1-1 and 1.3.2.1-2 has a large, bronze spherical bearing at the center of the span that supports the weight of the span when the bridge is in the open position. The span is balanced so that its center of gravity is over the bearing, which receives the weight of the span through a heavy cross-girder. The center bearing also keeps the span centered. A balance wheel system provides stability during rotation and in the open position on the perimeter of the pivot pier (Figures 1.3.2.1-3 and 1.3.2.1-4).

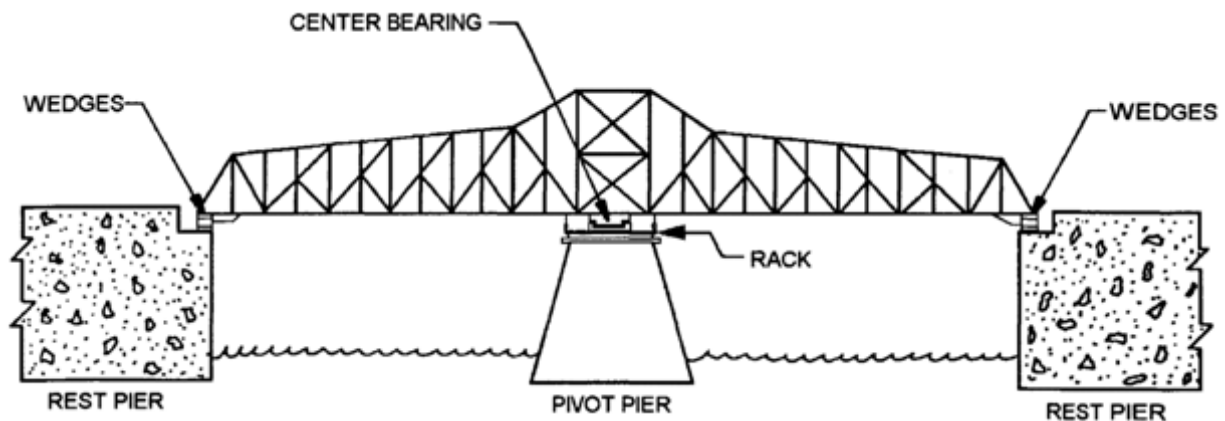


Figure 1.3.2.1-1 – Span rotates on center bearing; balance wheels stabilize span as it opens and closes

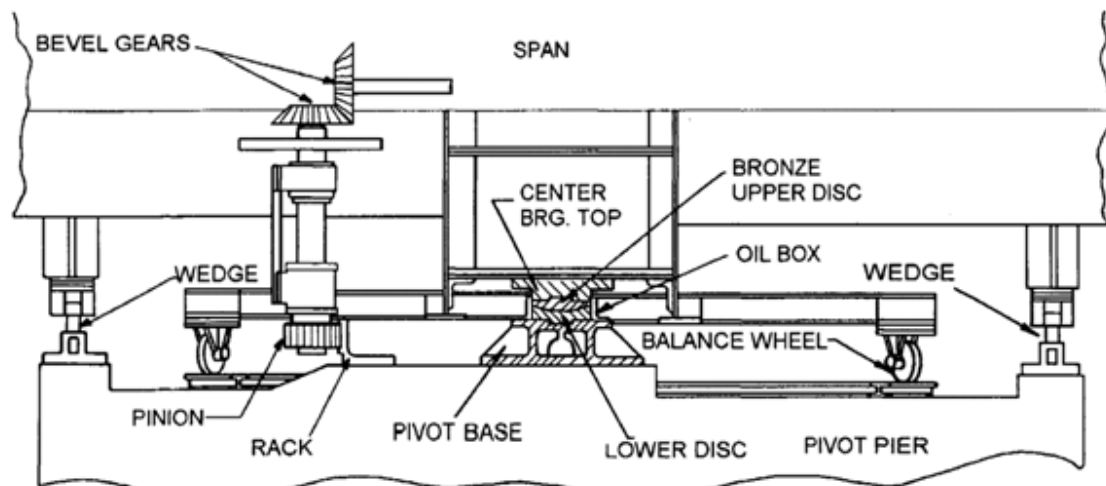


Figure 1.3.2.1-2 – Sketch of swing-span in closed position showing piers and location of operating components

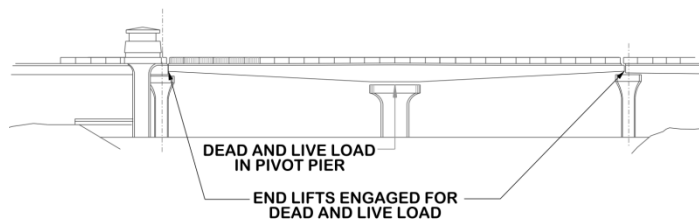


Figure 1.3.2.1-3 – Swing-span in closed position

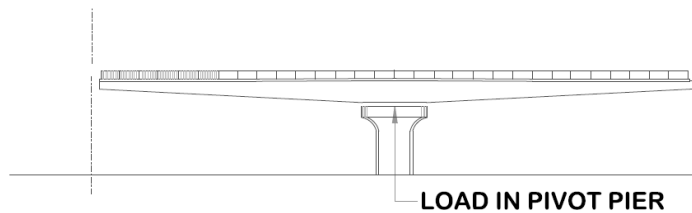


Figure 1.3.2.1-4 – Swing-span in open position

Rim Bearing Bridges: Rim bearing swing-span bridges ride on a large number of tapered rollers positioned around the center of the span (Figure 1.3.2.1-5). The rollers carry the weight of the span and provide stability during span operation. A center post is typically provided with radial members to keep the rim-bearing wheels centered. The weight of the span on the tapered rollers and sloping tracks prevent the rollers from moving toward the center bearing. The rollers are held in place both radially and circumferentially by a “cage” or a roller frame.



Figure 1.3.2.1-5 – Rim bearing swing-span

While a swing-span bridge is closed, the brakes are engaged and the machinery is at rest. When the electrical controls are engaged to open the bridge, the brakes are released, wedges or jacks are actuated and live load supports are pulled, then the motor is started, and the motor power is transmitted to spur pinions, which engage a curved rack. The pinions walk around the curved rack (Figure 1.3.2.1-6), causing the span to rotate.



Figure 1.3.2.1-6 – Rim bearing swing-span rollers and rack

A swing-span bridge normally rotates a maximum of 90° to open the channel to navigational traffic. Hence, the curved rack need not be a full 360° gear. When one spur pinion is used, 90° plus a few extra teeth for overrun is all that is required. When two spur pinions are used, two 90° segments are required. Some bridge designs incorporate a 360° curved rack on the center span to provide flexibility so that the span can be rotated in either direction. In the event that there is an obstruction in one direction, the span can open in the opposite direction. If a rack tooth fails or becomes fouled, preventing span rotation in one direction, the span is still able to rotate in the opposite direction to allow passage of marine traffic, or rack segments can be repositioned.

1.3.3—VERTICAL-LIFT BRIDGES

Vertical-lift bridges consist of a rigid horizontal span supported between two towers. The span is raised to allow passage of marine traffic. This type of bridge is the most efficient from the standpoint of providing a clear channel width. It also has the potential for greater span length than other types of movable bridges. Since the machinery on a vertical-lift bridge is typically mounted above road level, they are also appropriate in locations where below deck space is limited.

Vertical-lift bridges can be made with different structural systems such as steel plate girder, steel truss, steel, and concrete tower. Figure 1.3.3-1 shows the use of concrete towers and steel plate girders.



Figure 1.3.3-1 – Vertical-lift with concrete towers and plate girders

1.3.3.1—Design and Operation

Three types of vertical-lift bridges are readily identifiable. Two by the method of operation—tower-drive and span-drive—and one by an overhead connecting structure between towers—the connected tower type.

Tower-drive Bridges: On tower-drive vertical-lift bridges, as shown in Figure 1.3.3.1-1, drive machinery is mounted on top of each tower. A large sheave is mounted on each side of the tower, with counterweight ropes wrapping 180° around the sheaves. One end of the rope is attached to the span and the other to the counterweight.

As the drive machinery turns the sheaves in one direction, the cables raise the span and lower the counterweights (Figure 1.3.3.1-2). When the rotation of the sheaves is reversed, the span is lowered and the counterweights are raised.



Figure 1.3.3.1-1 – Tower-drive vertical-lift bridge

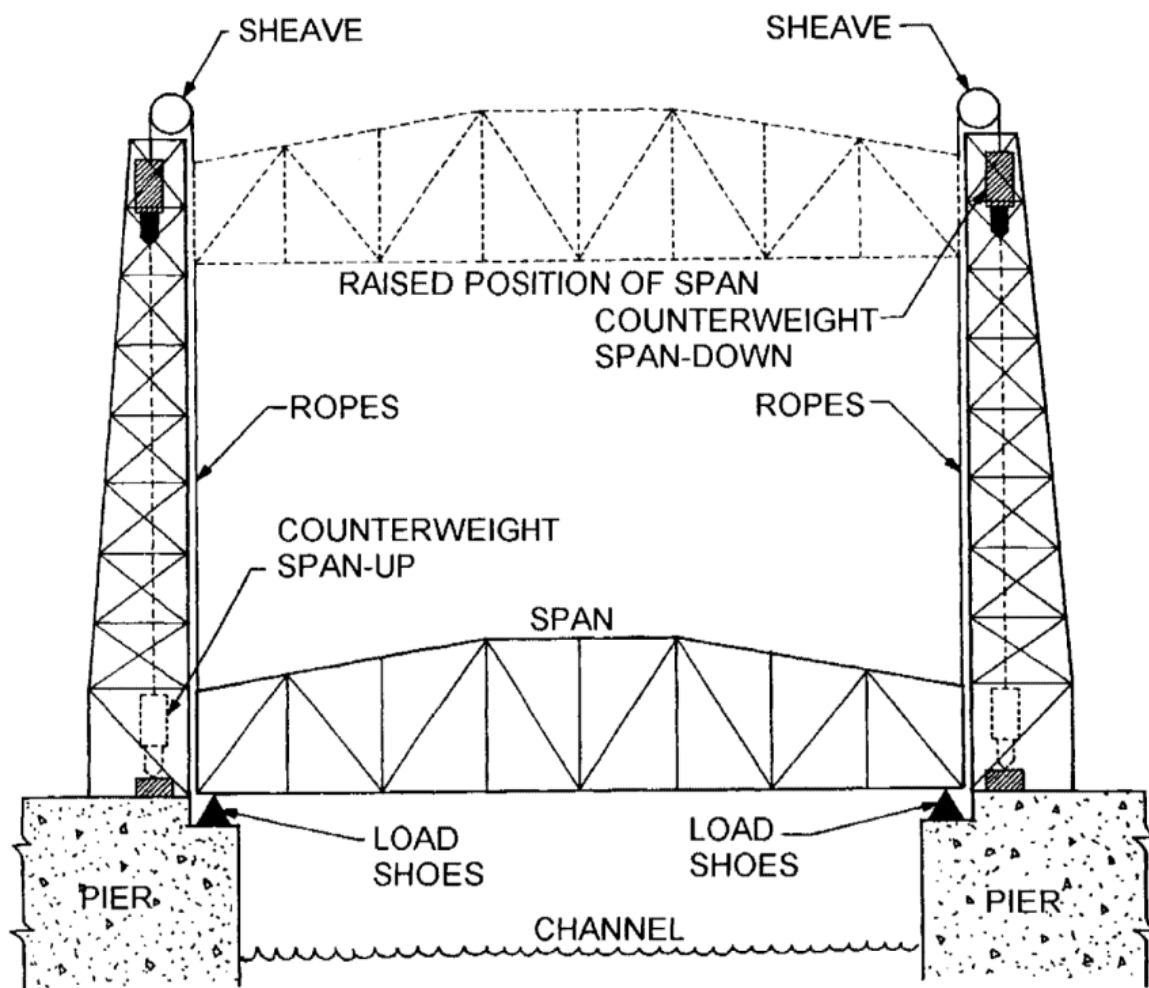


Figure 1.3.3.1-2 – Closed span rests on load shoes; as span is raised, the counterweights descend

Span-drive Bridges: Span-drive vertical-lift bridges (Figure 1.3.3.1-3) operate differently from tower-drive bridges. Counterweight sheaves are mounted on the towers, but the drive machinery is located on the movable span. Another difference is that this type of bridge has two separate wire rope systems.

The counterweight ropes pass over the counterweight sheaves, as in the other type, but they do not provide the lifting force. Instead, the span is driven by four drums, one located at each corner that provide lifting or lowering force to each corner of the lift span via operating ropes. Two operating ropes wrap around each drum, one secured at the top of the tower, the other at the bottom and as the drums reel in the ropes secured at the top of the towers, the span rises. When the rotation of the drums is reversed, the ropes connected to the bottom of the towers are reeled in, and the span returns to the closed position.

The drums may be located at each corner or in the machinery house at the center of the span and the operating ropes extend longitudinally along the span to the towers (Figure 1.3.3.1-4).

The operating ropes do not support the weight of the span as it moves up and down. The span weight is carried entirely by the counterweight ropes similar to the tower-drive and connected-tower designs.



Figure 1.3.3.1-3 – Span-drive vertical-lift bridge

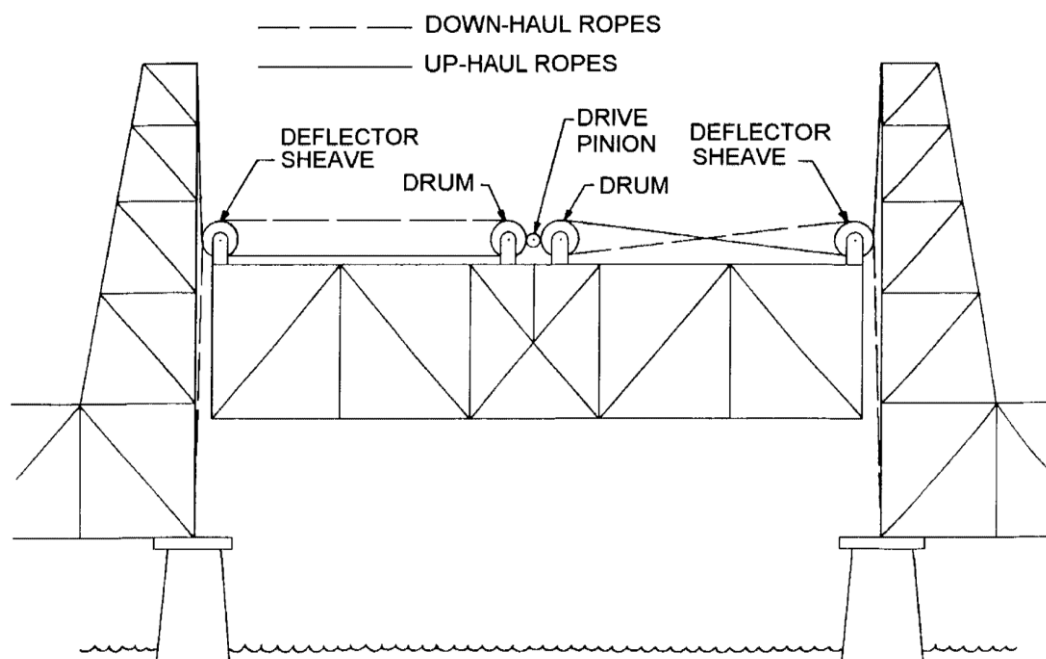


Figure 1.3.3.1-4 – Sketch of operating ropes on a span-drive vertical-lift bridge.

Connected-tower Bridges: Sometimes tower-span bridges are used for short span applications. This type of bridge has a rigid span between the towers (Figure 1.3.3.1-5). The operating machinery located at the center of the rigid span-drives all four sheaves to raise and lower the movable span.



Figure 1.3.3.1-5 – Connected-tower vertical-lift bridge

1.3.4—OTHER MOVABLE BRIDGE TYPES

Uncommon types of movable bridges are retractile, transporting, jackknife, reticulated, floating pontoon, and gyratory.

Louisiana includes a number of floating movable bridges, using steel pontoons that rotate open similar to a swing-span bridge. Operating systems include wire rope systems (Figure 1.3.4-1) or even propeller operating systems comparable to an outboard motor found on a boat.

Floating retractile bridges open by translating horizontally, pulling back away from the navigable channel. Floating retractile bridges may be the most economical solution for crossing channels that are very wide, very deep, or both, such as the Hood Canal Bridge in Washington State. (Figure 1.3.4-2).

Land-based retractile bridges, which roll back on railroad type tracks, are an obsolete type of which few historical examples remain.

Transporter bridges, another obsolete type, carry a segment of roadway over a water crossing.

There are many other uncommon, obsolete, or novel types of movable bridges. Recent trends—particularly for pedestrian movable bridges in Europe, but also in the United States—have seen the development of unique designs chosen for their ability to delight the public, rather than strictly economic considerations. Recent examples include gyratory and folding types, among others (Figure 1.3.4-3).



Figure 1.3.4-1 – Pontoon swing-span bridge with wire rope operation, Louisiana



Figure 1.3.4-2 – Floating retractile bridge at Hood Canal, Washington



Figure 1.3.4-3 – Folding bridge

CHAPTER 1.4—BRIDGE FUNCTIONAL SYSTEMS

1.4.1—GENERAL

The operation of a movable bridge can be separated into seven distinct functional systems: support, balance, drive, control, interlocking, navigation guidance, and traffic control. Each system may be comprised of structural, mechanical, or electrical components, or a combination of these.

1.4.2—SUPPORT SYSTEM

This assemblage of substructure and superstructure components provides span support in the open, operating, and closed positions. Typical components include:

- piers and abutments, trusses, girders, and bearings;
- rolling track girders, segmental girders, and tread plates.
- main trunnions and trunnion supports, bearings and journals;
- double bascule heel stops or shear locks;
- lift-span towers and cables
- swing-span rim bearing wheels or center bearings;
- swing-span end lifts or end wedges; and
- center wedges and live load shoes.

1.4.3—BALANCE SYSTEM

This system provides stability during motion, and is composed of structural and mechanical components that prevent swing-spans from tipping, and reduce machinery loads on lift spans and bascules.

The balance system is one of the most important design features and is often overlooked by inspectors or not fully understood. Inspectors should be aware of the function of balance in the continued safe operation of a movable bridge.

C1.4.1

It is important that inspectors and maintainers understand the purpose of each functional system, and are able to evaluate the operation of each system, as well as to assess the condition of individual components. An experienced inspector should be able to identify a component problem, evaluate the impact on the functional system, and extend the findings to determine the impact on bridge operation. Without understanding the functional systems, it would be difficult for an inspector observing an operational problem to diagnose the possible cause. The ability to view a movable bridge as a series of functional systems will assist the inspector in better understanding bridge operation.

C1.4.3

Some movable bridges have been designed to operate without counterweights. In this case, the leaf is usually driven up and down by hydraulic cylinders.

1.4.4—DRIVE SYSTEM

The drive system consists of electromechanical, hydraulic, or other components (or a combination of these) that provide motion to the movable span. The support and balance systems are designed to control motion and provide a manageable degree of span imbalance to the drive system. Operation of the drive system is monitored, sequenced, and directed by the control and interlocking systems.

The drive system can be separated into several subsystems, as follows:

- Power
- Electric motors
- Hydraulic motors
- Engines
- Hydraulic pumps.
- Generators.
- Auxiliary motor/generator sets
- Hand drive or manual drive (capstan, air motor, T-bar, etc.)
- Power transmission
- Shafts
- Couplings
- Bearings
- Wire rope
- Chains
- Gears
- Differentials
- Hydraulic cylinders or motors
- Brakes
- Motor brakes (thruster or solenoid brakes are common types)
- Span brakes
- Locking pawls
- Lock bars
- Buffer cylinders.
- Automatic drive power limiters (slow-seating provisions in control systems)
- Speed reduction
- Open and enclosed reduction gearing
- Electrical and electronic speed controlling circuits and drives
- Hydraulic control valves
- Engine throttle

1.4.5—CONTROL SYSTEM

The control system governs the operation of the movable span. The control system serves as the command interface between operator and machine, allowing the operator to direct the bridge to open and close.

The control system may be electrical, mechanical, manual, hydraulic, or a combination of these or other types. The operator interface may be as simple as a pair of push-buttons marked “up” and “down,” but the control system may be as complex as a programmable logic controller (PLC) with instrumentation to monitor critical operating parameters and telemetry that reports monitoring results periodically to a control maintenance management office. All control systems perform the same basic task regardless of type or complexity.

The control system consists of the operator's panel and associated indicator boards, panels, wiring, hydraulic control levers, programmable logic controllers, relays, switches, other operator accessible actuators, or some combination of these that are designed to govern the operation of the movable span.

The controls on a movable bridge may be classified as manual, semi-automatic, or automatic. Manual controls have no automatic sequencing and may have very little interlocking to prevent operator error. If the operator does not activate controls in the proper sequence, damage to machinery or unsafe conditions may result. A manual bridge control system may allow the operator to engage the span-drive motors without releasing the span locks. Semi-automatic and automatic controls have increasing degrees of automation typically with corresponding increased logic and interlocking devices which prevent certain types of operator error. Newer control designs are more likely to have interlocking and control logic in accordance with the current AASHTO specifications (Reference 6).

1.4.6—INTERLOCKING SYSTEM

The interlocking system is the electromechanical or hydraulic (or both) components, logic devices, and circuitry that monitor bridge motion and regulate the sequence of movable span operation.

The interlocking system is the most subtle functional system on the structure. Its elements are dispersed throughout the structure and all components may not be readily identifiable. The purpose of the interlocking system is to regulate when movable span components function during the various sequences of bridge operation. Since out-of-sequence operation may be hazardous to public safety, or might damage operating machinery or the structure or both,

it is appropriate to include devices in the design that prevent operation of the movable span in an unsafe or harmful manner. The interlocking system serves that purpose. A partial list of interlocking components includes:

- limit switches and wiring;
- relays and wiring;
- detectors, sensors, and wiring that indicate the position of moving parts;
- cams, levers, plungers, and other mechanical trip mechanisms;
- internal position detectors in hydraulic ram pistons; and
- software and hardware in PLCs dedicated to sequence of operations control.

1.4.7—NAVIGATION GUIDANCE SYSTEM

The navigation guidance system channels the travel path of an approaching vessel from the open channel through the bridge opening.

The navigation guidance system is comprised of numerous separate communication, lighting, vessel guidance, navigation, and channelizing devices functioning to allow safe, controlled passage of vessels through a movable bridge site.

The guidance systems should be in conformance with CFR requirements (References 2 and 3). This system also requires provision for efficient communication by audible and visual signals between the bridge operator and vessels. A partial list of the components of this system includes:

- Marine radio communication.
- Lights, whistles, and horns.
- Retroreflective panels.
- Radar reflectors or racons, or both (radar signal emitters).
- Fog signals.
- Fendering and other pier protection devices.
- White/red flags at control tower.
- Underclearance gauges and tide gauges.
- Permit drawings showing legal channel width and underclearance.
- NOAA navigation charts.
- Navigation lighting.

1.4.8—TRAFFIC CONTROL SYSTEM

The traffic control system serves to manage and control the traffic flow through a movable bridge span and to stop and store the vehicles safely during bridge openings.

The traffic control system is comprised of visual and audible signals, signs, and physical barriers coordinated according to state and federal regulations. All visual and audible signals are required to be effective at all times and in any weather condition from the perspectives of vehicular and pedestrian traffic and the bridge operator. Traffic control should be integrated and work in proper sequence with the other functional systems. A partial listing of this system includes:

- lights, bells, and sirens;
- stop signs and warning signs;
- traffic lights;
- resistance gates;
- retroflective panels; and
- impact attenuators.

1.4.9—MOVABLE BRIDGE HOUSE

While not strictly a bridge functional system, movable bridges typically include one or more houses for operating personnel, as well as enclosing bridge mechanical and bridge electrical equipment. A partial listing of components in each subsystem includes:

- House architectural systems: windows, doors, façade, roof, and weatherproofing
- House structural systems: columns, beams, trusses, and foundation
- House mechanical systems: plumbing and HVAC
- House electrical systems: receptacles and house lighting

CHAPTER 1.5—QUALITY MEASURES

1.5.1—GENERAL

Movable bridge owners should implement quality control and quality assurance processes to verify that the level of acceptable performance is upheld for all bridge related activities. Such programs should maintain the accuracy and consistency of bridge inspections, operation, and evaluation of these structures. The programs should particularly considering the quality of load ratings—that is, quantifying the live load carrying capacity of an existing structure specific to an owner-specified vehicle which is not consistent across the industry. Appropriate quality control and quality assurance procedures must be followed by all personnel involved for bridge inspectors to collect inventory and condition information on each bridge, including evaluators to process and assess the field data and make decisions on a repair/rehabilitate/replace strategy; bridge tenders to operate the structures under a wide range of field conditions; and maintainers to service the equipment to provide reliable, safe operation.

The accuracy and consistency of bridge condition information and the operational reliability of these structures' systems are vital to public safety, commerce, and navigation. As such, the procedures of quality control and quality assurance should be evaluated and updated regularly.

CHAPTER 1.6—RECENT INDUSTRY STANDARDS

At the time of writing this manual, three significant new industry practices included the consideration of sustainability, security, and resiliency (including climate change impacts). Many existing movable bridges were built before these items were commonly considered as a design practice. There is an opportunity for professionals to consider these items when inspecting, evaluating, or maintaining an existing movable bridge.

1.6.1—SUSTAINABILITY

The Federal Highway Administration (FHWA) defines sustainability as follows: “Actions are sustainable when they maintain or enhance our capacity to endure. The goal of sustainability is the satisfaction of basic social and economic needs, both present and future, and the responsible use of natural resources, all while maintaining or improving the well-being of the environment on which life depends.”

Several programs exist to rate highway or transportation infrastructure projects for sustainability, including movable bridge design and construction projects, including rehabilitation projects. These sustainability rating systems are analogous to and were inspired by the success of the Leadership for Energy and Environmental Design (LEED) rating system for buildings. Examples of sustainability rating systems that can be applied to movable bridge projects include:

INVEST, sponsored by the FHWA.

Envision, sponsored by Institute for Sustainable Infrastructure, a joint venture of American Society of Civil Engineers (ASCE), American Council of Engineering Companies (ACEC), American Public Works Association (APWA), and the Graduate School for Design at Harvard University.

Greenroads, a third-party, points-based system available to certify sustainable roadway and transportation infrastructure projects.

1.6.2—SECURITY

In 2003, at the request of AASHTO, the FHWA published *Recommendations for Bridge and Tunnel Security*. There is a generally increased sensitivity to security concerns by bridge owners. Background security checks are commonly required by owners before personnel are granted access to bridge sites. Security systems including door locks and cameras can be expected. Once at the bridge site, local law enforcement may

stop personnel to request identification and an explanation of activities. Movable bridge professionals should be prepared to encounter these issues before entering the field.

The operator's houses of several existing movable bridges have received gunshots and the installation of bullet-proof glass may be justified in many locations.

1.6.3—RESILIENCY

Existing movable bridges that are located in coastal areas and have low clearance above the waterway are particularly vulnerable to coastal storms, as well as potential effects associated with climate change including rising sea levels, increased storm intensities, and increased temperatures. As an example, Hurricane Katrina, which hit Louisiana and Mississippi in 2005, and Superstorm Sandy, which hit New York and New Jersey in 2012, caused substantial damage to dozens of existing movable bridges. A particularly acute issue was with regards to low-mounted electrical equipment that became inundated and irreparably damaged by water due to storm surge. In addition, many operator's houses were severely damaged due to inundation and wind damage.

Movable bridges are built to much closer tolerances than fixed bridges and can become inoperable when structure, machinery, or both are deformed due to unanticipated wave loading during a storm surge, due to impact from waterborne debris, or due to inundation of waterborne sediment into sensitive and low-mounted mechanical and electrical equipment. The currently predicted sea level rises due to climate change mean that vertical channel clearances will be reduced increasing the likelihood of collisions with marine vessels. Higher temperatures cause thermal expansion and increase the likelihood of movable spans becoming jammed against the approach spans and rendering them inoperable.

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 one foot of clearance over the 100-year design wave crest elevations, which includes the design storm water elevation."

Further, the *Guide* states that "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."

During the inspection, evaluation, and maintenance of existing movable bridges, professionals should consider the vulnerability of the subject bridge to the above resiliency related issues. For movable bridges, beyond just applying the wave loads to the structure, it is also important to recognize that bridge mechanical and electrical systems, as well as operator's houses, will sustain significant damage if inundated with water during a storm surge event.



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CHAPTER 2.1 – GENERAL

2.1.1—GENERAL

Inspection of any bridge structure requires that the use of personnel, equipment, tools, and access methods be coordinated in an efficient, logical manner. An inspection should be planned considering typical seasonal variations in site conditions; vehicular, pedestrian, and vessel traffic; weather; and numerous other factors that may only become apparent during a pre-inspection site visit.

Information gathered during the condition inspection of a movable bridge provides the necessary data for evaluating the physical and functional condition of the structure, establishing priorities for maintenance and repair programs, and providing assurance that the structure is safely performing as designed. A thorough inspection plan anticipates problems that may be encountered, streamlines the inspection operation, and can also result in early detection of significant defects or deficiencies.

Element-level condition assessment methods have been adopted by the FHWA. Element-level inspections collect information in a format that is focused on bridge management. This supplements the previous inspection methods for the National Bridge Inventory.

This Chapter provides an overview of the process for a typical movable bridge inspection. Reference 62 contains additional information on bridge inspection planning.

C2.1.1

The planning stage for a movable bridge inspection goes beyond gathering available bridge plans and reports; preparing field sketches; and organizing the proper tools, equipment, and personnel. The engineer/inspector should consider the need for one or more specialists, possible disassembly and/or cleaning of mechanical or electrical components prior to inspection, and the coordination of the work within traffic and navigational restrictions.

The planning operation should focus on objectives such as establishing priorities for maintenance, etc. and should also determine the methodology, equipment, means of access, and personnel requirements needed to conduct the inspection.

CHAPTER 2.2 – TYPES AND SCOPES OF INSPECTION

2.2.1—TYPES AND SCOPES OF INSPECTION

The *AASHTO Manual for Bridge Evaluation* (Reference 8) lists seven types of inspections: Initial, Routine, Damage, In-Depth, Fracture Critical, Underwater, and Special. These inspection types apply to movable bridges with specific modifications and additions as described herein.

The following inspection examination methods may be included in an inspection:

Visual Examination: Condition information is gathered and documented on individual components by the inspector based on external signs of deterioration or defects (e.g. corrosion, wear, abrasion, cracking, misalignment, allowable clearances, fluid levels, proper lubrication, exposed wiring, etc.).

Operational Examination: The component or system is inspected during operation of the bridge. The inspector observes the component, noting overall performance, unusual sounds, vibrations, temperature increase, unusual odors, and/or excessive clearance in shafts, bearings, etc.

Measurement Examination: The component or system is measured, with the measurements documented and compared to standard or previous measurements. For example, mechanical measurements may include gear tooth backlash and wear; bearing clearances; coupling alignment; brake reserve stroke, shoe contact, and shoe wear; rope diameter, lay, and crown wear; hydraulic pressures and flows, etc. Example electrical measurements include megger testing and motor current.

Special Examination: The component or system is disassembled and/or investigated by various nondestructive techniques (magnetic particle, ultrasonic, radiography, etc.).

There are three main types of movable bridge mechanical and electrical inspections: Routine, In-depth, and Special. Each type of inspection requires different levels of intensity. Many new mechanical and electrical systems experience adjustment or break-in problems. Therefore, it is recommended that the initial inspections on new mechanical and electrical systems of new or rehabilitated movable bridges be performed to the In-Depth level of intensity.

2.2.2—ROUTINE INSPECTION

Routine inspections include visual and operational examination. Measurement or special examinations are typically not included in a routine inspection.

C2.2.1

One of the goals of an initial inspection should be to identify existing system conditions and operating parameters to facilitate distinguishing between stable conditions and defects that continue to deteriorate further in subsequent inspections.

C2.2.2

Trial openings should be made as necessary to verify that all components and systems are functioning properly. Trial openings for the purpose of inspection

Routine inspection of the structural systems should conform to Reference 8 and any additional owner requirements. Routine inspection of the mechanical, hydraulic, and electrical systems should include visual and operational examination of primary components without major disassembly and evaluation of the function of each primary component and system. Routine inspections should, however, include checking movable span balance by the ammeter method (see Chapter 2.10) on bascules and vertical-lift spans. Swing spans should also be checked for unusual variations in power required to drive the span, but would not normally be checked for “balance.” If the ammeter method is not feasible or does not provide useful data due to an unusual electrical configuration, consideration should be given to checking balance by other more complex methods (see Chapter 2.10).

Chapter 2.9, Predicted Components Life, proposes a system of numerical coding based on observed condition of components, and describes two methods of coding sealed units of electrical, mechanical, or hydraulic components: the predicted life method and the engineering evaluation method. Visual inspection is sufficient to establish coding using the predicted life tables. To justify increasing the predicted life of a component beyond that shown in the tables, an engineering evaluation should be conducted. The results of the evaluation should be based on an in-depth inspection.

The text in Chapter 2.8 discusses the procedures for routine inspection in detail for various systems and components.

2.2.3—IN-DEPTH INSPECTIONS

In-depth inspections should include all of the scope of a routine inspection and, in addition, should include measurement examinations and disassembly of selected components for internal inspection.

A representative sample of bearing caps and couplings should be removed for shaft and bearing inspection. Shafts and bearings clearances should be measured with feeler gauges to precisely determine clearances. The inspection should include rope size and tension measurements, gear backlash measurements, and counterweight pocket cap removal. Electrical components should be inspected and tested. Motors should be vibration tested. Electric insulation should be meggered; controls should be examined; and wiring and wiring connections should be examined and checked for deterioration, corrosion, and connection tightness. Hydraulic and pneumatic systems should be performance tested, and systems that have a history of operational problems should be disassembled by qualified hydraulic or air motor technicians for internal inspection.

In-depth inspections should, in general, exceed the scope contained in Chapter 2.8 for routine component inspection.

should be made separately from openings for passage of navigational traffic so as not to divert the bridge operator's attention or extend the duration of the openings. It may not be possible to perform a trial opening if it is not safe to open the bridge. In this case, or in other unusual circumstances, the inspector should make note of why a trial opening could not be performed.

It is recommended that each inspector—Structural, Mechanical, and Electrical—witness each significant component in operation; this typically requires several span openings during each inspection. For bridges with significant traffic, consider performing the span openings at night or during off-peak hours. For bridges with infrequent operations, operational concerns, or history of operational problems (“getting stuck”), consider making arrangements to have maintenance staff on-site during the test span operations.

Typically, these inspections should be more extensive, cover a larger number of areas, and involve more cleaning and direct measurement of corrosion losses and other defects. In-depth inspections should also include some specific nondestructive testing and disassembly of selected components based upon the results of previous inspections for the purpose of quantifying the actual nature of defects that were evaluated in a qualitative or more approximate manner during routine inspections. Chapter 2.8 contains expanded scopes for in-depth inspection of individual components.

2.2.4—SPECIAL INSPECTIONS

These types of inspections remain unchanged from the definitions stated in Reference 8. These inspections may include any combination of the three inspection examination methods appropriate for the evaluation.

CHAPTER 2.3 – FREQUENCY

C2.3

The inspection frequency requirements of References 1 and 8 for fixed bridges should also apply to the structural, mechanical, and electrical systems of movable bridges. Specifically, the following maximum inspection intervals for mechanical, hydraulic, and electrical movable bridge inspections are recommended:

- Routine Inspections: 24 months
- In-depth Inspections: 6 years, in place of a Routine Inspection
- Special Inspections: as necessary

It is not uncommon for the mechanical, hydraulic, or electrical systems on some bridges to require more frequent inspections in order to maintain reliability. Individual owners may perform more frequent inspections where past experience justifies a shorter interval.

CHAPTER 2.4 – INSPECTOR QUALIFICATIONS

C2.4

Inspection of movable bridges requires a coordinated team of experienced structural, mechanical, hydraulic, and electrical inspectors.

The provisions of the *AASHTO Manual for Bridge Evaluation* (Reference 8, Section 4.4) relating to qualifications and responsibilities of inspection personnel are applicable with additional emphasis on movable bridge experience.

The inspection team leader should meet the requirements of References 1 and 8, and not less than three years of that experience should be in movable bridge design, inspection, or maintenance.

The lead inspectors for mechanical, hydraulic, and electrical inspections should meet the requirements of References 1 and 8 for team leader in their areas of expertise and not less than three years of the experience required in Reference 8 may be in design, inspection, or maintenance on movable bridges within their area of expertise. The inspection team leaders and lead inspectors should actually perform the inspection and/or be personally on site supervising the inspection for the full duration of the field work.

If the inspection team leader or lead inspector's qualifications are based upon experience rather than engineering certification, completion of a comprehensive movable bridge inspection training course based upon References 8, 59, and this Manual should be required. A fluid power engineer certification from the National Fluid Power Association may be substituted for 4 years of the experience requirements for hydraulic engineers.

If an individual is responsible for more than one area of expertise, the individual should qualify for each field and have not less than two years of movable bridge-specific experience in each area of expertise.

Reference 8 is based upon the requirements of Reference 1, The Code of Federal Regulations, Title 23, Part 650, National Bridge Inspection Standards.

The intent of this section is to certify that individuals involved in movable bridge inspection have some of the experience required in References 1 and 8 in the specialized area of movable bridges. It is not intended that the experience cited in Section 2.4 be an addition to the experience required by References 1 and 8. Overlaps are permissible. References 1 and 8 do not recognize time spent in design or maintenance as meeting the experience requirement (except as they may contribute to qualification for registration as a professional engineer). For movable bridge experience, design experience and maintenance experience are recognized. The required movable bridge training course may be either separate from or combined with the course requirements of References 1 and 8 for a bridge inspector.