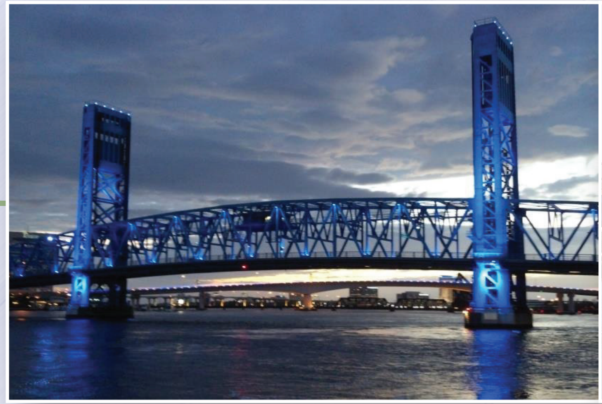


American Association of State Highway and Transportation Officials

AASHTO

Movable Bridge Inspection, Evaluation, and Maintenance Manual


Second Edition ✦ 2016

AMERICAN ASSOCIATION OF STATE HIGHWAY AND TRANSPORTATION OFFICIALS
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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 SSBN 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

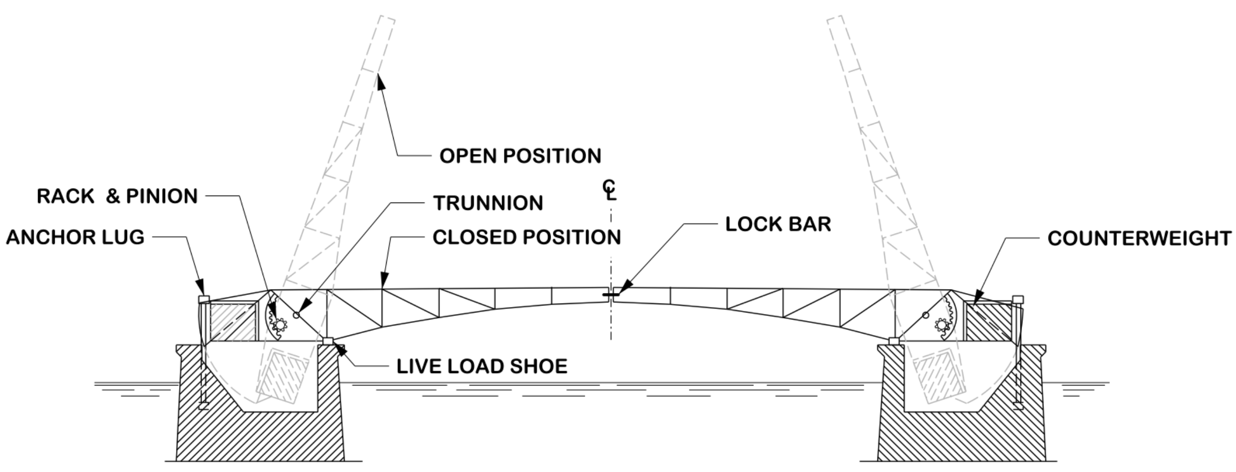

Figure 1.3.1.1-2 – Operating components of a double-leaf trunnion bascule bridge

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

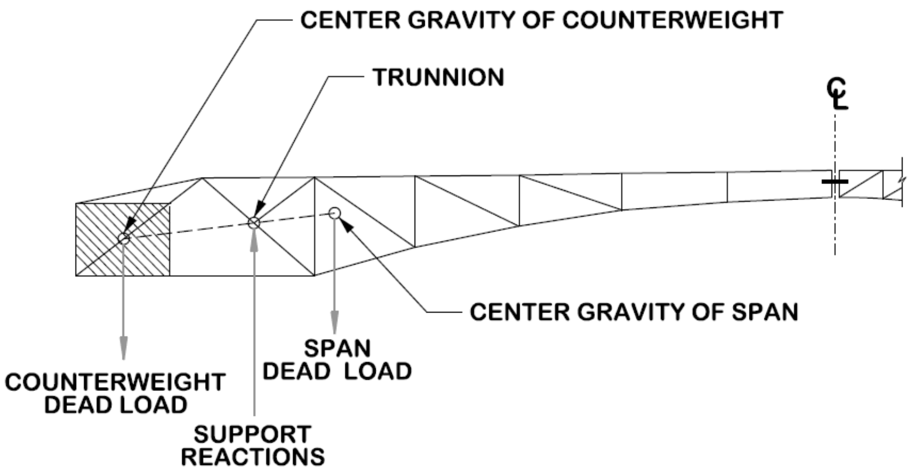

Figure 1.3.1.1-4 – Load distribution on trunnion type bascule bridge

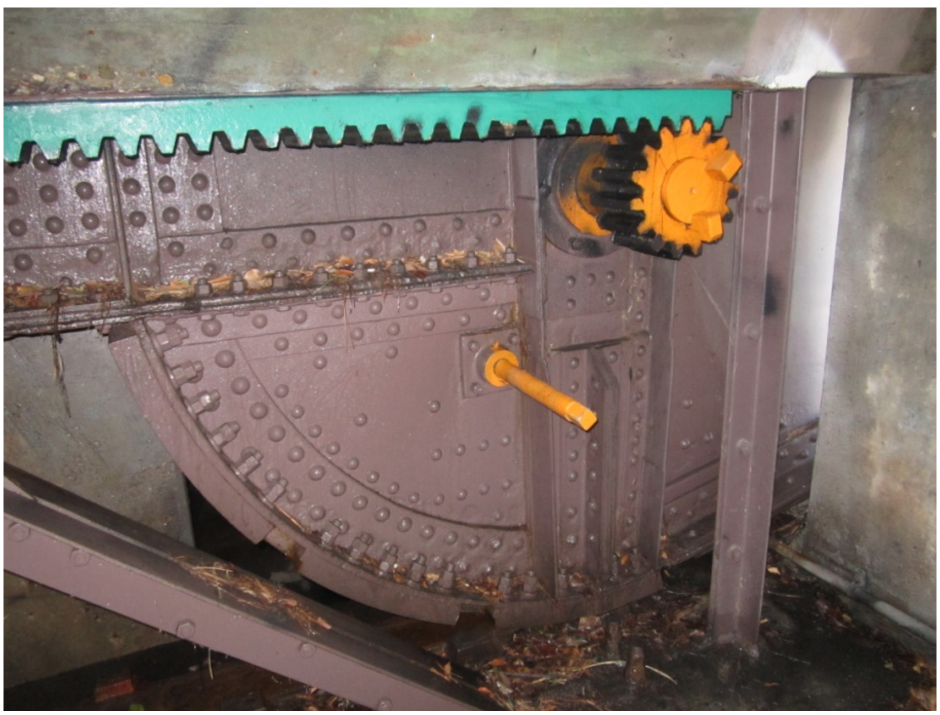

Figure 1.3.1.1-5 – Rolling leaf rack, pinion, and curved tread

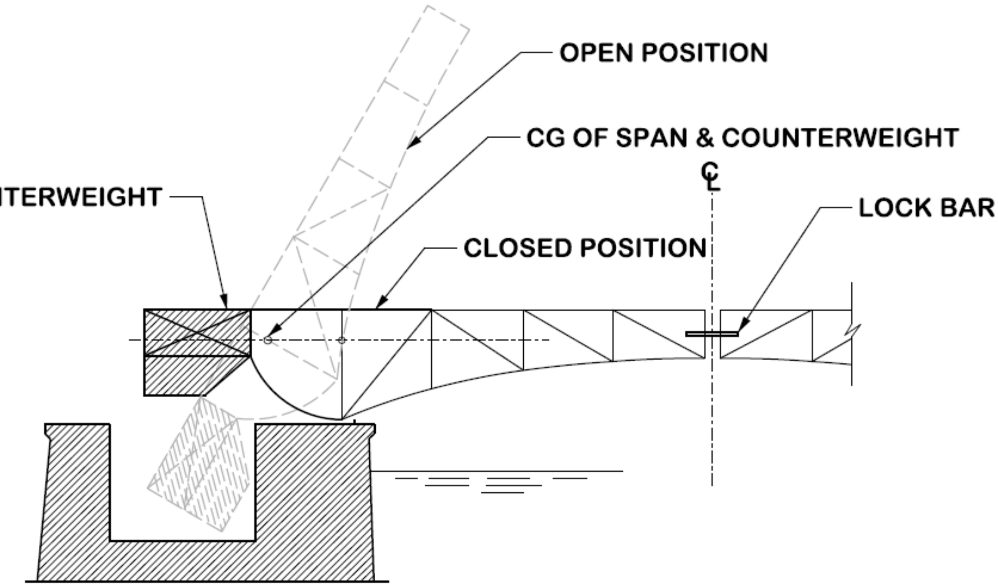

Figure 1.3.1.1-6 – Rolling-lift double-leaf bascule

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

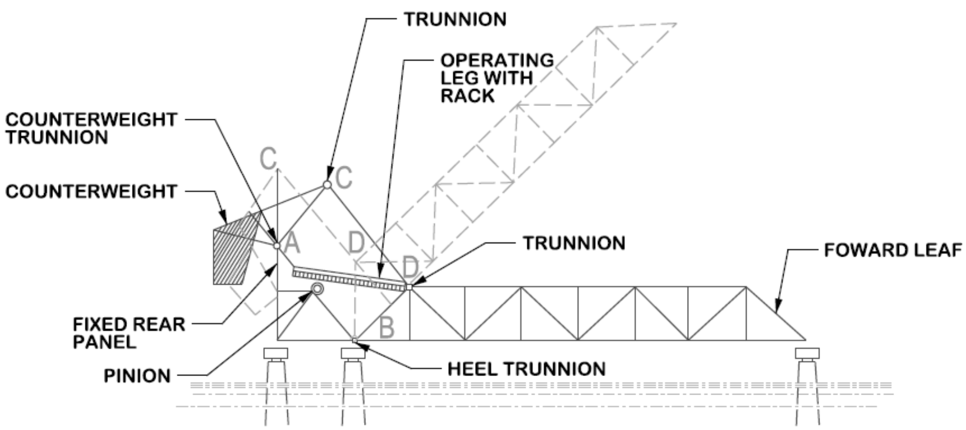

Figure 1.3.1.1-8 – A heel-trunnion bridge has two fixed trunnions, A and B. The leaf rotates about B, and the counter weight rotates around A. Link Pins C and D move as the leaf is raised.

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.

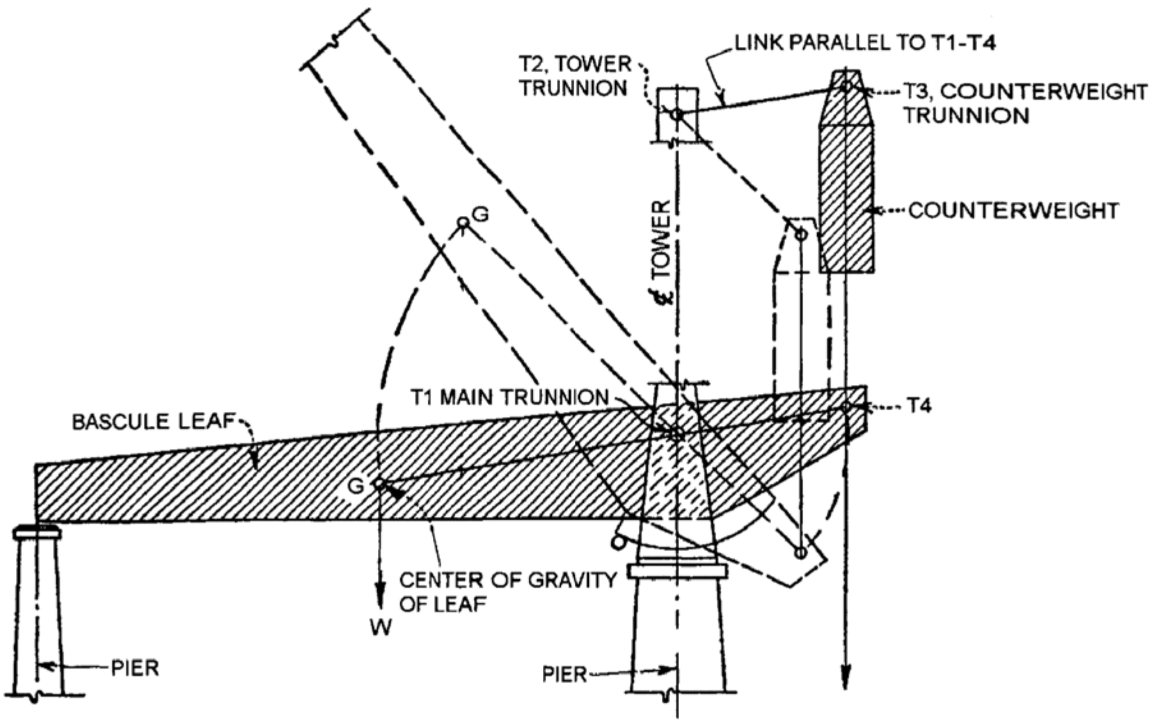

Figure 1.3.1.1-9 – Overhead counterweight-type multi-trunnion bascule

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.

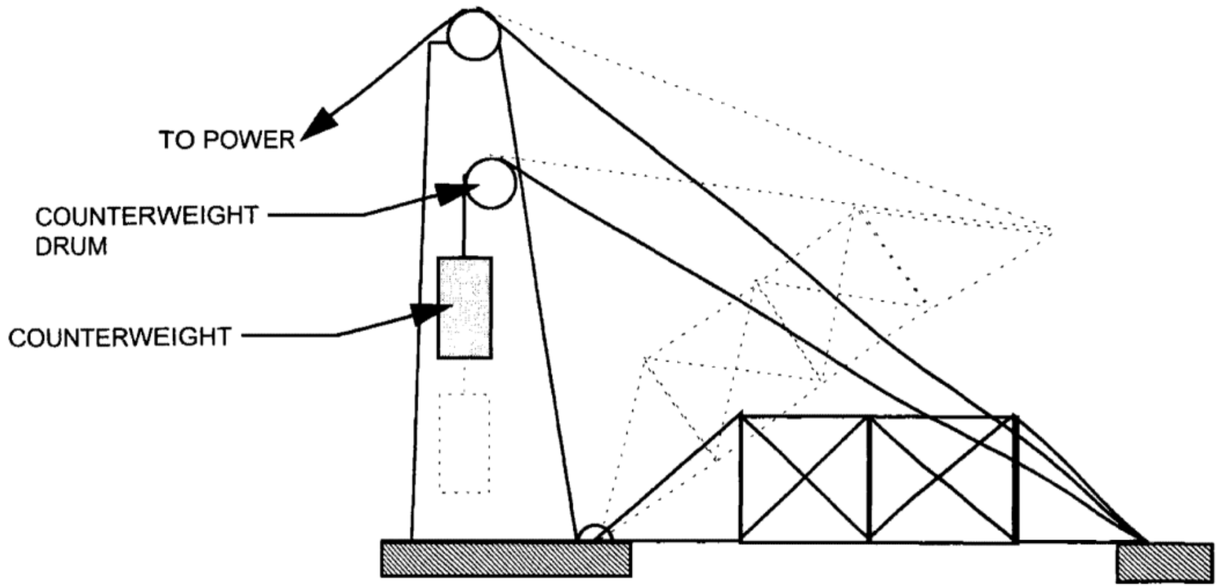

Figure 1.3.1.1-10 – Cable bascule with counterweight

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).

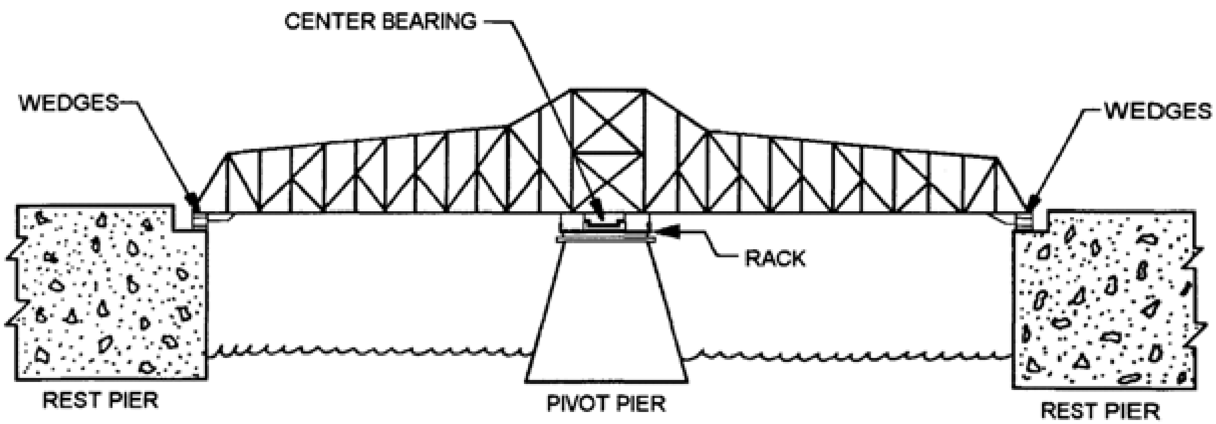

Figure 1.3.2.1-1 – Span rotates on center bearing; balance wheels stabilize span as it opens and closes

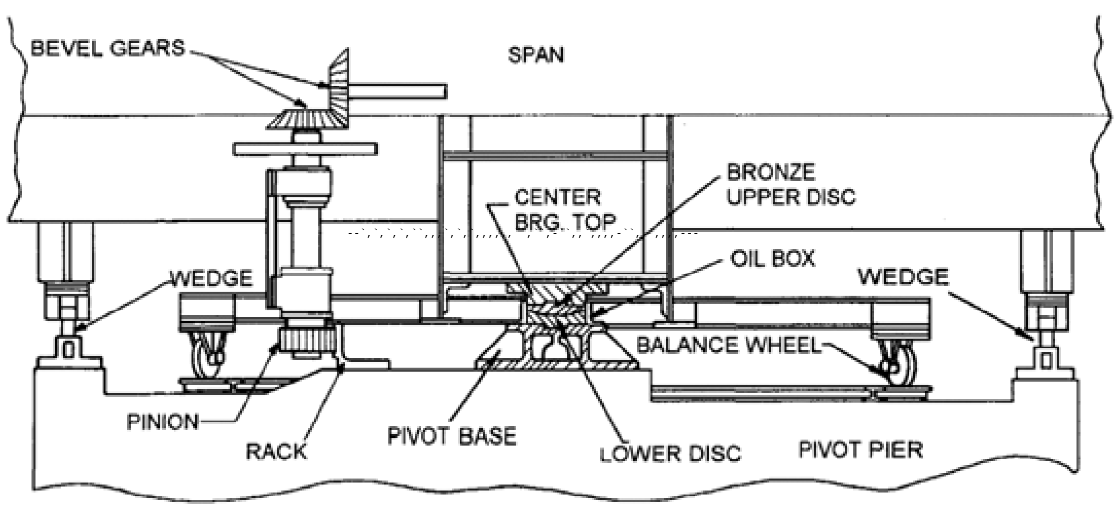

Figure 1.3.2.1-2 – Sketch of swing-span in closed position showing piers and location of operating components

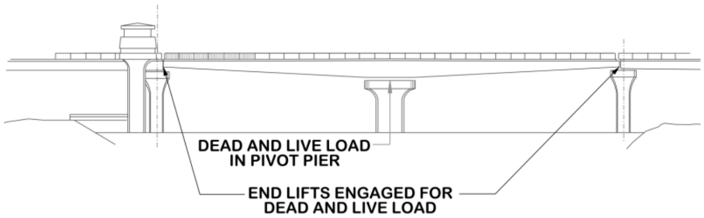

Figure 1.3.2.1-3 – Swing-span in closed position

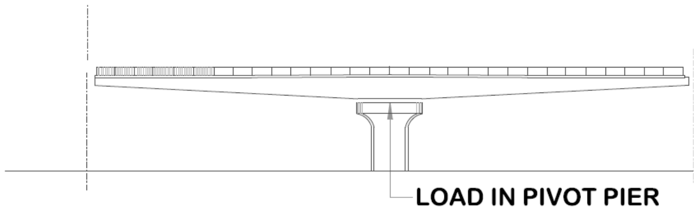

Figure 1.3.2.1-4 – Swing-span in open position

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. Each roller is mounted on a radial shaft and restrained from moving away from the center post. 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

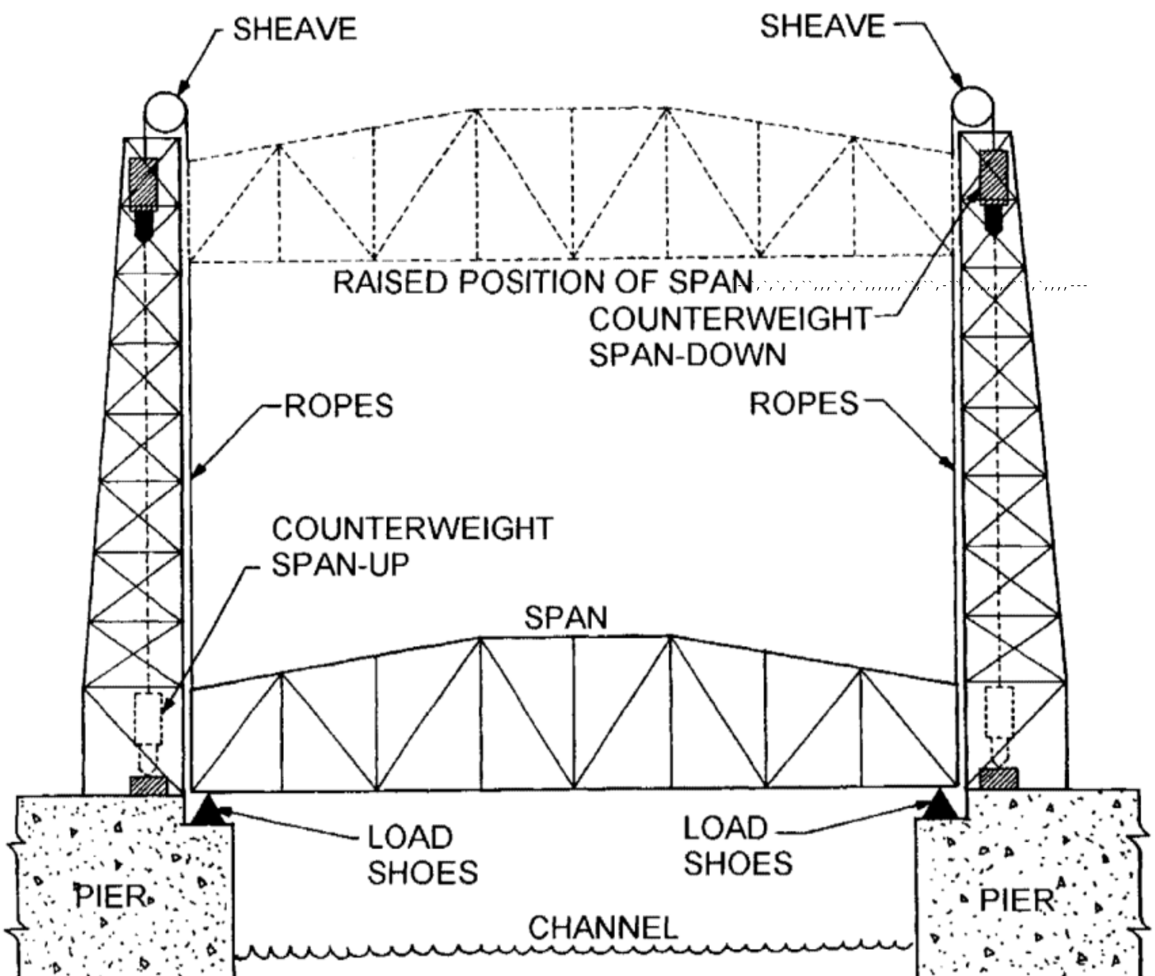

Figure 1.3.3.1-2 – Closed span rests on load shoes; as span is raised, the counterweights descend

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

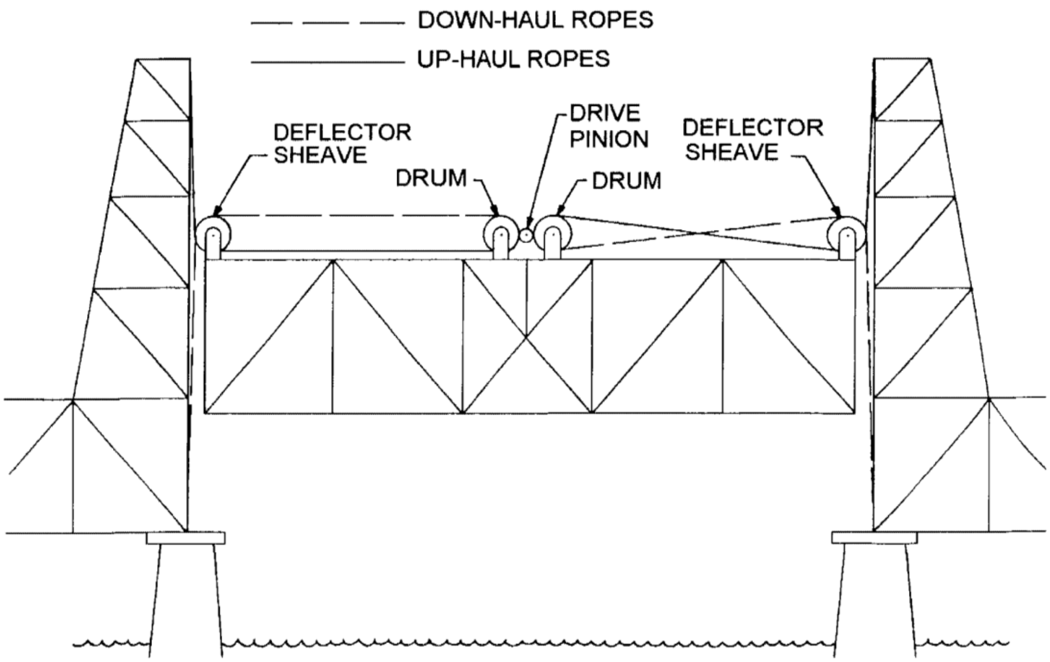

Figure 1.3.3.1-4 – Sketch of operating ropes on a span-drive vertical-lift bridge.

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.

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.

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.

C1.4.3

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.
- Retroflective 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.

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.

2.2.2—ROUTINE INSPECTION

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

C2.2.2

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

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

C2.3

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

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.

C2.4

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.

CHAPTER 2.5 – SAFETY

2.5.1—HEALTH & SAFETY PLAN

A movable highway bridge user or inspector is subject to the hazards common to fixed highway bridges, as well as safety hazards unique to movable bridges. The hazards that can occur during the inspection, operation, or maintenance of a movable bridge should be understood and controlled prior to planning or conducting any activity involving the bridge. If a health and safety plan has been developed for the individual bridge or group of bridges to be inspected as outlined in Section 2.5.4, all members of the inspection crew should receive a copy of the plan and should be required to read and understand the plan. The inspection team leader and/or other supervisory personnel should meet with the field crew prior to the start of work to discuss the plan sufficiently to determine that the crew understands the potential hazards that are unique to the structure(s) to be inspected. General health and safety plan information may be distributed in the same way or by regularly scheduled training courses. Untrained personnel should not be part of an inspection crew unless a specific program of on-the-job health and safety training has been completed. The following sections identify a number of potential personnel and public safety hazards, offer recommendations to minimize these hazards in the bridge environment, and provide guidelines to develop a bridge specific safety and health plan.

C2.5.1

The number of safety, health, and environmental standards associated with the inspection, operation, and maintenance activities performed on a movable bridge cannot be readily organized into a format tailored to the diverse needs of each bridge owner. Bridge owners are encouraged to develop and implement a written plan specifically designed for their movable bridge inventory that identifies and minimizes specific safety and health hazards; addresses the well-being of operators, inspectors, maintainers, and the public; and provides contingency plans in case of personnel, public or bridge emergencies. Section 2.5.4 is intended to assist the bridge owner in the development of such a program, and to provide an outline of the minimum guidelines.

2.5.2—PERSONNEL SAFETY

The basic concerns for safety and health protection of bridge personnel should be addressed on three levels: (1) adherence to a set of straightforward rules and regulations designed to provide a safe and healthy work place; (2) an understanding of the actual hazards, as determined through a hazard assessment, involved at individual structures and the methods available to minimize the risk of injury or other undesirable consequences; (3) the development of a group of trained personnel and other problem response capabilities to minimize the effects of a hazard should an accident or unplanned event occur.

Personal Protective Equipment (PPE) is required while on a bridge. PPE can include a hard hat, ANSI Class II or III high visibility vest, adequate foot protection, eye protection, hearing protection, gloves, respirator, personal floatation device (PFD), and fall protection. Specific PPE may be required depending on the trade working on the bridge.

C2.5.2

For a general discussion on bridge inspection safety equipment and clothing the reader is referred to *Bridge Inspector's Reference Manual* (BIRM) (Reference 62) and any bridge-specific safety plan as established by the state.

2.5.2.1—OSHA and Standard Requirements

General requirements for safety and health standards in the work place have been developed by the Occupational Safety and Health Administration (OSHA) and are found in the Code of Federal Regulations (CFR) in Title 29 1910 (Reference 2). State OSHA regulations may have more stringent requirements than Federal OSHA. Other industry standards related to specific activities such as NFPA 70E for electrical safety, or as identified by Federal or state requirements by subpart may be useful guidance.

C2.5.2.1

There are no specific OSHA requirements defined for maintenance activities, including bridge inspection. The OSHA regulations apply to all industries. OSHA provides useful guidance on the avoidance of hazards in the work place. In addition, there are state OSHA regulations that may have state specific requirements that are more stringent than Federal OSHA.

2.5.2.2—Hazard Assessment and Elimination of Personnel Hazards

Hazards result from potentially dangerous conditions that can exist on a movable bridge work site or the unsafe actions of personnel. Personnel accidents can be reduced through the identification of the specific conditions that lead to an unsafe situation, training, and by initiating corrective actions to promote a safe work environment. A job hazard activity assessment can help to identify the hazards and mitigations associated with the work being performed. Some examples of typical problems and corrective actions include:

- Inadequately trained inspection, operational, and maintenance personnel do not use proper safety procedures while conducting their work.
  Corrective Action: Institute movable bridge safety training programs to keep personnel up-to-date with recognized safety and health considerations. Involve the personnel in the hazard assessment process to help identify hazards and mitigation for their work activities. Conduct safety meetings prior to the start of an inspection or maintenance operation. Meeting agendas should cover bridge-specific safety practices, any unusual features or hazards of the individual bridge, and contingency plans in the event of an emergency.
- Inspectors and maintenance workers must often closely observe, touch, or partially disassemble mechanical equipment (gears, shafts, bearings, motors, locks, etc.) during routine inspection. This presents an immediate hazard if the equipment is inadvertently activated or if stored energy is released during such work.
  Corrective Action: Install lockout devices at the point of power disconnect for each trade/craft to prevent inadvertent bridge operation during inspection or maintenance. The team leader of each trade/craft or an authorized crew member should be responsible for setting the lock and determining that each crew member is safely located before removing the lockout devices.

C2.5.2.2

Sources of personnel hazards can include: rigging, climbing or lifting equipment, moving machinery, confined spaces, tripping hazards, slippery conditions, petrochemicals, and other potentially toxic substances. The typical problems and solutions presented in the text are intended to illustrate a number of common problems encountered on movable bridges and to provide guidelines on how such typical problems have been successfully corrected. It is not intended to provide a complete or exhaustive list of hazards and readers should not interpret the listed corrective actions as the only solutions.

- Discarded objects and debris (e.g. loose rust flakes, road gravel, bolt heads, scrap welding rods, pieces of lumber, empty paint cans, etc.) can accumulate on the structure. These objects are potential tripping or falling hazards, and may cause damage to open machinery.
  Corrective Action: Extraneous objects and debris should be removed at the end of any repairs, lubrication, or other contractual or maintenance work, and the structure should be regularly cleaned and inspected for loose parts, debris, and structural bolts by maintainers.
- Original catwalks, platforms, ladders, and machinery room floors that are constructed of metal grating or wood may be near the end of their useful life in a harsh environment.
  Corrective Action: Institute a program of regular inspection and maintenance of ladders, platforms, scaffolds, and walkways. Do not use access platforms, catwalks, ladders, etc. without properly inspecting the devices first.
- Inspection or maintenance of the bridge in dark or poorly lit areas exacerbates other hazards such as tripping or falling.
  Corrective Action: Install permanent lighting or weatherproof electrical outlets for temporary lights. Where lighting or power is not permanently installed, be prepared to take in adequate lighting for the work involved.
- Lubrication or hydraulic oil, vital for maintaining the service life of moving parts, can cause slipping hazards on walking surfaces or ladders.
  Corrective Action: Walking surfaces and ladders should be regularly cleaned. Maintenance workers or others performing lubrication work should be cautioned to clean up any spills or excess lubrication.
- Exposed, substandard, or deteriorated electrical conduits, wiring cabinets, or boxes create a potential shock hazard.
  Corrective Action: Regular inspection and maintenance should identify and repair older systems. Replace, enclose, cover, or otherwise create an insulation or barrier between live electricity and workers as part of the bridge maintenance program.
- Many movable bridges were designed before OSHA safety rules and/or FHWA inspection standards were developed and have catwalks, ladders, and other access provisions designed for maintenance, rather than inspection, and are not in conformance with current, enlightened safety standards.
  Corrective Action: Install new permanently mounted access equipment and lifeline attachments to provide for safe inspection access as needed on each individual bridge. This can include the installation of safety cables, inspection walkways, mounting brackets for staging or scaffolding, anchored attachments for temporary safety cables or

climbing ropes, etc. Regular inspection and certification of these devices is required prior to use.

- Several bridge locations are covered in pigeon excrement. **Corrective Action:** These areas should be cleaned prior to maintenance and inspections.

2.5.2.3—Personnel Training Programs

Inspectors, operators, and maintainers should be given comprehensive movable bridge safety training, as well as training on the equipment being used.

Regular instruction of inexperienced workers by supervisors and experienced co-workers can have a major impact upon the overall identification and elimination of hazards on movable bridge structures.

C2.5.2.3

At present, no national training program exists. Some states have developed their own local programs. Local program courses should be based upon this Manual, References 2 and 62, and the specific requirements of the individual owners and work sites.

2.5.3—PUBLIC SAFETY

Public safety encompasses the use of accepted practices and adherence to national, state, and local standards that were developed in the interest of protecting pedestrian, vehicular, and navigational traffic. *The Manual of Uniform Traffic Control Devices* (MUTCD) (Reference 65) and any state supplement should be used when planning traffic control.

2.5.3.1—Pedestrian and Vehicular Safety

In the open position, a movable bridge creates a large opening in the roadway. Traffic should be stopped and held in a safe location prior to opening. Further, movable bridge openings can be an unexpected event for inattentive drivers. A proper system of warning devices, traffic guidance and control, and protective gates is basic to public safety. Traffic controls and advance warning devices must be visible over a long enough distance to provide for a safe stopping distance for the forward drivers and for the entire line of traffic that accumulates during a normal opening duration. On high traffic roadways (1,000 vehicles/hour/lane) accumulation of a large number of vehicles in a ten-minute opening will mean that the area where a stop is necessary may extend up to two or three thousand feet back from the traffic control gates in each lane.

Pedestrian and vehicular safety issues on movable bridges are varied and require identification and corrective action by experienced personnel. Examples of typical problems and corrective actions include:

- **Item 1.** Unexpected span motion can occur without setting off warning devices and traffic control.
  Corrective Action: Inspectors and maintainers should give careful attention to testing and adjusting span balance on bascules and lift-spans and to checking tread plates on rolling-lift bascules and rim bearing swings for out of level

C2.5.3.1

It is not possible to list all of the complex eventualities that could lead to an unsafe condition on such structures, because each site and each structure have unique features of design, construction, and maintenance that make most movable bridges unique. It is possible, however, to generalize a number of potential hazards to the bridge, the public, and workers. These fall into a few general categories as follows:

System Error: Item 1 is an example. The mechanism works in an unexpected and hazardous way.

Human Error: Item 2 is an example. Humans do not react as anticipated during design, creating a hazard.

The recommended delay is intended to provide reaction time for drivers to notice that the lights have turned red prior to actuation of the traffic gates. This system works well where drivers observe traffic controls and are not prone to "run the light". In some urban sites, it may be advisable to give the operator the option to lower gates immediately by surfaces. They should also file a deficiency report on any structures without positive mechanical locks or centering devices to hold the movable unit in the closed position. Such structures require special attention in order to prevent uncontrolled span motion.

- **Item 2.** Pedestrians, bicyclists, and some motorists have a tendency to try to "beat the light."

  Corrective Action: The sequence of lights turning red and traffic gates closing should be timed to avoid trapping or impacting stragglers within the traffic and/or resistance gates. In urban areas with high pedestrian, bicyclist, or motorcycle usage of movable bridges it may become necessary to place an emergency stop button at critical locations and to station personnel at some or all four comers on the approaches. This is done to control traffic and prevent inadvertent damage to stragglers by implementing manual intervention via the emergency stop. Operator visibility is key to safe operation in such areas if the use of additional personnel is not feasible. The use of closed circuit television or other means may be advisable if direct vision is obstructed.
- **Item 3.** An uneven floor break area on movable bridges is a potential tripping hazard for pedestrians and can cause a loss of control of vehicles, bicycles, and motorcycles.

  Corrective Action: High visibility yellow coatings and localized improvements in lighting can serve to alert the public crossing the floor break.
- **Item 4.** Many existing movable bridges have wooden plank sidewalks and open metal grid roadway decks that can have poor traction characteristics in wet or icy conditions.

  Corrective Action: Wooden walkways can be painted with sand paint or other grit-type coatings that enhance traction and also increase the life of the planks by preventing moisture damage. Open metal grid can be grooved, studs added, or the deck can be replaced. Warning signs can be placed on the bridge approaches and variable message signs can be utilized to warn of poor road conditions in bad weather.

bypassing the delay to prevent a line of drivers from "running the light" and thereby making it impossible to lower the gate. This is not a feature to be incorporated without due consideration of potential hazards, and should only be done after the owner has attempted to alter driver behavior by increasing law enforcement presence at the bridge to issue fines to vehicles "running the light".

Built-in Condition: Item 3 is an example. An existing feature is inherently a potential hazard to the unwary. Some of these conditions are permanent and unavoidable in the short term; others can and should be corrected. All of these conditions are made safer if attention is drawn to them by bright colors, warning signs, or other methods used to make users aware of the potential hazard.

Environmental Condition: Item 4 is an example. An existing condition is a hazard at times due to adverse environmental conditions such as fog, ice, or snow. These conditions are just a special case of a built-in condition, but are harder to detect since they are intermittent.

Other examples of a few likely errors of each type include:

System error

- Operation of motors with brakes or locks not fully disengaged.
- Mechanical failure leading to uncontrolled motion.

Human error

- Operation of bridge with vehicles or pedestrians on the movable span.
- Failure to open the bridge soon enough to clear a vessel that cannot hold position due to currents.

Built-in condition

- Resistance gates and other roadside obstructions that are not protected by railings or attenuators.
- Poor sight distance to traffic controls on the approach roadways.

Environmental condition

- Bridge is not visible to mariners in poor visibility conditions such as rain or fog.
- Ice or snow accumulates on the movable span and adversely affects span balance, causing machinery overload.

2.5.3.2—Navigational Safety Practices

Safety issues that should be considered by inspectors during on-site work relating to navigational guidance systems are covered in Chapter 4.5. Signals and signs should adhere to USCG, USACOE, and CFR regulations.

Navigational safety is a topic covered extensively in USCG and USACOE regulations and other documents.

The navigation equipment and aids to navigation on a bridge must meet USCG requirements, and are generally described by the USCG on the permit for each bridge. The requirements may be revised over time to accommodate changing usage and site conditions. The owner should review the navigation equipment present at the site for conformance with the permit and any revisions thereof.

The owner should notify the USCG of each incident involving a marine vessel impacting the bridge. Repetition of similar incidents may initiate a reaction by the USCG requesting modification of the navigation equipment.

In addition, any navigational lighting deficiency should be considered a condition that requires immediate repair.

2.5.4—BRIDGE-SPECIFIC SAFETY PLAN

A health and safety plan specific for movable bridges can enhance the general well-being and safety of bridge personnel and the general public, minimize unsafe or hazardous conditions, and provide personnel with guidelines for procedures and standard practices to be followed to avoid recognized hazards.

Movable bridge health and safety plans should be prepared as a supplement to any general health and safety plans owners have in place. It is not necessary to duplicate material already covered elsewhere, but the existing plan and the supplement for movable bridges should, at a minimum, cover the following areas:

- Statement of general health and safety policies.
- Administrative responsibilities for implementing the safety plan: identification and accountability of personnel responsible for accident prevention, hazard assessment, and safety aspects of the movable bridge environment.
- Employee responsibilities for adherence to the health and safety plan.
- Means for controlling and checking on procedures used for inspection and maintenance activities of in-house personnel and outside entities.
- Procedures to be used to maintain safe access to various areas of the bridge.
- Procedures to be used for safety indoctrination of new personnel and continued safety training.

C2.5.4

Some owners prefer to develop a movable bridge health and safety plan for each individual structure, while others may choose to develop a general document to cover all their movable bridges.

Movable bridge safety is a complex subject. It is rare to find one source that contains the necessary combination of information and experience to predict all possible hazards or to develop corrective measures for each bridge. The group developing bridge-specific health and safety plans should include representatives who are experienced in design, inspection, and maintenance as practiced by the owning agency and others who have a background in hazard assessment and safety programs. Health and safety plans should not be static documents, but rather should evolve to react to new information and problems. The plan should be reexamined and may need to be amended in response to any safety-related incidents.

- Personnel protective equipment requirements for personnel involved in inspection, operation, and maintenance.
- Provisions for periodic unscheduled inspections of bridge site to determine compliance with the plan.
- Responsibilities and procedures for reporting and investigating accidents and unsafe or hazardous conditions.
- Contingency plans in the event of bridge shutdown due to hazardous structural, mechanical, electrical, or operating conditions.

CHAPTER 2.6 – PLANNING, SCHEDULING, EQUIPMENT, AND MOBILIZATION

For an inspection to be executed properly, the team leader should follow a planning process to prepare an appropriate schedule to mobilize resources efficiently, considering the equipment available.

2.6.1—PLANNING

The development of a detailed inspection schedule and accompanying work sequence is necessary to ensure that significant bridge components are inspected by the appropriate personnel. The inspection team leader is generally responsible for coordination of the planning effort and should brief all team members on known specific problems with the bridge. The following items should be accomplished during the planning stage:

- Assemble bridge plans, reports, maintenance and repair records, and other pertinent information.
- Determine the type of inspection required (initial, routine, in-depth, or special).
- Determine the number of personnel required for the inspection (team members, maintainers, machinists, electricians, bridge operator, etc.).
- Determine the safety equipment needs for inspection personnel (personal protective equipment, lanyards, ropes, etc.), methods of access, and inspection access equipment needs.
- Prepare bridge-specific inspection field notes, forms, charts, and schematics.
- Prepare the inspection schedule/sequence.
- Determine if advance notice of inspection schedule is necessary to other government/regulatory departments (USCG, District Bridge Office, USACOE, state/county/local agencies, local or state police, fire departments, ambulance services, etc.).
- Determine if component disassembly is required for inspection and arrange to have the required tools, personnel, and spare parts available.
- Confirm the type of lubricants that may be required if the machine will be cleaned or disassembled.

C2.6.1

During the initial stages of the planning phase, a reconnaissance (pre-inspection) visit to the structure should be undertaken. This includes observing general bridge configuration, current site conditions, methods of access, and traffic control necessary to enter areas on or below the structure with inspection vehicles and equipment. This is especially important if the team leader is unfamiliar with the structure and its surroundings. Further, since site conditions can significantly change due to reconstruction or environmental factors, a pre-inspection may be necessary even if the team leader has previously inspected the structure.

Fasteners or other parts may be damaged during disassembly of components. It is advisable to have replacement parts on site prior to disassembly of critical operating systems.

2.6.1.1—Data Collection and Review

All available information on the subject structure should be reviewed to identify areas of the bridge that require special attention. These special attention areas should be scheduled first

C2.6.1.1

The bridge operator, maintainers and the previous inspection team leader can provide additional information on existing bridge in the inspection sequence. The documents include, but are not limited to:

- Design drawings of original and rehabilitation construction.
- Shop and working drawings (original and rehabilitation).
- As-built drawings (original and rehabilitation).
- Previous inspection reports (structural, mechanical, electrical).
- Maintenance records.
- Bridge operation records.
- Bridge logs/bridge operator's manuals, maintenance manuals, and/or lubrication charts.
- Maintenance schedules.
- Geotechnical data.
- Deficiency reports.
- Evaluation reports.

A discussion of the three types of drawings listed above is appropriate to familiarize inspectors with them and their degree of reliability:

- **Design drawings** are prepared by the original designer of the bridge or by subsequent rehabilitation designers. These drawings represent the original design concept and are in general the least likely to represent the actual conditions on site.
- **Shop and working drawings** are prepared by the contractors and/or fabricators of the original bridge and any rehabilitations. These drawings represent the details of each individual bridge component and are generally more likely to represent actual bridge details than design plans, especially if they are copies of the final approved set of such drawings. Shop drawing details are subject to some modifications in the field if fit or operational problems were encountered.
- **As-built drawings** are prepared by one of the parties involved in construction; the owner, designer, or contractor. They are distinguished by a clear title or stamp that labels them “As-Built”. They are intended to represent the exact details of the bridge upon completion of construction of the original bridge or any rehabilitations. When prepared as intended, they are the most accurate of the three listed types, but should be verified by on-site spot checking of dimensions and details.

Review of the available bridge documents provides initial understanding of bridge details and helps identify areas with chronic problems. Maintenance records may show components that receive more than usual service, indicating a potential problem area. The inspection team should study plans and records in detail and develop an inspection checklist of known and suspected bridge deficiencies (e.g., areas of repair, fatigue sensitive details, damaged areas, location of any cracks, conditions. If possible, they should be interviewed prior to the inspection and asked about recent repairs, whether or not maintenance schedules are followed, any unusual noises or problems noted, and if any recent vehicle or vessel impacts have occurred.

When drawings are not available or are incomplete, it is recommended that the inspection team schedule several days at the bridge prior to the actual inspection to prepare as-built sketches and electrical, mechanical, or hydraulic schematics.

All three types of drawings may be inaccurate, and there is no guarantee that any set of documents truly represents the structure currently on site. Modifications are often made without documentation. It is vital that any drawings believed to represent the structure be verified on site and that critical elements’ dimensions and details be checked for accuracy by field measurement of a statistically significant sampling of such areas. If discrepancies are found between drawings and the field measurements, all critical data should be field measured.

excessively worn components, vibration problems, location of any unusual noises, etc.).

If previous inspection or deficiency reports indicated potential trouble areas or recommended maintenance work, determine if the maintenance work has been accomplished. If it has not, be sure that these preexisting trouble areas are documented and thoroughly inspected. If maintenance records indicate frequent repair or replacement of a component, an attempt should be made to determine the cause during the inspection.

2.6.1.2—Identification of Site-specific Conditions

The development of the inspection sequence requires addressing site specific factors, including:

C2.6.1.2

The lists given are presented as a sample of the types of decisions that are generally necessary to properly prepare for an inspection. Movable bridges are unique individual structures, however, and no general listing can identify all of the factors that will be significant for a particular structure. Owners should develop site-specific data for each structure that takes all features into account during inspection planning.

2.6.1.2.1 Site Conditions

Is it a difficult access structure? Structures in this category require the use and coordination of personnel lift equipment, staging, rigging, scaffolding, rope access, etc. Some owners may have security-related background checks before inspectors will be granted access to the site.

Are traffic/navigation closures required? Disassembly of machinery components or installing special access equipment may require temporary interruption of roadway or navigation traffic.

Is a bridge operator required? Some movable bridges are not manned full-time and require a prior request to obtain an operator.

Is advance notice required? USCG and other affected agencies often require advance notice if the inspection interrupts the normal operation of the bridge.

Is a staging area available? Parking areas for inspection vehicles and storage of equipment should be surveyed in advance.

2.6.1.2.2 Structural, Mechanical, Electrical Considerations

Is nondestructive structural testing required? The bridge may require special testing or inspection techniques to supplement the visual inspection (e.g. dye-penetrant, magnetic particle, ultrasonic).

Is special equipment or team staffing required? Inspecting machinery components may require the need for special tools, equipment, or personnel to perform disassembly of operating components prior to inspection, and reassembly after inspection.

Is a machinist, mechanical or hydraulic expert, or electrician required for inspection? A specialist should be part of the inspection team if unusual problems have been noted that require such expertise.

Is mechanical or electrical testing equipment required? (e.g., strain gauges, oil analysis, DC megger, ammeter, voltmeter).

Is temporary lighting required in the machinery area? These areas are often poorly lit and require additional lighting to aid inspection.

2.6.1.3—Preparation of the Inspection Schedule and Sequence

The team leader should prepare a brief inspection schedule and sequence for distribution to inspection team members and affected agencies. The schedule need not be elaborate, but should at least contain the following information:

- Brief scope of inspection.
- Inspection start and finish dates and milestones of the inspection.
- Dates of important events that affect bridge operation, such as special testing or bridges closures.
- Daily work schedule (information on where inspection personnel are scheduled to be on the structure at any given time).

When preparing the inspection sequence, it should be determined if there are periods when the bridge is always open, always closed, or cannot be operated. If there are no regular periods when the bridge is held out of service, the maximum length of time that the bridge can be held open and/or held closed for inspection purposes should be determined. If the bridge cannot be held in a stable closed or open position for an hour or two, it may not be possible to thoroughly inspect many components. The inspection schedule should indicate limitations and list those components that cannot be completely inspected.

C2.6.1.3

The inspection schedule should include allowances for inclement weather, unforeseen problems or delays due to complexity and/or age of structure, coordination around bridge maintenance activities, and delays due to seasonal traffic.

Components with known defects, or those that require care to disassemble and inspect, should be scheduled early in the inspection effort. These components may create a need for unanticipated follow-up attention such as further testing or additional disassembly. If these components are inspected first, time remaining in the inspection schedule can be devoted to this necessary but unanticipated effort. If the inspection is scheduled over a duration of more than one day, additional personnel may be brought in to accomplish the additional tasks.

In instances when all components cannot be completely inspected, assistance should be sought from appropriate authorities to overcome any limitations identified during

In preparing the inspection sequence, the logical format involves first inspecting bridge components that require the most attention. This generally involves scheduling the span-drive machinery first, followed by the other components. Any component that has been previously reported with known problems should receive top priority. Figure 2.6.1.3-1 has been prepared to show sample inspection sequences for the machinery components of the common movable bridge types. In a similar manner, logical inspection sequences can be developed for hydraulic, electrical, and other systems.

preparation of the inspection schedule. Special testing or other means not normally available during routine inspection may be needed to provide full inspection of all components.

SWING-SPANS

Pivot Pier

1. Drive Machinery–main reducer, gears, bearings, couplings, rack and pinion.

*2. Wedge and operating machinery–reducers, gears, bearings, couplings, cranks, levers, connecting rods, and center wedge assemblies.

3. Center bearing and balance wheels or rim bearing tapered rollers.

Rest Piers

1. End wedges or shoes.
2. Centering latch machinery.
3. Buffer cylinders.

VERTICAL-LIFTS

Towers

1. Drive machinery (if tower-drive) and emergency drive.
2. Counterweight ropes, sheaves, and trunnions.
3. Span locks.
4. Tensioning devices.

Movable Span

1. Drive machinery, drums, operating ropes (if span-drive)
2. Guide rollers
3. Observe operation of balance chain as span travels up and down.

Piers

1. Buffers.
2. Strike plates and load shoes.
3. Centering devices
4. Span locks.

TRUNNION BASCULES

Machinery Pier

1. Drive machinery and emergency drive.
2. Trunnions and trunnion bearings.
3. Buffers (double-leaf only).
4. Load shoes and strike plates (double-leaf only).
5. Tail locks.

Forward End of Span (double-leaf)

1. Span locks.
2. Centering guides.

Rest Pier (single-leaf)

1. Buffers.
2. Strike plates and load shoes.
3. Centering device.
4. Span lock.

* New swings often use hydraulic operating systems.

Figure 2.6.1.3-1 – Sample inspection sequence; problem components should be scheduled first, but all components in one area should be done at one time

2.6.2—MOBILIZATION

Inspection mobilization involves assembly of the inspection personnel, special equipment, tools, and the preparation of bridge-specific field notes and forms in sufficient quantity to

C2.6.2

Inspection mobilization should include coordination with bridge operation and maintenance personnel who will assist with assure completeness, uniformity, and continuity of the inspection operation. Many factors influence these requirements including structure size, complexity, age, type of inspection, and method of access. The following sections are considered to be the minimum guidelines for a typical movable bridge inspection. The team leader should exercise judgment when determining the specific needs for each bridge inspection, and adjust these requirements accordingly.

the inspection. For instance, gear teeth and other machinery parts usually require cleaning before measurements can be taken, and maintenance personnel may be needed in conjunction with the inspection team to expedite this work. In addition, separate structural, mechanical, and electrical inspections may often be done concurrently. This type of coordination will reduce the inconvenience to bridge users by shortening the time when the span must be operated or not operated for inspection purposes.

2.6.2.1—Preparation of Inspection Notes

Preparation of bridge inspection field notes, forms, charts, and checklists is preferred for a well-organized and efficient inspection. Photocopies of sketches and details from previous inspection reports should be made for reference in order to update the condition of any defect or deficiency. If plans or previous sketches are unavailable, the team leader should develop a general set of framing plans; typical elevations; and mechanical, hydraulic, and electrical schematics during the pre-inspection visit. Sample forms, which may be used as a guide for the preparation of movable bridge inspection and maintenance records and record keeping, are discussed in Chapter 2.7. Some of the general requirements that should be considered when preparing the field notes include:

- Uniform notation system for reporting condition of bridge elements and components should be known to all team members.
- Standard nomenclature and/or abbreviations for bridge elements and components should be known to all team members.
- Numbering sequence and format for photographs should be standardized.

The general requirements for the structural, mechanical and electrical bridge components are as follows:

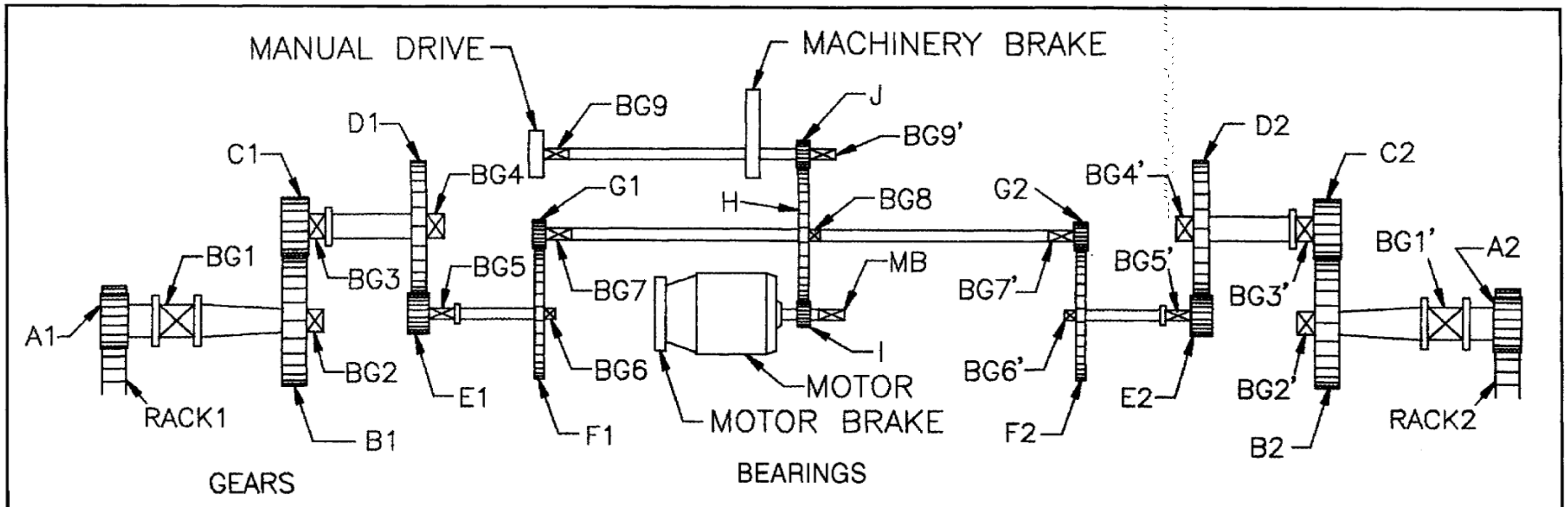
Structural: Structural inspection forms and recording of data are covered extensively in References 8 and 62. Inspectors may use the forms presented in those documents, supplemented by inspection task checklists, previous inspection and deficiency reports, and structural drawings.

Mechanical: Figure 2.6.2.1-1 shows sample machinery sketches prepared for a bascule bridge and Figure 2.6.2.1-2 shows operating machinery for a swing bridge. Dimension charts should be prepared for components to be measured, such as gears, bearings, and bushings. The charts should contain piece numbers for each component, the as-built or design dimension and clearance, and a column to record the actual

C2.6.2.1

To ensure consistency throughout the bridge file, bridge component terminology, numbering and identification systems should be generally the same as the previous inspection(s), and should be consistent in structural, mechanical, hydraulic, and electrical reports.

measurements in the field. The piece numbers refer to the assembly drawings. For complete assemblies, such as gear reducers or mechanical lockbars, general inspection checklists containing items to be covered during the inspection are preferred.



GEAR	BACKLASH		COMMENTS	BRG	CLEARANCE		COMMENTS
	NORMAL	ACTUAL			NORMAL	ACTUAL	
RACK 1				BG1			
A1				BG2			
B1				BG3			
C1				BG4			
D1				BG5			
E1				BG6			
F1				BG7			
G1				BG8			
H–I				BG9			
H–J				BG1'			
RACK 2				BG2'			
A2				BG3'			
B2				BG4'			
C2				BG5'			
D2				BG6'			
E2				BG7'			
F2				BG9'			
G2				MB			

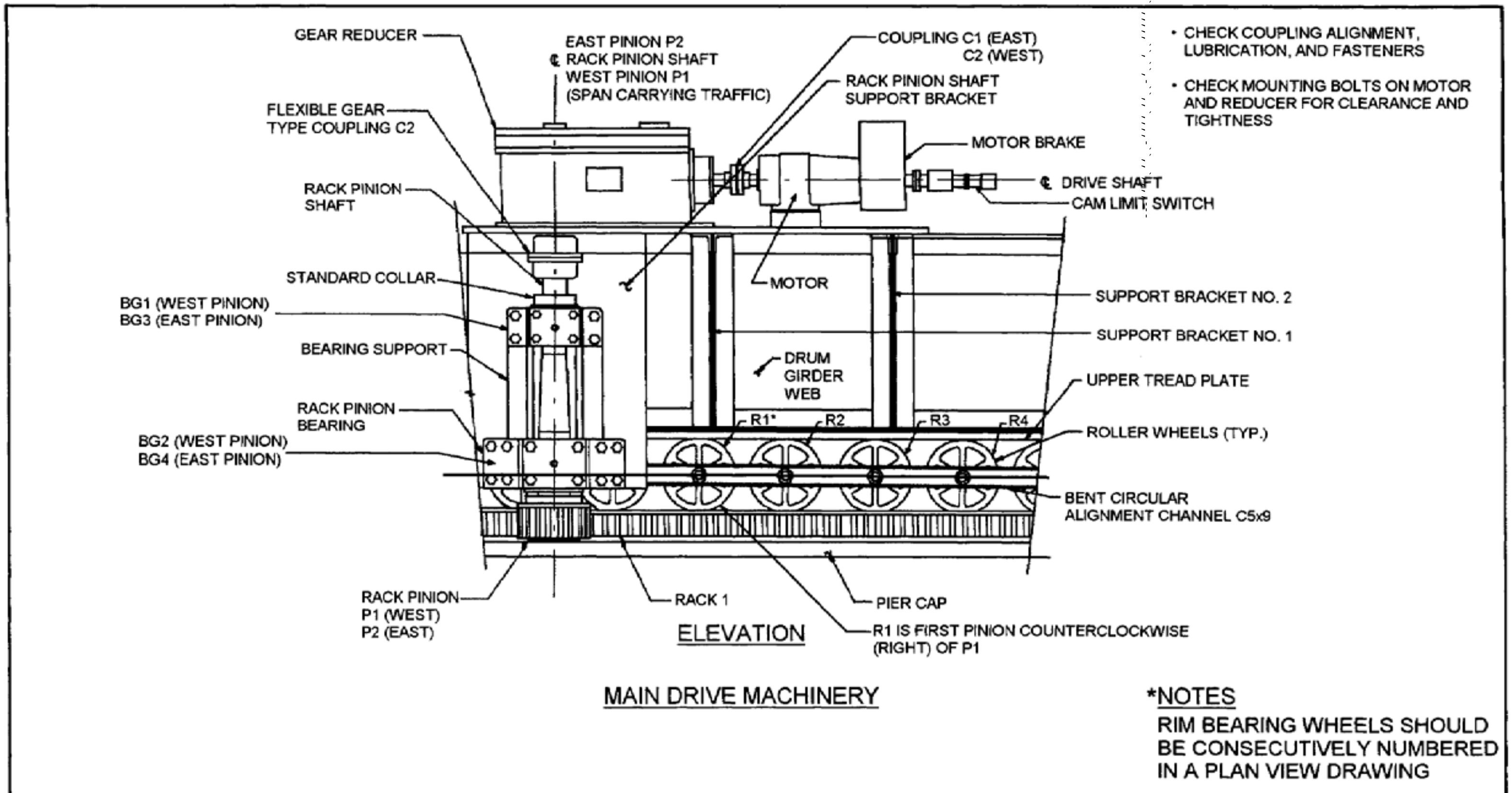
INSPECTION FIELD NOTES

BASCULE BRIDGE

OPERATING MACHINERY

Inspection Crew:	Date:
	Sheet of

Figure 2.6.2.1-1 – Typical drive machinery layout sketch of a bascule bridge



GEAR PINION P1/P2	BACKLASH NORMAL	BACKLASH ACTUAL	COMMENTS	BRG	CLEARANCE NORMAL	CLEARANCE ACTUAL	COMMENTS
				BG1			
CLOSED				BG2			
45°				BG3			
OPEN				BG4			

ROLLER SHAFT BEARINGS - BEARING CLEARANCE

BRG	NORMAL	ACTUAL	BRG	NORMAL	ACTUAL	BRG	NORMAL	ACTUAL
R1			R4			R7		
R2			R5			R8		
R3			R6			R9		

INSPECTION FIELD NOTES

SWING BRIDGE

OPERATING MACHINERY

INSPECTION CREW	DATE
	SHEET OF

Figure 2.6.2.1-2 – Typical main drive machinery of a swing bridge

Electrical: Figures 2.6.2.1-3, 2.6.2.1-4, and 2.6.2.1-5 show typical electrical schematic diagrams and physical layout drawings for conduit and electrical components in the various subsystems and panels. Checklists for inspection tasks should be prepared based on Chapters 2.7, 2.8.3, previous inspection and deficiency reports, and electrical drawings.

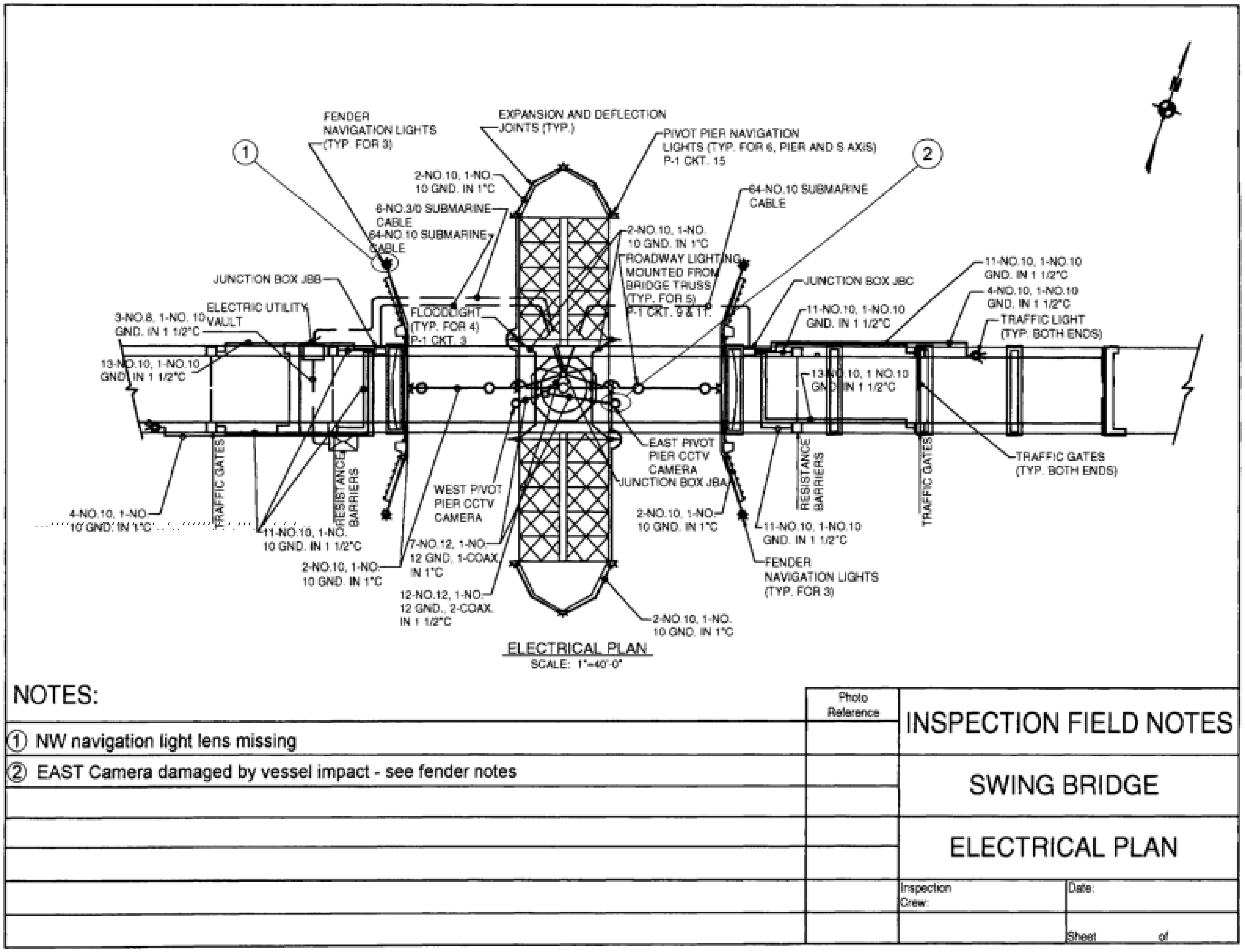


Figure 2.6.2.1-3 – Typical electrical plan

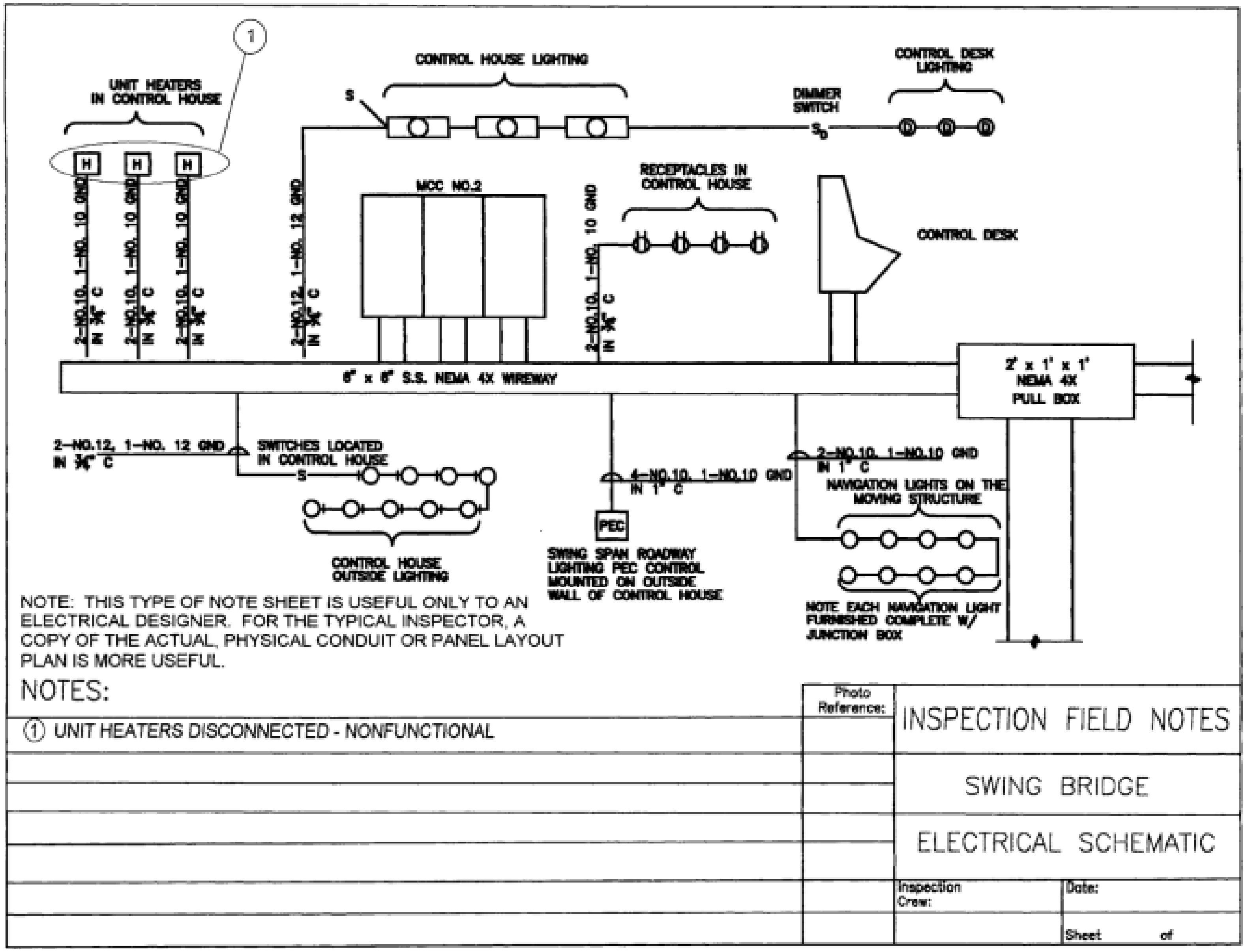


Figure 2.6.2.1-4 – Typical electrical schematic

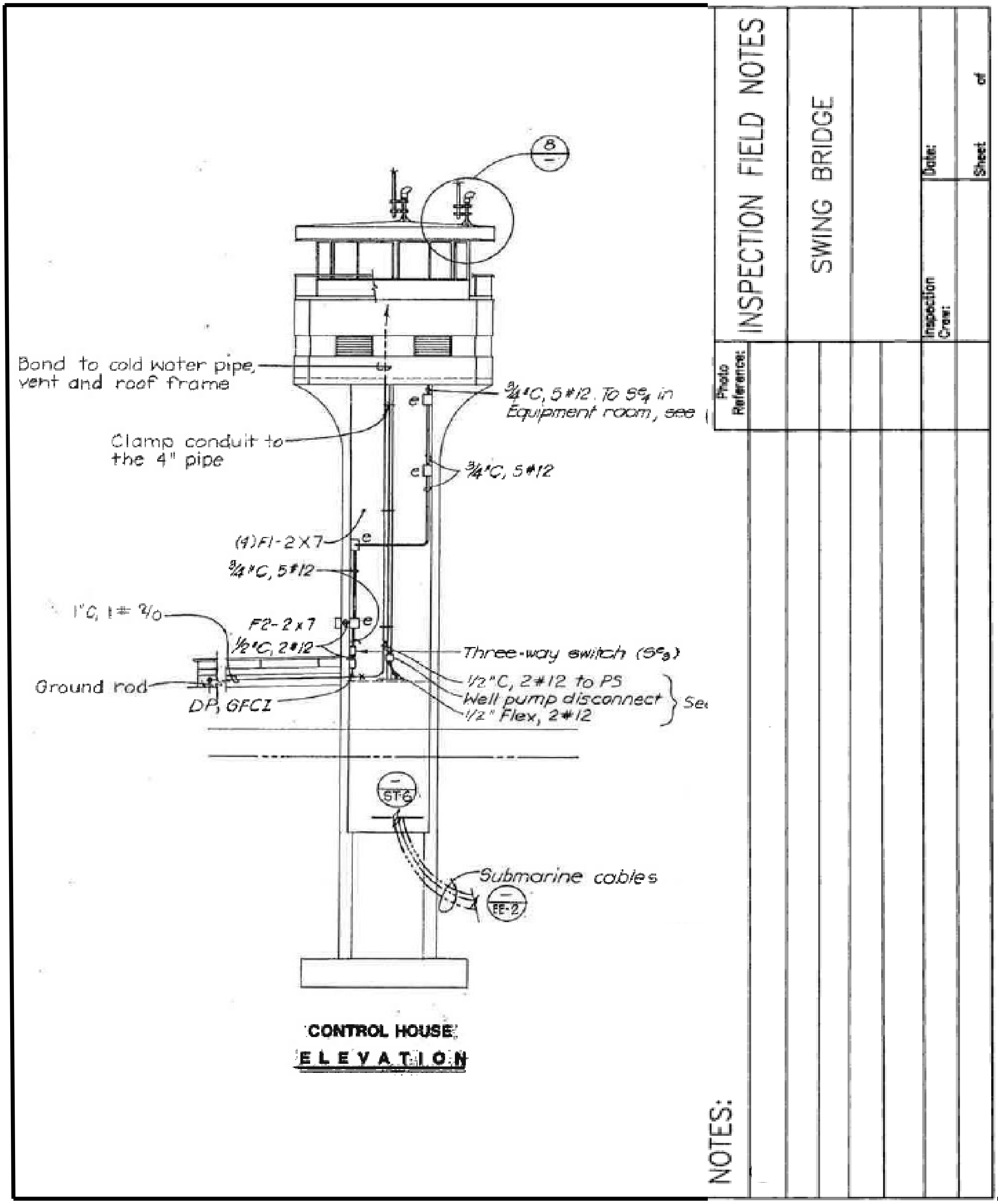


Figure 2.6.2.1-5 – Example field notes for typical movable bridge house

2.6.2.2—Inspection Equipment

The availability of appropriate equipment makes the task of inspecting much easier, and also helps in obtaining accurate inspection data. A sample equipment checklist would include the following:

Mechanical and Electrical Tools

- 6.0 in. (150 mm) scale
- 24.0 in. (600 mm) scale with square
- 50.0 ft. (15 m) steel tape measure
- Feeler gauges, adjustable arm reach swivel head mirrors, etc.
- Stethoscope for listening to bearings, etc.
- Standard vernier calipers
- Machinist's level
- Multimeter
- Clamp on ammeter
- AC ammeter
- DC megger
- Flashlight and portable extension light
- Tachometer
- Equipment tags (Danger-Tag Out)
- Dew-check inspection kit
- Piano wire for trunnion shafts
- Screw drivers
- Adjustable wrenches
- Allen head wrenches
- Files
- Scrapers
- Chalk
- 2 lbs. machinist's hammer or the nearest metric equivalent
- Nonflammable solvent and clean rags
- Lubricant (per as-built drawings or latest approved maintenance practice by owner)
- Digital camera with flash
- Two-way radio
- Tablet and clipboard

Testing and Instrumentation Equipment

- Dye penetrant, magnetic, ultrasonic, or radiographic equipment for crack detection
- Optical instruments such as a transit or theodolite (for checking alignment)
- DC ammeter
- Oil testing unit
- Oscilloscope (for solid state controls)
- Recording meter instrument
- Oil sampling containers

C2.6.2.2

See Chapter 2.5 for additional information about safety.

See Chapter 2.10 for additional discussion of testing equipment.

Scale and tape sizes shown in the metric system are the nearest metric equivalent likely to be available.

- High voltage test probe
- Low voltage high current supply

Personal Safety Equipment

All inspection team members should be outfitted with adequate personal safety equipment. Refer to Chapter 2.5 for guidelines on safety related issues.

See Chapter 2.10 for further details on special testing equipment and procedures.

2.6.2.3—Special Notifications

Bridge inspection crews and maintainers must adhere to USCG (Reference 2), USACOE (Reference 3), and MUTCD (Reference 65) regulations. Should it be necessary for the movable bridge to be closed to vehicular and/or navigational traffic for an amount of time, local, city, and/or state highway and navigation regulatory officials should be notified in advance. The notification should detail the duration and frequency of the closure and specify a contact person in case of emergency.

C2.6.2.3

See the selected reference list in Appendix B for full data concerning referenced regulations. Individual states may also have their own MUTCD and/or regulations pertaining to navigation.

CHAPTER 2.7 – INSPECTION FORMS AND REPORTS

2.7.1—GENERAL

Bridge records for movable bridges are similar to those kept for fixed bridges. In both instances, the bridge file—bridge chronological history records maintained by the bridge owner—should ideally be comprised of the following items:

- Bridge plans (construction plans, shop drawings, as-built plans).
- Technical specifications.
- Record file of noteworthy correspondence.
- General photographs (elevation, bridge deck top and underside, defects, repairs).
- Material and testing data.
- Record of maintenance.
- Record of repairs.
- Accident records.
- Posting and permit loads.
- Flood data.
- Traffic data.
- Structure inventory and appraisal forms.
- Engineering reports (inspection, evaluation, Structural Bridge Load rating, design).
- A record of flood elevations.
- A file of inspection reports.

Inspection reports for movable bridges may be more complex than for fixed bridges due to presence of structural, mechanical, and electrical components.

Due to the variety of features present in movable bridges, a standard, complete set of inspection forms applicable to all movable bridges is impractical. However, consistency in general report format and procedures for reporting and documenting inspection findings can be achieved. General purpose inspection forms for movable bridge functional systems and their components are presented herein. Alterations and supplements to the forms will be necessary for use on a specific movable bridge.

There are many sources of information on inspection records and reporting. FHWA has published manuals such as *Bridge Inspector's Reference Manual* (Reference 62), and *Recording and Coding Guide for the Structure Inventory and Appraisal of the Nation's Bridges* (Reference 66). Additionally, most state DOT's and toll bridge authorities have developed inspection guides and standard forms. Many of the forms included in this chapter are adapted from FHWA sources and the Florida

Department of Transportation's *Movable Bridge Inspection Training Course Student Workbook* (Reference 59). These forms are not intended to replace forms already in existence in other manuals, but are intended as supplements in areas specifically needed for movable bridge inspections.

2.7.2—INSPECTION FORMS

Forms and notes appropriate for the specific bridge should be developed by the inspector and/or bridge owner based upon the pre-inspection visit, previous inspection reports, available plans, or other bridge records.

The following items should be considered in planning and completing inspection forms:

- For consistency in the bridge file, numbering and terminology should be consistent with the bridge plans and previous inspection reports.
- The notation system, nomenclature, coding, and abbreviations should be consistent throughout the inspection forms and a summary sheet documenting these should be a part of the inspection report.
- Deficiencies noted should be supplemented with a photo and/or sketch.

C2.7.2

Among the movable bridges in existence, each has a unique combination of structural, mechanical, hydraulic, and electrical components. The general purpose inspection forms provided in this manual are intended to be modified prior to inspection to suit the needs of the individual bridge and the owner. Making alterations to the forms in the field during inspection could be awkward and inefficient.

2.7.2.1—Condition Rating Summary

This form is a rating summary of the bridge functional systems and their major components. This form should be used to summarize more detailed notes and comments; it should be filled out at the end of inspection by the inspectors. It is recommended that it be reviewed in the office by a senior quality control engineer.

2.7.2.2—Component Inspection Forms

The structural, mechanical, and electrical inspection forms consist of component or assembly sketches with space allocated on the form for comments, photo references, and additional field sketches; tabular forms for identifying original versus field measured dimensions of machinery components (e.g., gears, bearings, bushings); and piece by piece checklists for assemblies (e.g., reducer, lockbar operating assembly). Forms should be supplemented with field sketches and photographs as needed. In addition, the forms may require revisions in order to suit a particular bridge. Much of the information on the type and proper operation of the bridge can be obtained prior to the inspection from plans and previous inspection reports. However, all data obtained prior to the inspection should be verified during the inspection.

2.7.3—REPORT

The purpose of an inspection report is to record and present in a consistent and logical fashion the findings resulting from field work necessary to:

- Evaluate the physical condition of the structure and its components
- Evaluate the performance of the bridge functional systems
- Prioritize maintenance and repair needs for distributing budgeted funds and personnel, and
- Monitor the condition and performance of components over time.

C2.7.3

A bridge inspection report is a legal document that may be used in any litigation involving the bridge. The data produced from an inspection is the primary tool used by the bridge owner to program maintenance and rehabilitation.

2.7.4—REPORT FORMAT

Owners should develop a simple straightforward method of recording recommendations and tracking the timelines of follow-up actions. Such a system could include log sheets with appropriate dates and a "look ahead" schedule to program the actions and monitor performance.

As discussed in Chapter 1.4, a movable bridge should be addressed at three levels: the entire bridge, the functional systems, and the individual components. A well-organized report will be arranged in the same manner.

An example of the contents of a movable bridge inspection report follows:

- Cover sheet
- Index
- Summary of recommendations
- Deficiency reports
- Discussion of the status of follow-up actions on previous reports
- Notation, nomenclature, abbreviations, description of condition ratings
- Bridge and functional systems description
- Structural, mechanical, and electrical description and inspection findings
- Sketches and photographs
- Typical structural, mechanical, and electrical inspection forms and notes

CHAPTER 2.8 – PROCEDURES

Defects found in various portions of the structure will require a thorough investigation to determine and evaluate their cause. The cause of most defects will be readily evident; however, it may take considerable time and effort to determine the cause of some defects and to fully assess their seriousness.

If possible, bridges should be observed during passage of heavy loads to determine if there is any excessive noise, vibration, or deflection. If detected, further investigation should be made until the cause is determined. Careful measurement of line, grade, and length may be required for this evaluation. Seriousness of the condition can then be appraised and corrective action taken as required.

Possible fire hazards should be identified, including accumulation of debris such as drift, weeds, brush, and garbage. The storage of combustible material under or near a bridge, in control houses on movable bridges, or in storage sheds in the vicinity of the bridge should be reported.

Unusual or unique bridges, such as floating pontoon bridges, or unique portions of bridges may require special considerations. These should be defined in the inspection plan for the bridge. Items common to these procedures are discussed below.

2.8.1—STRUCTURAL INSPECTION PROCEDURES

Inspection of typical structural components (such as floor beams, trusses, stringers, substructure, superstructure, etc.) that are common to fixed and movable bridges is covered in depth in FHWA *Bridge Inspector's Reference Manual* (BIRM) (Reference 62) and the AASHTO *Manual for Bridge Evaluation* (Reference 8). Inspector should observe the global operation of the movable span or spans.

This section contains inspection of structural components that occur primarily on movable bridges, such as:

- Machinery access ship ladders, walkways, and platforms
- Counterweights and counterweight pits
- Pier protection system and other waterway protective devices
- Operator's (tender's) house
- Traffic signs and signalization (structural components)
- Live load shoes and strike plates
- Span locks
- Trunnion support members for bascule bridges
- Towers for vertical-lift bridges

There are several considerations applicable to inspection of structural members on movable bridges. For example,

C2.8.1

The primary difference in inspecting structural members on a movable bridge versus those on a fixed bridge is that the members may be subjected to unusual loadings during span motion. Significant differences between "as-built" and "as inspected" conditions may affect span balance and other operating systems.

lubricants and other coatings will tend to accumulate on structural members located under movable bridge machinery. These coatings interfere with the inspection of the members and should be removed to permit close inspection. Also, certain structural components are most heavily loaded during span operation. The critical design loading of such members often does not include vehicle live load. The inspection of such components should be based upon the knowledge that distress may be present due to loads resulting from span operation, which are not necessarily vertical loads in all cases.

Various items that should be inspected during a routine inspection are discussed in the text. Where additional work is suggested for in-depth inspections, it is listed separately. Where no specifics are listed for an in-depth inspection, the in-depth inspection should cover the same areas and will involve similar tasks, but should involve more actual measurement of corrosion losses, rigging, testing, and/or disassembly to allow direct inspection of hidden areas or inaccessible areas that are not done "hands-on" during routine inspections.

2.8.1.1—Substructure

When examining substructure components of movable bridges during a routine inspection, the inspector should consider the following:

- Check for rocking or any motion of the piers when the leaf is opened. This is an indication of a serious deficiency and should be reported at once.
- Check the braces, bearings, and all housings for cracks, especially where stress risers are present.
- Check for cracks in areas where machinery bearing plates, anchor bolts, or braces are attached. Note the tightness of bolts and the tightness of other fastening devices. Loose anchorages can cause movement of machinery and result in misalignment and abnormal wear.
- Visually survey the spans, including towers, with a plumb bob and/or a spirit level to check both horizontal and vertical alignment. These measurements will help to identify any foundation movements that may have occurred. Movement or settlement can cause machinery operational problems.
- Check for standing water in the counterweight pit. This can be a serious problem. Buoyancy forces on the counterweight can overload machinery and motors.
- Check if the span or counterweight contacts the substructure during span motion.
- Check if the substructure interferes with full opening of the span. This can restrict the horizontal or vertical clearance in the navigational channel limits.

C2.8.1.1

When conditions are discovered involving movement of the structure, such as misalignment or out of plumb conditions, monitoring should be initiated to determine whether the movement is ongoing. Data should be recorded at regular intervals for evaluation.

- During in-depth inspections, these checks should be made in all areas. During routine inspections only, the worst examples of a particular type of defect should be fully cleaned, measured, and tested.

2.8.1.2—Superstructure

Routine inspection of the superstructure components should include the following:

- Examine the live load bearings and span lock bars for proper fit, alignment, and, if applicable, amount of lift. When span locks are provided to hold the span in the open position, check for movement under wind loads.
- Inspect joints for adequate longitudinal clearance to provide for thermal expansion and allow for vertical movement under heavy loads. For instance, on a double-leaf bascule bridge the differential vertical movement (if any) at the center joint between the two leaves should be observed and measured under heavy loading conditions.
- For open grid decks, structural welds should be sound and the grid decks should have adequate skid resistance. Grid decking or grating without studs or notches that has worn smooth under traffic should be reported. Check the roadway surface for evenness of grade and for adequate clearance at the joints where the movable span meets the fixed span.
- On rolling lift bascule bridges, check the segmental track casting and the support track girders for wear. Check for cracking in the fillet of the angles forming the flanges of the segmental and track girders. Inspect rack support for lateral movement when the bridge is in motion.
- If the machinery is located under the bridge deck, check for leaks or areas through which debris could fall onto the machinery. If water and debris from the roadway are falling into the machinery area, it should be reported.
- During in-depth inspections, data should be gathered in most areas of deterioration by fully cleaning, examining and measuring typical defects to provide information that describes the precise effect of observed defects.

C2.8.1.2

A location that allows grease and other debris to collect is also likely to collect road deicing salts and other agents that promote deterioration. Grease will not protect metal from corrosion damage if is contaminated with deicing salts or other deleterious substances.

2.8.1.3—Ship Ladders, Walkways, and Platforms

Ship ladders, walkways and platforms are used to provide access to the bridge machinery and structure. During routine inspection of ship ladders, walkways and platforms:

- Check support connections for loose or missing fasteners, cracked welds, fatigue cracks, or other deficiencies.
- Check stair treads and walkway surfaces for adequate connection to their supports. Loose planking or grating creates a tripping/slipping hazard. Check surfaces for

traction deficiencies or accumulations of lubricants or debris that may create a slipping or falling hazard.
- Check railing connections for loose or missing fasteners, cracked welds, fatigue cracks, or other deficiencies.
- Check bridge structural components that support ship ladders and/or walkways for evidence of distress or deterioration.
- During routine inspections, most of the access for inspection may be from above unless severe deterioration is suspected below the walkway grating. During in-depth inspections, provisions should be made for access to supports from below for full inspection.

2.8.1.4—Counterweights and Counterweight Pits

During routine inspections, check the following:
- Inspect counterweights to determine if they are sound and are properly affixed to the structure. Also check temporary supports for the counterweights that are intended for use during bridge repair, and bumpers which prevent bascule leaf overtravel, and determine their condition.
- Where steel members pass through or are embedded in concrete, check for any corrosion of the steel member and for rust stains on the concrete. On multi-trunnion (Strauss) bascule bridges, check the strut connecting the counterweight trunnion to the counterweight for fatigue cracks. On several bridges, cracking has been noted in the web and lower flanges near the gusset connection at the end nearer the counterweights. The crack would be most noticeable when the span is open.
- Examine the counterweight pit for water. Check the condition of the sump pump, the concrete for cracks, and the entire area for debris.
- During in-depth inspections, scheduling, cleaning, and NDT of any deteriorated counterweight members should be considered to check for internal cracks.

2.8.1.5—Pier Protection System and Other Waterway Protective Devices

The pier protection system is a major appurtenance of a movable bridge, serving to protect the bridge structure and its machinery, to facilitate mariner passage and minimize damage.

The pier protection system should be inspected in a manner similar to that used for inspecting the main substructure elements including an underwater inspection at the same frequency required for the underwater portions of the bridge structure (NBIS, Reference 1). During routine inspections, check the following:

C2.8.1.5

The inspection of components of the navigation guidance system is covered in Section 3.11.

Where possible, the navigation clearance shall be checked against the listed clearance.

- Check connections for loose or missing fasteners, cracks, or other defects.
- In concrete pier protection members, check for impact damage, spalling, and/or cracking of concrete or corrosion of the reinforcing steel.
- Check the splash zone (i.e. up to 2.0 ft. [0.6 m] above high tide or mean water level) carefully for deterioration.
- Examine steel parts for corrosion, cracks, impact damage, or other defects.
- Check paint specifications to determine if spark arresting paint was used on painted pier protection components.
- Review previous inspection reports and take core borings to verify the condition of areas of suspected internal timber deterioration.

During underwater inspections, check the following:

- Investigate for deterioration of piles at the mudline and waterline, and check for structural damage caused by marine traffic impacts.
- Check timber pier protection members between the high waterline and the mud line for marine borers, limnoria or other defects.

2.8.1.5.1 Protrusion or Pile Clusters on the Side of Pier Protection Devices

The navigation side or face of a pier protection system should not have protrusions beyond the waler face, since these are areas where the forward rake of a barge or the bow of a vessel can catch. The inspector should check that the outer face of the pier protection system is a straight, smooth, and continuous surface.

2.8.1.5.2 Bolts, Washers, Steel Corner Plates

During routine inspections, check the following:

- Check bolts for proper countersink depth. At least 1.0 in. (25.4 mm) of timber wearing surface should be present beyond the head of the bolt and washer. See Figure 2.8.1.5.2-1.
- Check countersunk holes for the presence of tar or other protective mastic material.
- Any metal or fasteners that are not recessed should be painted with a spark arresting coating. During in-depth inspections, check pier protection plan details and/or specifications if available. Consideration should be given to spot removal of selected fasteners during in-depth inspections to check for hidden fastener corrosion and internal deterioration of timber members at the fasteners.

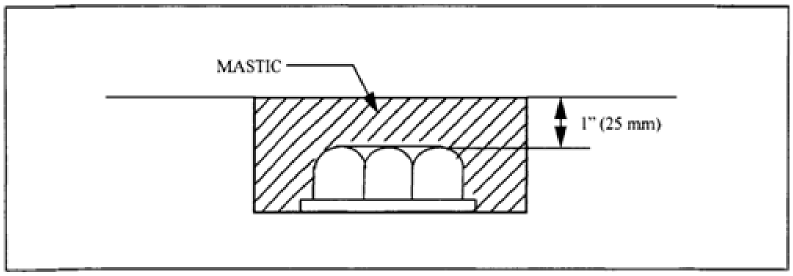


Figure 2.8.1.5.2-1 – Countersink depth for bolts in timber fendering

2.8.1.5.3 Debris Collection

Debris can collect in a pier protection system in different ways. Systems with wide-spaced horizontal wales are susceptible to tree limbs and timbers becoming lodged between wales (Figure 2.8.1.5.3-1). Debris collecting between a pier and its protective device can create safety hazards for commercial and recreational vessels when it becomes dislodged. Also, debris accumulation can cause odor and fire hazards if garbage, oil, or combustibles are present. Any accumulation of debris should be recorded and reported to the bridge owner for corrective action.

Figure 2.8.1.5.3-1 – Debris accumulation on fender system and damage to navigation lights

2.8.1.5.4 Dolphins and Pier Protection Cells

Dolphins or pier protection cells in particular are used in conjunction with fenders to satisfy various waterway and bridge protection requirements. The use of pier dolphins (Figure 2.8.1.5.4-1), margin of channel dolphins, and pier protection cells (Figure 2.8.1.5.4-2) are alternative means of providing protection to bridge piers. Nose dolphins (Figure 2.8.1.5.4-3) are sometimes added to provide additional protection beyond the limits of the fendering. Dolphins or pier protection cells should be lighted.

Pier protection cells are essentially circular cells constructed of driven steel sheet piling filled with sand, rock, or concrete and topped with a concrete cap. The outermost surface that could be contacted by the mariner is typically protected by timber wales or sheathing. Figure 2.8.1.5.4-4 shows a damaged cell. This 45.0 feet (13.7 m) diameter cell was destroyed, laid over and pushed back toward the pier a distance of about 50.0 feet (15.2 m) in a major vessel impact. However, the bridge sustained no damage and the vessel sustained only repairable damage to its bow.

Figure 2.8.1.5.4-1 – Pier dolphins

Figure 2.8.1.5.4-2 – Pier protection cell and fenders

Figure 2.8.1.5.4-3 – Nose dolphins

Figure 2.8.1.5.4-4 – Damaged pier protection cell

2.8.1.5.5 Kinematic Pier Protection Systems

When a kinematic pier protection system is present, the inspector and evaluator will have to check several important items during a routine inspection. These include the following:

- Check to make sure that rubbing surfaces where a vessel could make contact are protected by timber or high density polymer and all fasteners are countersunk.
- Check for hidden structural damage to the rubber and steel fastening areas. Also check the support backing for the timber or high density polymer outer rubbing surface.
- Check that adjacent sections of the pier protection system are tied together so that as one section is deflected the adjacent section will also deflect and not permit a vessel to impact the blunt end of the next section it hits.
- Check to make sure the outer rubbing surfaces are chained or tied to a structural member or portion of the pier protection system so that if damaged it will not readily be set adrift.

C2.8.1.5.5

It is important that kinematic fendering systems be designed so that the fully deformed protection system does not permit the vessel to impact the structure. It is not feasible for inspectors to performance test such systems in the field, but they should be alert to any evidence that a vessel impact has occurred and look for signs of over travel and impact during inspection. If impact evidence is found, the inspector should examine the bridge logs and question the operators to attempt to determine the size, type, and impact direction of the vessel to provide insight into other possible areas of damage, and if over travel is suspected, to determine what size vessel caused the observed damage, and the approximate vessel speed at the time of impact.

2.8.1.5.6 Clearance Gauge Inspection

During routine inspections, check the following items with regard to the clearance gauge based on type and location:

C2.8.1.5.6

33 CFR § 117.47 (Reference 3) states that clearance gauges are required on movable bridges over navigable waters discharging

- The configuration of the clearance gauges is shown in Figure 2.8.1.5.6-1. The foot (meter) marks must be spaced every foot (0.3 m) for nominal day visibility of less than 500 feet (150 m), every two feet (0.6 m) for a visibility of more than 500 feet (150 m) but less than 1,000 feet (305 m) and every five feet (1.5 m) for more than 1,000 feet (150 m). Refer to 33 CFR § 118.160 Vertical Clearance Gauges, for type, size and spacing of numerals per nominal day visibly.

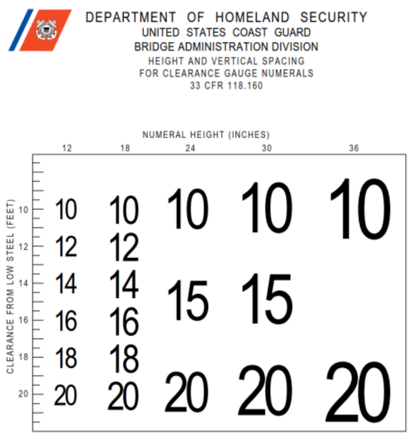


Figure 2.8.1.5.6-1 – Relative sizes of clearance gauges

- On bridges where clearance gauges are required by federal regulations, at least two clearance gauges should be present indicating the vertical distance between "low steel" of the bridge channel span and the level of the water, measured to the bottom of the foot mark, read from top to bottom.
- Each gauge should be located on the end of the right channel pier or pier protection structure, facing approaching vessels. The range of the gauge should cover at least the distance between low steel to the low level of the water.
- Does the gauge extend to a reasonable height above high water so as to be meaningful to the viewer, as in Figure 2.8.1.5.6-2?
- Is each gauge permanently fixed to the pier or pier protection structure?
- Is the gauge made of durable material of sufficient strength to provide resistance to weather, wind, tide, ice, and current?
- Is each gauge marked by black numerals and foot (meter) marks on a white background? Paint, if used, should be of good exterior quality and resistant to excessive chalking or bleeding. Manufactured numerals and background material may be used.

into the Atlantic Ocean south of Delaware Bay, or into the Gulf of Mexico except the Mississippi River. See Reference 3, Part 117 Subpart A and Subpart B for exact listings on canals, Mississippi tributaries and requirements on specific movable bridges elsewhere. Gauges may be painted directly on the bridge channel pier or pier protection structure if the surface is suitable and has sufficient width to accommodate the foot marks (graduations) and numerals. Infrequently on opened higher level movable bridges the clearance in relationship to mean high water (MHW) may be painted right on the lift span. To make the clearance gauges more visible to the larger vessels or larger tows, the clearance gauges may be mounted on top of the fender system (see Figure C2.8.1.5.6-1). These gauges are also illuminated for nighttime navigation. These and the other board gauges can be made using retroreflective material. The lighting can be by a shielded light that shines on the clearance gauge without blinding the mariner or destroying his night vision or by the use of lite pipes with the numbers mounted on the pipes. The lite pipes provide background illumination around the numbers. Digital electronic gauges may also be installed in addition or as an alternative to the standard gauges prescribed in 33 CFR § 118.160.

Figure C2.8.1.5.6-1 – Clearance mounted on fender

- Navigation lights, signs, and pilings should not obstruct the view of the mariner to clearly read the gauge.

Figure 2.8.1.5.6-2 – Gauge showing vertical clearance to low steel

2.8.1.6—Operator's (Tender's) House

During in-depth inspections, the operator's or bridge tender's houses should be checked for conformance with the following:

- The operator's house should be located to permit the operator an uninterrupted view of the navigation channel and approach roadways during all phases of the movable bridge cycle. The house should provide adequate protection to the bridge operator and controls from the environment, traffic, and other detrimental forces. Existing operator's houses that do not have a clear view should be reported for possible corrective action such as installation of additional windows, closed circuit television, etc. in a deficiency report.
- Bridge machinery controls should be adequately secured and supported.

During routine and in-depth inspections, check the following:

- Check interior and exterior of house for cracks, decay, marine and plant growth, or other defects.
- Check for proper installation and function of smoke alarms, fire extinguishers, and firefighting systems; and function and visibility of control systems as required by current federal, state and local regulations.
- Check condition of the operator's house roof, doors, windows, stairs, handrails, lights, emergency lights, receptacles, and HVAC system.
- Refer to Section 2.8.3.13 for the requirements to inspect the control console.

C2.8.1.6

Security and vandalism may be a problem on some bridge structures. Movable bridges often are accessible from the water as well as from land. Inspectors should be particularly alert to these issues for structures which are not manned at all times and on infrequently visited areas of fully manned structures.

The operator's house should be maintained such that at a minimum it fulfills the requirements of the applicable state or local building code, and is suitably weatherproof and adequately insulated. Although the inspector is not expected to have specific knowledge of all applicable building code requirements, obvious deficiencies should be reported with a request for further investigation by evaluators with appropriate expertise.

2.8.1.7—Traffic Signs and Signalizations

Signs, lights, bells, sirens or other devices are used on movable bridges to inform/warn vehicular and pedestrian traffic of bridge operations. During routine inspections, check the structural components of these traffic control devices as follows:

- Observe the device during a complete operation cycle. Check structural supports and connections for movement during operation.
- Check connections between the device and its structural supports for loose or missing fasteners, cracks, or other defects.
- Check members of structural supports in accordance with AASHTO's *Manual for Bridge Evaluation* (Reference 8) and MUTCD regulations.
- Check connections between the structural support and its foundation structure for loose or missing fasteners, cracks, settlement, displacement, or other defects.

2.8.1.7.1 Resistance Gates

When the bridge is closed to vehicular and pedestrian traffic, resistance gates may be employed to provide positive closure to the approach roadways. These gates may be in the form of trusses or built up members. Routine inspection of resistance gate components should include:

- Observing the gate during a complete operation cycle. Check structural supports and connections for movement during operation.
- Check connections between the barricade and its structural supports for loose or missing fasteners, cracks, or other defects.
- Check members of the structural supports in accordance with the current criteria for the inspection of bridges listed in accordance with AASHTO Manual for Bridge Evaluation (Reference 8), MUTCD regulations, and NCHRP Report 350, *Recommended Procedures for the Safety Performance Evaluation of Highway Features*.
- Check connections between the structural support and its foundation structure for loose or missing fasteners, cracked welds, fatigue cracks, settlement, displacement, or other defects.

2.8.2—MECHANICAL INSPECTION PROCEDURES

Mechanical components discussed in this section form the support, balance, drive, control, interlocking, navigation guidance, and traffic control systems that comprise the mechanisms that create motion. Hydraulic components are specifically covered in Section 2.8.2.12, but they serve the same general purposes.

The mechanical components are intended to provide a

C2.8.2

There are many ways in which complex machinery can fail to perform its intended function. More than 80 percent of the movable highway bridges in the United States were built prior to 1970 and almost 50 percent were built before 1940. Time, wear, environmental conditions, and degree controlled, appropriate type of motion. Controlled means moving only when authorized and at the correct speed. Appropriate motion means that only the intended motion (e.g. horizontal rotation) is provided while other types of motion—vertical rotation, horizontal translation (sliding), and vertical motion—are prevented by the machinery.

The purpose of this section is to discuss inspection of the mechanical components. It is intended for inspectors and maintainers. There is always some overlap between the efforts of bridge condition inspection and bridge maintenance inspection groups. Some owners perform both inspections simultaneously, but many agencies have separate groups. It is important to coordinate the findings of both inspections. If maintenance inspectors disassemble components, then the data they collect should be recorded on inspection forms and made available to bridge condition inspection teams during the planning and mobilization stages of their work. If a component is identified as requiring repair or corrective action by the condition inspection team, a deficiency report should be transmitted to the maintenance team for action.

of maintenance can have a deleterious effect on the condition of aged components.

To avoid duplication, mechanical components have been grouped into a general and a special machinery section. The components in Chapter 2.8.2.10 are common to most types of movable bridge: swing, bascule, and lift spans. Chapter 2.8.2.11 covers mechanical components that are unique to each specific movable bridge type. Inspection of brakes is covered in Chapter 2.8.3.5.

In the United States, most movable bridges built prior to World War II had open gearing. After World War II, gear manufacturers began to recommend enclosed reducers. Hydraulic systems also became increasingly more available with increased reliability in the 1950s and afterward. These hydraulics were installed to operate subsystems and entire drive and peripheral systems on increasing numbers of movable bridges.

2.8.2.1—Open Gearing

Open gearing, in movable bridge terminology, refers to individual gears mounted upon individual bearings or in a fabricated machinery frame instead of being contained in a sealed housing. Typically, such open gear sets were assembled in the field during construction of the bridge, although they may in some cases have been assembled in a common frame (such as a Hopkins frame) prior to field installation.

Two types of gears—spur and straight bevel—are normally used as open gearing on movable bridges. However, other types—helical, herringbone, spiral bevel, and worm gears—may be present in encased speed reducers. Spur gears transmit power and regulate the speeds of parallel shafts while bevel gears perform the same function for shafts that are mounted at an angle to one another, usually 90°.

On bridges that have a mechanical span drive or other operating system, gear sets convert low torque, high speed input from the prime mover (electric or hydraulic motor, internal combustion engine, or other source) to the low speed, high torque needed at the final drive element, usually called the rack. Any operational problem with the gears can put a bridge out of service for a prolonged period. It is important for the inspector to learn to recognize potential problems, determine the causes, measure and identity gear wear, and detect potential operational problems before a failure occurs.

C2.8.2.1

Open gearing presents a potential hazard to inspectors and maintainers during operation of the bridge. Reference 2 (OSHA) requires enclosures or guards on gears, sprockets, and chains in 1910.219f.

Caution: Before removing covers or touching gears or other moving parts, be certain the bridge operator clearly understands that the machinery is not to be operated until sufficient notice is given to the inspection team and he receives a positive response that it is okay to proceed with operation. If possible, inspectors should mechanically lock out power or the controls to prevent operation and possible accidents.

Inspection of open gearing is complicated by the presence of covers, lubricant, and other coatings that may obscure defects. Inspectors should have flashlights, inspection mirrors, borescopes, or other inspection aids as necessary to perform gear inspection without the need to disassemble guards unless such disassembly is scheduled as part of the work. It may be

Gears and pinions on movable bridges have usually been designed conservatively; they should have long, trouble free operational lives, provided they are given the attention that precision machinery deserves. In order to detect machinery flaws, the inspector should have a fundamental knowledge of gears and gearing to correctly and accurately evaluate and report the observed conditions and make proper recommendations for required maintenance and repairs.

Assembly and alignment of open gears in the field is difficult, and for such installations initial misalignment was and is still a common problem. The misalignment condition can be exacerbated if the support bearings were not properly secured and have worked loose on the mounting during operation. Shop assembly is more likely to achieve correct initial alignment as well as continued integrity of the bearing mounting. In either field or shop assembly, wear of open gears is compounded by the constant exposure to weather and the presence of abrasive, foreign materials that lodge in the gear mesh.

In order to offer some protection to the exposed teeth, and to protect workers against moving machinery, sheet metal protective covers are typically placed over the gearing to assist in keeping dirt and debris from entering the mesh. These covers do not completely seal the gears to protect them from environmental influences, but will generally shed debris falling from above, and will provide a degree of protection against inadvertent contact with moving machinery.

necessary to steam or solvent clean open gearing during inspection to check for defects in the teeth. The contact height of the wear zone typically increases over time as the teeth "wear in." The critical dimension for determining percentage of full faced contact is the width of the wear zone as compared with the full possible width of the tooth contact. Pinions are often wider than the teeth they engage, so 100 percent full face contact on a pinion may occur over less than the full width of pinion tooth.

Information about gear mechanics, gear tooth shapes, and formulae and examples for determining the gear tooth dimensions is provided in Appendix A.

2.8.2.1.1 Gear Alignment

Proper alignment of gear sets is critical to reliable, efficient performance. Misaligned gears are subject to accelerated wear and/or fracture of teeth due to overstress. Correct alignment is defined as the condition where the tooth faces of the gear and pinion are parallel, the full effective faces are in contact, and the proper amount of backlash is present. Backlash is the space between adjacent, non-contacting teeth. It may be thought of as the freedom of one gear to move while the mating gear is held stationary. All gear sets require backlash in order to provide a space that allows for the presence of lubricant and that prevents engagement of both tooth faces at the same time.

C2.8.2.1.1

Large gear diameters usually require increased backlash to handle thermal expansion.

2.8.2.1.1.1 Spur Gears

Spur gears are correctly aligned when their center lines are parallel, pitch circles are tangent (center distance correct), and teeth are in mesh for their entire effective length. Figure 2.8.2.1.1.1-1 shows the contact area of a tooth in perfect mesh. Notice the area extends across the face and flank of the tooth from just above the fillet to just below the tip of the tooth.

There are several frequently encountered conditions that cause misalignment that the inspector should be able to identify

C2.8.2.1.1.1

Perfect full face contact such as this will rarely, if ever, be observed in open gear sets; however, it is desirable to have the best possible condition with no less than 85 percent full face contact.

quickly. The inspector should remember that the bridge machinery gearing is required to transmit loads when the bridge is being opened as well as during closing so that contact, and resultant wear, will be present on both sides of the teeth.

- If the shafts are out of parallel as shown in Figure 2.8.2.1.1.1-2, cross bearing will result. That is, a tooth will have loading on one face at one end, and on the opposite face at the other end. Sometimes the condition is apparent by visual observation of the gear set and it can always be confirmed by checking the amount of backlash at each end on both faces of the tooth width. This condition is confirmed if the pitch circles are not tangent on both ends and if the total backlash (from both faces) is greater at one end than the other.

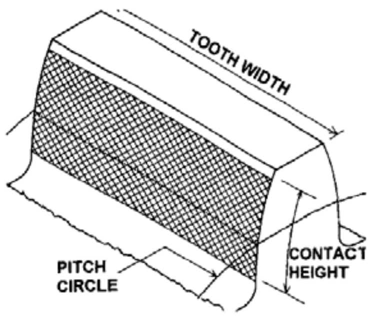


Figure 2.8.2.1.1.1-1 – Shaded area indicates the contact wear zone of a well aligned tooth.

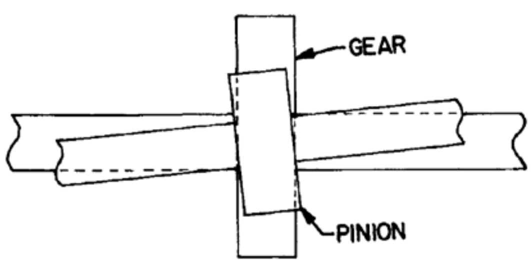


Figure 2.8.2.1.1.1-2 – Out of parallel shafts cause cross bearing in the gear set

- Figure 2.8.2.1.1.1-3 illustrates a situation of nonparallel shafts that causes end loading on both faces at one end of the same tooth. This condition is confirmed if the pitch circles are not tangent at both ends and if the backlash (from both faces) is greater at one end than the other.

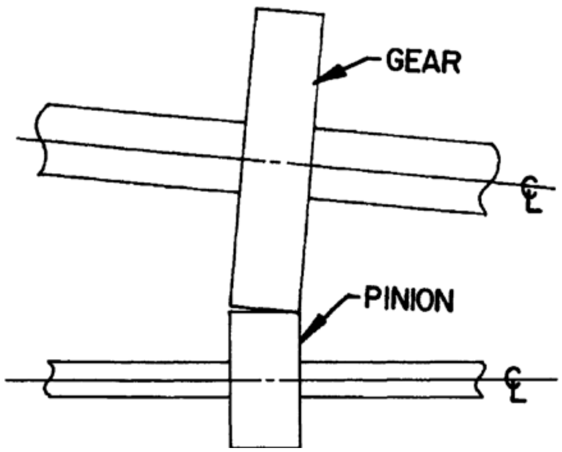


Figure 2.8.2.1.1.1-3 – Convergent, nonparallel shafts result in end load

Note: During the initial stages of cross bearing and end bearing, very high stresses are present at the tooth ends during operation and tooth fracture or breakage can occur. As the gear set continues to rotate under such a condition, the contact area will begin to spread across the face of the teeth due to tooth wear. The wear resulting from this condition causes destruction of gear tooth involute profiles and accelerated wear that will lead to premature failure.

- Radial misalignment means the center distance between the gear and pinion is not correct. Slight variations in center distance will not affect gear action for involute gearing. A major variation will cause improper tooth contact throughout the engagement. If the center distance is too great, as shown in Figure 2.8.2.1.1.1-4, the parts of the teeth not in contact will not wear and a step will develop on the gear tooth profile between contacting and non-contacting surfaces. The time of engagement between teeth is reduced, and if the condition is "severe," one pair of teeth may lose contact before the next pair engages. The teeth will then slam into engagement and impart shock loads on those teeth as well as throughout the system. In addition, since the load is now being applied further out from the root of the tooth, the bending stresses at the root are increased significantly and cracks or tooth failure can result.

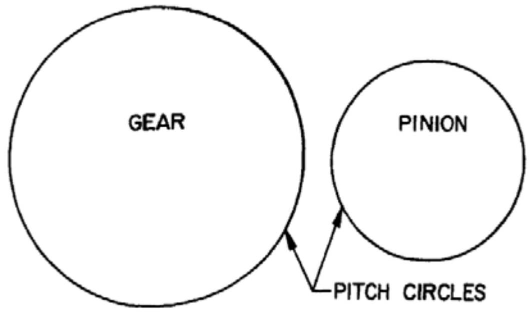


Figure 2.8.2.1.1.1-4 – Separated pitch circles show the center distance is too great

When the center distance is too short, as in Figure 2.8.2.1.1.1-5, the pitch circles are overlapped and backlash and/or root clearance are reduced or eliminated entirely.

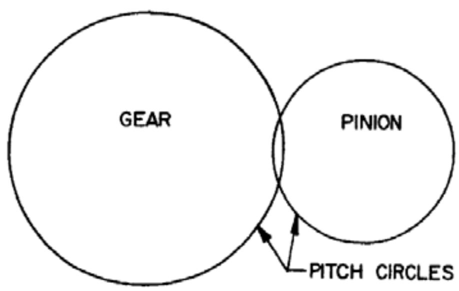


Figure 2.8.2.1.1.1-5 – When pitch circles are overlapped, the center distance is too short

Too little backlash permits wiping of the lubricant from the tooth faces so that insufficient lubricant is present. Lack of backlash and lack of root clearance may also result in binding and/or rapid wear of the gears. During prolonged operation, gear and/or bearing wear may tend to alleviate the condition or failure may occur. Any gear set operating with too short a center distance is likely to experience excessive tooth wear and damaged involute profiles. In some cases significant bending stresses can be created in pinion and gear drive shafts due to this condition.

- Axial misalignment is present when the pinion and gear are axially offset one from the other so that the teeth cannot be engaged along their full effective face, as shown in Figure 2.8.2.1.1.1-6. Normally, the pinion is intentionally manufactured slightly wider than the gear. When correctly installed, the gear should not protrude from either end of the pinion. Proper axial alignment permits full face contact. It is obvious that the stresses are increased if the length of face contact is reduced and the load is carried by only part of the tooth. This condition will also accelerate tooth wear and contribute to early failure. It is important to recognize that several types of misalignment can be present in a given gear set at any time. If compound misalignment does exist, the inspector should try to determine which types are present and identify their causes.

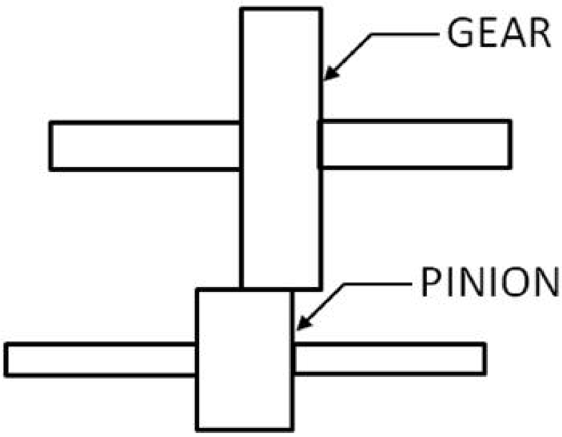


Figure 2.8.2.1.1.1-6 – Axial misalignment

2.8.2.1.1.2 Bevel Gears

Similar types of misalignment discussed for spur gears also apply to bevel gears. When in proper alignment, bevel gear shafts form a given angle in the same plane with one another and the teeth will engage to the proper depth. In bridge machinery this angle is generally 90° and it will be so assumed for these discussions.

- End-loading will occur at the heel of the teeth if the angle of engagement is greater than 90°, as in Figure C2.8.2.1.1.2-1. If the angle is less than 90°, end-loading will be present at the toe end of the teeth.

- Cross bearing results when the shaft centerlines are not in the same plane and do not intersect, Figure 2.8.2.1.1.2-1.

Just as in spur gears, when the teeth in bevel gears engage too deeply, backlash is reduced and rapid wear results. If the teeth do not engage deeply enough the teeth will become stepped, engagement time is reduced and early failure can occur.

C2.8.2.1.1.2

When actual shaft angle exceeds the design shaft angle toe loading occurs. Heel loading is caused when actual shaft angle is less than the design shaft angle. See Figure C2.8.2.1.1.2-1.

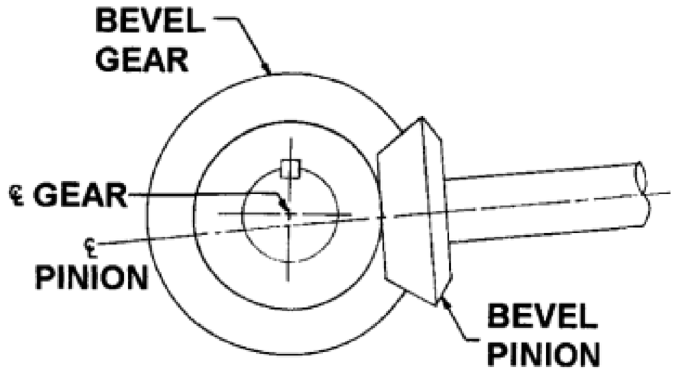


Figure 2.8.2.1.1.2-1 – Non-intersection of shaft centerlines causes cross bearing in bevel gears

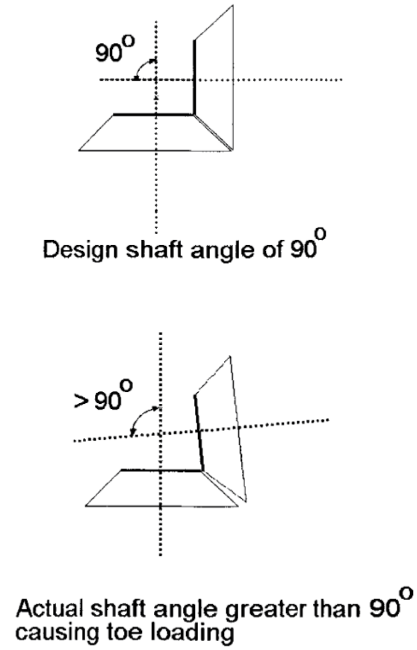


Figure C2.8.2.1.1.2-1 – Toe loading due to actual shaft angle being less than the design shaft angle

2.8.2.1.2 Gear Tooth Wear Measurements

A very important part of bridge machinery inspection is accurate observation and measurement of gear tooth wear. Measurements will indicate what type and how much wear has occurred, help establish a historical pattern of wear, and assist in identifying which gears need immediate attention or require continued critical observation in order to avoid service interruptions. As subsequent inspections are conducted it will be possible to determine if the rate of wear is accelerating or has stabilized. Such information is invaluable in establishing long range maintenance and repair programs.

C2.8.2.1.2

Excessive gear tooth wear is frequently the result of other conditions in the machinery system, or other bridge systems, and correct interpretation of the observed conditions can help in pinpointing the problem areas; thus permitting attention and correction before failures occur.

Accurate evaluation of gear tooth wear requires knowledge of gear tooth terminology and geometry as well as special precision measuring instruments and the ability to use them with patience and perseverance.

2.8.2.1.2.1 Measuring Gear Teeth

The two most common and accurate means of determining gear tooth wear are the use of a vernier tooth caliper and/or a standard vernier caliper.

Figure 2.8.2.1.2.1-1 schematically illustrates the use of a vernier tooth caliper. The vertical vernier scale is set to the proper chordal addendum and the caliper placed squarely on the tooth so the vertical anvil is tangent to the tooth outside diameter at the tooth midpoint. The horizontal vernier scale then measures the chordal tooth thickness at the pitch line. In

C2.8.2.1.2.1

The purpose of accurately measuring gear teeth is to determine how much wear has occurred by comparing the present tooth thickness to the original amount. To do this, it is necessary to know the original thickness. Sometimes the chordal dimensions are given in the as-built drawings. Another possible source is previous inspection reports. Often this order to have the caliper firmly seated on the tip of the tooth any burrs, fins, or other upset metal should be filed off. Chordal thickness should be measured at both ends and the midpoint of spur gear teeth. On bevel gears, tooth thickness readings are taken both at the large end and heel of the tooth.

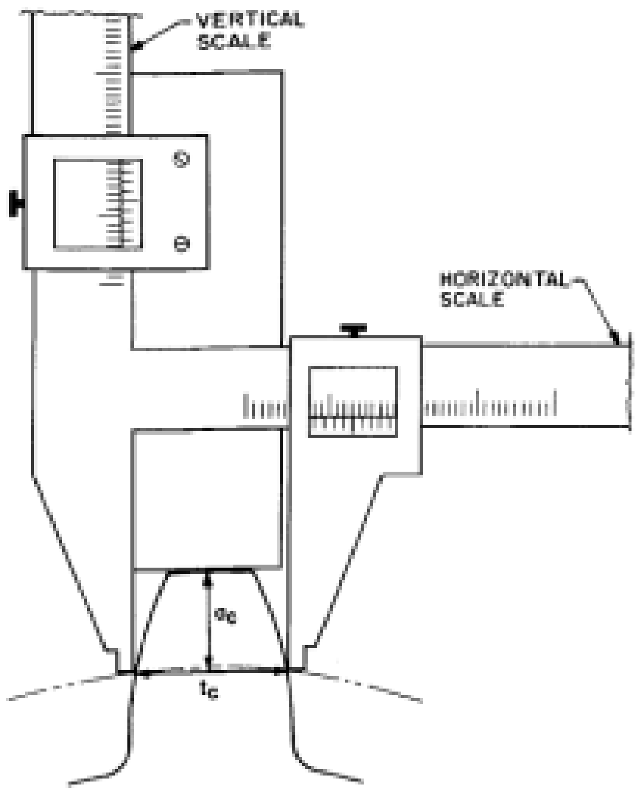


Figure 2.8.2.1.2.1-1 – Vernier tooth caliper

While vernier tooth calipers permit accurate measurements of individual gear teeth, they do have a drawback. Normally the outside diameter of a gear is not held to a precise tolerance and this affects the accuracy of the chordal tooth thickness. For this reason span dimensions are measured whenever possible. Span measurements are obtained using standard vernier calipers and are taken over two or more teeth. Figure 2.8.2.1.2.1-2 illustrates the means of obtaining a span measurement. Notice that the measurement is obtained directly between two tooth faces and is independent of the addendum and does not have to be on the pitch line. To ensure accuracy, the jaws of the vernier should be tangent to the tooth faces over which the measurement is being made.

Obtaining span measurements is restricted to the length of vernier caliper available. Usually it is impractical to use verniers over 24 in. (610 mm) long in the field so that when span dimensions are longer than the available caliper tooth measurements should be made with tooth verniers. Racks on swing spans and trunnion bascules as well as ring gears on information will not be available and the inspector will be required to calculate the original measurements from the pitch, number of teeth, pressure angle, pitch diameter and backlash. See Appendix A for worked examples for calculating chordal addendum and original chordal tooth thickness for a given gear tooth.

counterweight sheaves and operating rope drums on vertical-lift bridges are typical locations that are not suitable for making span measurements.

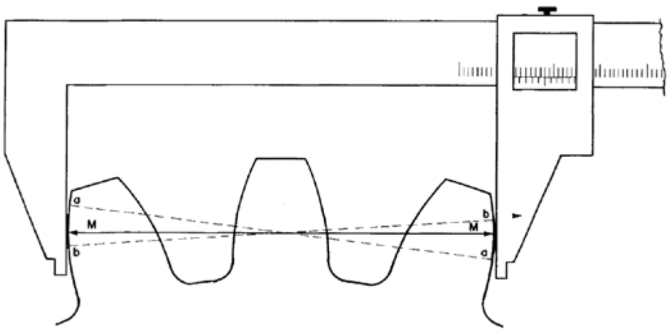


Figure 2.8.2.1.2.1-2 – Taking span measurements using a vernier caliper. The caliper jaws do not need to be on the pitch line; chords M-M, a-a, and b-b are all equal.

2.8.2.1.3 Appearance and Identification of Gear Tooth Wear and Destruction

From the instant gears are installed on a bridge they are subject to wear and deterioration. Most wear occurs during operation of the span but gears are also exposed to adverse influences of the environment. Dirt and debris, rust and corrosion, the presence of foreign materials and shock loads caused by improper adjustment of the locks and live load shoes all have adverse effects even when the leaf is not moving. Reference 17, ANSI/AGMA 1010-E95, *American National Standard – Appearance of Gear Teeth – Terminology of Wear and Failure* (2007), extensively covers the subject of gear tooth wear and destruction, including photos; this standard should guide mechanical movable bridge inspectors' reporting on gear condition.

2.8.2.1.3.1 Wear

Operating gears are subjected to wear from many sources. Improper, inadequate or abrasive materials in the lubricant; shock loads; faulty installation, alignment or manufacture; and corrosive deterioration are a few. Careful observation of wear pattern and type provides a clue to its origin and cause. Frequently the causes can be identified and remedied before failure or other service interruptions occur. The importance of accurate evaluation of gear tooth wear cannot be overemphasized. Measurements of the existing tooth dimensions should be compared with calculated values if necessary to determine the degree of wear. It may also be possible to measure portions of individual teeth not subjected to wear to compare with dimensions in worn areas. Comparing recent wear measurements with values from previous reports is helpful in estimating the rate of wear.

2.8.2.1.3.1.1 Polishing

During the initial period of operation of a gear set, minor imperfections will be smoothed out and the working surfaces will polish up. This wear is a surface phenomenon. The polishing is a slow process in which the asperities (roughness) of the contacting surfaces are gradually worn off until smooth surfaces develop. This condition is normal and cannot be avoided; it will continue throughout the life of the gear set.

As polishing occurs and continues, across the full face of the tooth, the pitch line will become visible as an unbroken line. Polishing wear is a slow process and not necessarily a problem.

2.8.2.1.3.1.2 Abrasive and Corrosive Wear

Abrasive wear can be caused by insufficient or improper lubrication, abrasive material in the lubricant, or overload. Abrasive wear progresses much more rapidly than polishing, and will alter the tooth profile as proven by successive measurements. When abrasive wear progresses to a state that the tooth surface profile is destroyed, the wear will further accelerate and finally cause tooth failure.

Radial scratch marks or grooving of the tooth surfaces is typical of abrasive wear. If severe enough, the grooving can be quite deep, appearing like furrows proceeding toward the outside diameter of the gear. Even in cases of subtle abrasion, the surface appearance of the tooth will differ from the appearance of a smooth “polished” appearance that generally lacks any aligned scratch marks.

Open gearing is particularly vulnerable to abrasive wear caused by dirt, abrasive grit, and foreign material trapped in the mesh. Particles such as metal chips, weld spatter, sand, gravel, and other roadway debris commonly cause this type of wear.

Surface deterioration by chemical action is called corrosive wear. It is frequently initiated by the presence of water in the lubricant attacking the tooth surfaces. Open gearing is regularly soaked by rain, snow, salt spray, and other corrosive products in the bridge's environment. The oxides (rust) resulting from the corrosion then abrades the surface and promotes a pockmarked appearance and/or scratching or grooving of the contact surfaces.

2.8.2.1.3.1.3 Tip and Root Interference

When the tip of a tooth interferes with the root of a meshing tooth, localized scoring will result as well as possible plastic flow of the metal away from the area of interference. Often the tips of the pinion or gear show unmistakable signs of metal removal and have an abraded look and tear marks in the direction of rotation. This condition will usually result in considerable damage if not corrected. This condition is different from abrasive scoring, and is caused by either improper tooth geometry or poor installation. The tooth profile might have an error in the root area, the pinion tooth might require tip relief or the set might be improperly installed with a short center distance. The tight mesh causes heavy tooth loading and breaks down the lubricant film. Rapid metal removal and tooth abrasion follows.

2.8.2.1.3.1.4 Scuffing

Scuffing is the transfer of metal from one surface to another caused by adhesion that occurs when metal surfaces under compressive stress form metallic bonds, and are then torn apart. Scuffed areas appear as plastically deformed, rough, or torn areas with the damage being radial, in the direction of sliding.

Very high loads applied to the gear teeth in the absence of satisfactory lubricant causes extremely high instantaneous pressure and temperature that result in the momentary welding together of tooth surfaces. As the gears continue to rotate the weld is broken and metal is removed from one or both of the tooth faces. Scuffing is not a fatigue phenomenon, although it is often confused with destructive pitting.

2.8.2.1.3.2 Surface Fatigue

Metal failure of the tooth surfaces, called surface fatigue, occurs when the fatigue limit of the gear material has been exceeded. Repeated surface or subsurface stresses that surpass the endurance limit of the gear material cause surface fatigue and deterioration.

Characteristically small amounts of metal are removed and cavities are formed. Although initially quite small, they will increase in size and combine with others as the fatigue continues. Pitting and spalling are types of surface fatigue.

2.8.2.1.3.2.1 Pitting

Pitting usually begins as very small pits (0.015 in. to 0.030 in. dia. [0.381 mm to 0.762 mm dia.]) in overstressed areas and tends to redistribute the load by removing the high spots. If percentage of overstress is not excessive, pitting may stop, and continued operation will polish the contacting surfaces. However, if pitting is widely distributed across a large portion of the tooth surfaces, it tends to progress to a destructive condition. Initial pitting can be caused by improper tooth profiles, surface irregularities or misalignment across the face of the mesh that results in very high stresses along a small portion of the tooth face.

When initial pitting is left unchecked and the overstress is excessive, the pits will continue to increase in number and size until destructive pitting is present. This condition will continue until the tooth profile is completely destroyed, causing very rough and noisy operation. Another result can be formation of a fatigue crack and tooth breakage.

2.8.2.1.3.2.2 Spalling

Spalling is similar to pitting except the pits are usually larger, irregular in shape, and quite shallow. This condition occurs most often in medium hard material. It can take place in the relatively softer gear materials, particularly after long service when the tooth surfaces have “work hardened” to some extent.

Excessively high contact stress levels promote spalling and large irregular voids develop as the edges of the initial pits break away to join with other voids.

2.8.2.1.3.3 Plastic Flow

Plastic flow is inelastic deformation of the tooth surfaces and is caused by high contact stresses combined with the rolling and sliding action through the mesh. This condition is very common on bridge gearing since it is generally associated with softer gear materials. It will be observed on most bridge gears after several years of service. It is a surface deformation that results from yielding (stretching) of the surface metal under heavy load. Plastic flow is also often observed in the tracks of rolling lift bascule spans.

The condition may be recognized by evidence of material flow. Frequently surface material has been worked over the tips and ends of the teeth, giving a finned appearance. The tooth tips may become heavily rounded-over, depressions appear on the tooth contact surfaces, and sometimes the faces appear dented and battered.

A common result of plastic flow on bridge gearing is plastic flow buildup, or ridging, on the gear (driven member) and a corresponding depression, or grooving, at the pitch line of the pinion (driver). This phenomenon occurs because the sliding action tends to push or pull material in the direction of sliding. Other terms used to identify plastic flow are cold flow, rolling, peening, and rippling. Normally this type of deformation will become very noticeable, with a large ridge, long before complete tooth failure occurs.

2.8.2.1.3.4 Tooth Breakage

Tooth failure by breakage in bridge machinery is rare. The gears usually have been conservatively designed with an adequate safety factor and should operate for a long time under the most adverse conditions. However, there are conditions that can cause abrupt or sudden failure. Extreme overload or shock loads can cause rapid tooth destruction. Failures of these types normally start with a crack originating in the root section of the tooth and progressing until the whole tooth, or a portion of it, breaks away.

There are many other possible causes for tooth breakage including: bending, fatigue failure, overload fracturing, excessive tooth misalignment, foreign objects trapped in the mesh, and material deficiencies.

2.8.2.1.3.5 Gear Tooth Wear Observations and Inspections

In most cases, gears will show signs of a combination of several types of wear. It is the inspector's responsibility to accurately report them all. The appearance of the teeth before cleaning is very important in determining the mechanism of wear. The lubricant pattern can reveal misalignment, poor tooth contact, and other conditions that should be recognized and reported.

Before cleaning away the lubricant during routine inspections, visually observe the gear sets in operation. Watch for any peculiar movement of the gears and listen for any unusual and/or loud noises. Then inspect each gear set for signs of misalignment, poor tooth contact, and other indications of distress. Take color photographs of the teeth.

End and cross bearing conditions are easily recognized because the loaded areas of the teeth will have pushed most of the grease to other locations. If the operating center distance is too great or too little, the grease pattern will reveal it. Look at the gear set from one end, if possible both ends, and notice the alignment of the pitch circles. Are they tangent, separated or overlapping? Do they confirm or disagree with the condition indicated by the lubricant pattern?

After inspecting the teeth with lubricant present, several teeth should then be cleaned with a suitable solvent for further visual inspection of the surface conditions and measurement for wear determination. Gloves should be worn for protection against the solvent as well as metal slivers from the tooth surfaces during cleaning. Photograph the cleaned teeth. The condition and cleanliness of the lubricant should also be observed and recorded.

Look carefully at the root areas of the teeth and check any suspect areas for cracks using dye penetrant or other nondestructive methods. Proceed with tooth vernier or span measurements and record those dimensions on the inspection report form. At times the teeth will be so worn and deteriorated that meaningful measurements cannot be obtained. If so, report it. If not, do a thorough job and obtain accurate measurements. Measure the present backlash using feeler gauges. Be sure to do this at both ends of the teeth, if possible. Compare the present

C2.8.2.1.3.5

A pinion having a width greater than the gear can be checked by taking gear tooth or span measurements on the unworn portion of the tooth. The measurements should ideally be made early in the life of new gears when the as-measured dimensions may be slightly more than the standard values. If such an unworn shoulder exists, it will serve as an independent check of calculated standard dimensions in the gear tooth thickness inspection forms.

Since many pinion teeth are wider than the gear teeth, the ends of the pinion teeth are unworn and in some cases significantly thicker than the loaded tooth surface. This condition makes taking accurate backlash measurements difficult unless a flexible feeler gauge can be worked into the gap past the shoulder formed by this condition. It may be possible to measure backlash approximately by relative position of teeth in full contact first in one direction of rotation and then the other using a dial gauge in conjunction with direct manipulation of the machinery with the hand drive or a strap wrench. This method is not as reliable as the feeler gauge method. Another possibility is to grind the unworn shoulder area flush with the inner portion of the tooth on selected teeth to allow use of feeler gauges.

measurements with the original or as-built data and determine the amount of wear and change in backlash.

Examine all teeth, ribs or spokes, and hubs for corrosion and signs of stress or cracks. Particular attention should be given to the areas where gear spokes meet the hub and the corners of keyways in the hubs and other locations where stress concentrations occur. Dye penetrant should be used if a crack is suspected. Upon completion of the inspection, replace any removed lubricant before operating the leaf.

2.8.2.2—Enclosed Gearing

Gear sets that are mounted in dust proof, oil tight housings are generally referred to as enclosed gearing. These assemblies are also generally called speed reducers. In most cases, they are manufactured by companies that specialize in the design and manufacture of mechanical power transmission equipment. Those in movable bridge usage are normally special units, custom-made for the application and are not available as standard, stocked items. See Figure 2.8.2.2-1.

On many older existing movable bridges, cast iron was the accepted material for reducer housings, but most newer bridges were constructed using fabricated steel housings. The sealed housings protect the gears, shafts, and supporting bearings from rain, roadway drainage, and other deleterious external debris. They also make proper lubrication possible by serving as an oil bath container. In addition, the housings help minimize wear and field adjustment during installation by providing rigid shop-aligned mountings for the shaft bearings. Accurate machining of all critical surfaces of the housing and precision boring of the bearing seats essentially eliminates shaft misalignment and associated wear problems that are more likely to occur on open gearing.

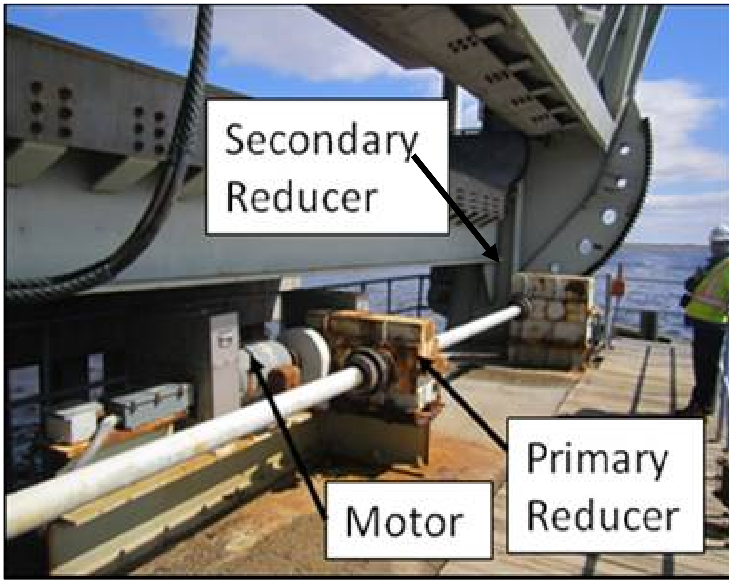


Figure 2.8.2.2-1 – Primary and secondary reducers on a bascule bridge

Bearings supporting the shafts are typically ball or roller type as required by Reference 6. They have typically been selected very conservatively and usually have extremely long service lives. Prior to adopting the use of anti-friction bearings as usual design practice, sleeve type bronze, or occasionally babbitt, bearings supported the shafts. Many of these sleeve bearing units are still in service today, but are more prone to wear and should be carefully checked for excessive radial clearance during inspection.

Lubrication of the gears and bearings in enclosed reducers is usually automatic and continuous when the reducer is running. Sometimes pump driven, force feed lubrication systems are used and the bearings are then lubricated independent of the gears. In all cases, though, provision is made for draining and replenishing the lubricant without disassembly of the unit and sight gauges or dip sticks are included to allow inspectors and maintainers to monitor the lubricant level.

Seals around each shaft extending through the reducer casing are designed to prevent the lubricant from leaking out and also assist in keeping foreign matter from entering. These seals require some lubricant between the sealing element and rubbing surface on the shaft in order to avoid rapid seal wear; therefore, it is normal to observe a small amount of lubricant around the shaft at the seal lip.

During operation, the temperature inside the reducer increases due to friction generated heat buildup and the air inside must expand. If there were no way for the air to escape the inside pressure could build up to a point that shaft seal rupture could occur. While at rest, the recently active reducer cools, the air inside contracts, and additional air must be allowed to enter the housing. Most reducers are equipped with a filtered breather that permits clean air to flow out of and into the reducer, thereby protecting the seals against pressure differentials and preventing contaminants from entering.

Removable inspection covers are located in the housing to facilitate visual inspection of the gears and housing interior without the need for removing the casing top.

Caution: Before opening a sealed reduction unit to inspect the internal parts, be certain that the bridge operator clearly understands that the machinery is not to be operated until sufficient notice is given to the inspection team and he receives a positive response that it is okay to proceed with operation. If possible, inspectors should mechanically lock out power or the controls to prevent operation and possible accidents.

The gear types used most frequently on movable bridge enclosed gearing include: helical, herringbone, spiral bevel, and worm. Helical and herringbone units are, generally, parallel shaft reducers while spiral bevel and worm units are typical for right angle units. The parallel shaft and right angle nomenclature is a reference to the orientation of the input and output shafts. Due to the wide variation in design concepts for movable bridge systems, reducers often are made up of a combination of gears so that right angle units can have helical or herringbone gears in combination with spiral bevel or worm gear sets.

Performance records of reducers on movable bridges indicate they have very long service lives. It is not unusual for speed reducers on movable bridges to provide trouble free operation for more than 50 years. Enclosed gearing is more prevalent in newer designs and at present Reference 6 states that speed reducers should be used in preference to open gearing for new movable bridge designs.

2.8.2.2.1 Parallel Shaft Reducers

The majority of speed reducers used on movable bridges are parallel shaft types where the input, output and intermediate shafts are parallel. Most of the primary reduction units in the span drive systems on all types of movable bridges are parallel shaft units. Parallel shaft units are also frequently used in the other drive systems that actuate span locks, wedges, and centering latches.

Figure 2.8.2.2.1-1 illustrates a triple reduction, parallel shaft reducer with the casing top removed. Notice the pinions and gears are helical, not spur gears as discussed in the open gearing section. Helical gears operate more smoothly, are quieter, and have greater load capacity than spur gears for the same face width. Since helical gear teeth are positioned at an angle to the shaft centerline, an axial or thrust load is present in each gear and pinion during operation. In the case of the unit pictured, the axial loads are cancelled out since it is a balanced design. That is, the two pinions or gears on each shaft have opposed helices that produce equal and opposite axial loads that cancel one another. This reducer also has a unique type double helical gear, known as a herringbone gear, in the final reduction set. In this design the output shafts are fixed, or restricted in their axial movement, by the shaft support bearings. The other shafts are designed to permit axial float through the bearings sufficient to allow correct axial alignment of the gear sets.

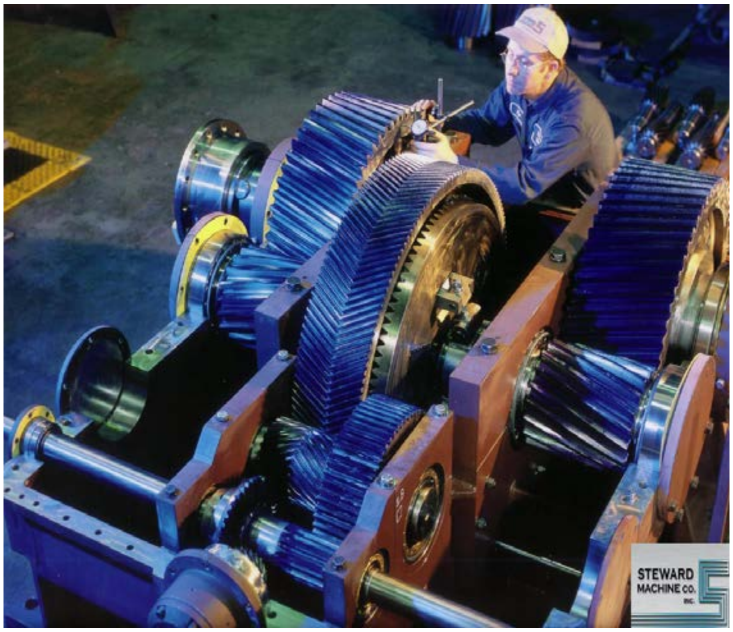


Figure 2.8.2.2.1-1 – Balanced helical/herringbone gear, parallel shaft speed reducer with a differential

Parallel shaft, helical gear reducers are not always a balanced design, but can have offset pinions and gears so that each shaft must be located axially and must also be fitted with bearings capable of supporting the applied radial and thrust loads. Figure 2.8.2.2.1-2 shows a cross section of such a unit used in the span lock drive system of a vertical-lift bridge. Inspectors should be alert to the possibility of wear causing longitudinal movement of shafts and gear misalignment in this type of reducer.

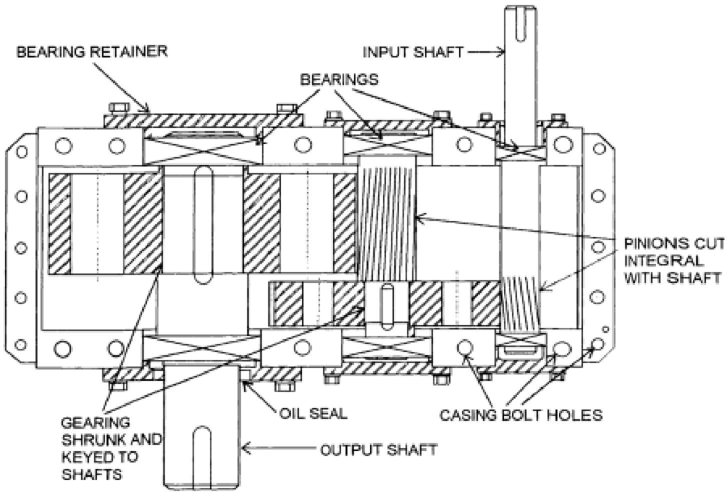


Figure 2.8.2.2.1-2 – Offset helical gear parallel shaft speed reducer

2.8.2.2.2 Right-angle Reducers

Right angle reducers are usually either spiral-bevel or wormgear units, and are used where power must be transmitted at a right angle from the input to output shaft.

Spiral-bevel gears are bevel gears that have a lengthwise curvature, or spiral, to their teeth that is constructed at an angle with the axis of the gear. Their appearance is similar to that of a helical bevel gear. In spiral-bevel units when more than one reduction is required, the first reduction is usually a spiral-bevel set and subsequent reductions are designed as helical gears. The reducer shown in Figure 2.8.2.2.2-1 is a double reduction unit.

All the reducers listed above have relatively low reduction ratios in each individual gear set. Therefore, large overall ratios are designed by using multiple reductions: double, triple, or quadruple, since the overall reduction is the mathematical product of all of the individual reductions. At times, however, it is desirable to transmit power at a right angle through a single, large reduction ratio. Wormgears are used in such applications. The wedge drive systems on some swing spans are one example. Wormgears provide a high ratio in a relatively compact space, but they are very inefficient due to the sliding friction between the worm and wormwheel. Figure 2.8.2.2.2-1 pictures a wormgear reducer with the casing top and worm inspection cover removed. Inspectors should be alert to the possibility of rapid tooth wear in such reducers if proper lubrication is not carefully maintained.

C2.8.2.2.2

Some manufacturers do provide high reduction ratio wormgears (up to 100:1). In addition, designs of wormgears with high efficiencies also exist.

Figure 2.8.2.2.2-1 – Spiral bevel/helical gear, right angle speed reducer

2.8.2.2.3 Differential Reducers

Frequently it is necessary to design for an even distribution of loading between multiple final drive pinions in the bridge span drive system; for example, bascule and swing span bridges that have two pinion drives on each movable leaf. While the required load sharing can also be accommodated electrically it is more typically accomplished mechanically on existing bridges by use of a differential, or equalizer, in the gear drive train. Usually the differential is included in the primary reducer. A cross sectional view of a typical, herringbone-bevel gear type differential is shown in Figure 2.8.2.2.3-1 and a close-up of the herringbone gear is pictured in Figure 2.8.2.2.3-2.

Briefly, the herringbone gear has a carrier attached to its inside rim. Several bevel pinions, usually three, are mounted equally spaced around the carrier, with their axes pointed toward the center of the herringbone gear. Two bevel gears, one mounted on each output shaft, engage the bevel pinions. The output shafts are accurately mounted so their axes are coincidental and one is piloted in the other with a sliding fit. As the herringbone gear rotates, the bevel pinions on the carrier rotate with it, driving the two bevel gears. As long as the load on both bevel gears is equal (that is, the same loading exists on both sides of the bevel pinions) the bevel pinions do not rotate on their shafts. But if the load is greater on one output than the other, unequal loading will occur on the bevel pinions and they will rotate. As this happens, the bevel gear with the lighter load will turn faster until the loading equalizes on both shafts. It can be seen that if one shaft were locked, the other would rotate at twice the rotational speed of the herringbone gear.

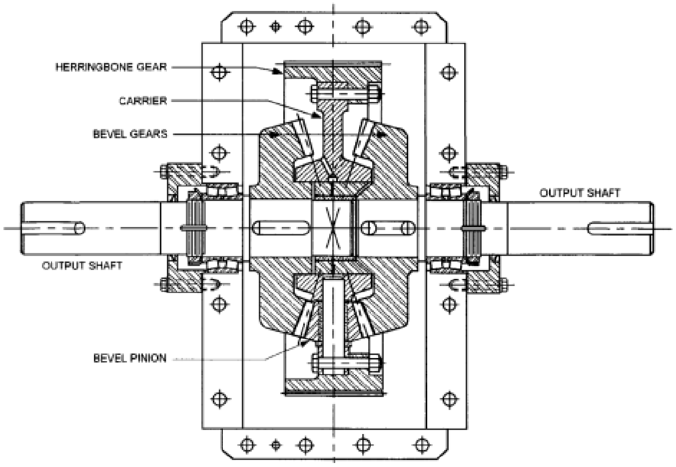


Figure 2.8.2.2.3-1 – Cross-sectional view of bevel gear type differential

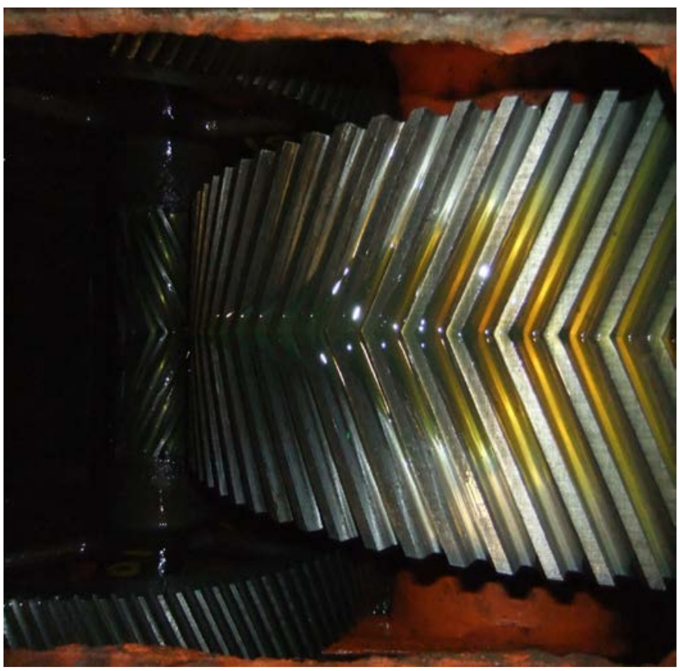


Figure 2.8.2.2.3-2 – Close-up of herringbone type gear

2.8.2.2.4 Inspection

Reducer inspection is a three-step procedure: first, examine the exterior of the reducer; second, make auditory and visual observations of the reducer during operation; and third, remove the inspection cover and inspect the interior.

C2.8.2.2.4

Caution: Before opening a sealed reduction unit to inspect the internal parts, be certain the bridge operator clearly understands that the machinery is not to be operated until sufficient notice is given the inspection team and he receives a positive response that it is okay to proceed with operation. If possible, inspectors should mechanically lock out power or the controls to prevent operation and possible accidents.

2.8.2.2.4.1 External Inspection

During routine inspections:

- Carefully check the structural supports on which the reducer is mounted. If it is situated directly on the pier, assess the condition of the surrounding concrete. If it is mounted on structural steel or a steel machinery platform, examine the support members for corrosion and indications of stress.
- Inspect each of the foundation and mounting bolts for rust, corrosion, fit of the shaft to the hole, and tightness.
- Clean and examine the reducer mounting feet and flange fillets for any signs of distress, corrosion, or cracking.
- Check all flange bolts holding the housing halves together, as well as seal carrier and bearing cover plate bolts for tightness. No oil or other lubricant should be seeping from inside the housing through the flange joint or contact surfaces of the seal and cover plates.
- Make certain the shaft seals are tight and that they are not leaking excessively or dry and wearing rapidly. Also check that no seals are dislodged or distorted.
- Remove the breather and examine the condition of the filter element (often this looks like steel wool). If it is clogged, it should be reported in a deficiency report to be cleaned or replaced.
- If the reducer is equipped with sleeve bearings, determine the bearing clearances.

2.8.2.2.4.2 Operational Inspection

During routine inspections, observe, feel, and listen to the reducer at close range. Listen for unusual noises and feel for vibration through several complete operational cycles.

- Observe the entire unit, particularly as the span starts to raise and again as it is seating, to see if there is any small movement of the unit during starting and stopping of the span. If the anchor or turned bolts are not secure, the unit

may move slightly when torque is increased or reduced during acceleration or deceleration of the span.
- Look for any radial or axial movement of the input and output shafts relative to their bearings.
- Listen carefully for any abnormal noises. A correctly functioning reducer should run quietly. Noises can indicate a problem. Unusual metallic sounds, a whine, clunks, screeches, or hard knocks indicate some part is worn, deformed, out of position, and/or not properly lubricated. If possible, check the operational noises with a decibel sound meter. Periodic checks will reveal any changes in noise level and alert the inspector to possible problems.

2.8.2.2.4.3 Internal Inspection

During in-depth inspections:
- Remove the inspection cover and visually observe the gear teeth with a flashlight for pitting, abrasive wear, plastic flow, breakage and/or corrosion.
- See if all the gears are well lubricated.
- Wipe the lubricant off several pinion and gear teeth with a rag and feel them with bare fingers for any surface roughness or finning due to metal removal. (**Caution:** Worn teeth can have burrs or wire edges that are sharp. *Look* and then feel gently to avoid injury.)
- Inspect the inside surfaces of the housing, using a flashlight or flood lamp, for corrosion or other signs of debris accumulation. Corrosion is more likely above the internal oil level, but is also possible below the oil level if the oil is contaminated.
- Determine the oil level by observing the oil level indicator. Carefully obtain a small sample of the reducer lubricant and examine it for the presence of contaminants, water, and metal particles. Inspectors should carry a small quantity of replacement oil to allow topping off the lubricant if necessary. Analysis of the oil is covered in Chapter 2.10.
- Check the level of lubricant and compare with that observed at the sight gauge. If they don't agree the indicating gauge may be clogged. Determine if water is present; if so, it will be beneath the oil or churned into the oil as an emulsion. If there is space and your arm is long enough, run your hand or an inspection tool (e.g., clean wooden dowel, furring strip, etc.) on the bottom of the housing to determine if there is a collection of sludge. If there is, examine it for foreign matter and metal particles. Presence of sludge is an indication that the unit has not been properly flushed and refilled with lubricating oil frequently enough. Such conditions should be rated "poor" or "severe" depending on the degree of corrosion present, and a critical deficiency report should be filed.

C2.8.2.2.4.3

Caution: Before opening a sealed reduction unit to inspect the internal parts, be certain the bridge operators clearly understand that the machinery is not to be operated until sufficient notice is given the inspection team and they receive a positive response that it is okay to proceed with operation. If possible, inspectors should mechanically lock out power or the controls to prevent operation and possible accidents.

Prior planning is the key element in the successful performance of internal inspection of enclosed reducers. Locking out the drive will only be possible during certain times. Replacement bolts, gaskets, and other parts that may be damaged during disassembly or reassembly should be available if needed and appropriate skilled personnel, tools, and equipment should be on hand to perform required tasks.

In some circumstances, the movable span is not properly balanced or is normally left in the open position. The normal lock down operation of such bridges may leave the gears stressed, with all backlash removed. This situation makes opening the enclosed gear reducer potentially hazardous. Release of the locked down gear sets (possible traffic interruptions might be required), or mechanically chaining the span down to stop movement may be required in such cases to avoid accidents when the reducer is opened.

- If the reducer has a circulating oil pump, verify that oil has been flowing to each point requiring lubrication through the distribution pipes or tubes.
- Replace the inspection cover. Inspection covers are usually sealed with a gasket and a nonhardening sealant. When the cover is removed, the gasket may be damaged and require replacement and new sealant will be required in any case. The gasket is necessary to prevent lubricant from leaking around the inspection cover during normal operation. Inspection crews should carry replacement gaskets and approved sealant to allow proper reinstallation of the cover. Inspectors should observe the cover replacement seal after several operational cycles for lubricant leakage.
- The gears inside a speed reducer are all precision manufactured to AGMA specifications. Manufacturers use specific individual tooth modification practices to supply a unit that will fill or exceed the operational requirements demanded by the bridge. These modification practices are proprietary and generally not available to the inspector. Accordingly, tooth measurements taken in the field would serve no useful purpose since there is no baseline data on which to evaluate wear. Thus, do not attempt to obtain chordal or span measurements. If tooth wear appears unusual or excessive, the report should direct the owner to contact the manufacturer for direction and assistance.

2.8.2.3—Bearings

Bearings are machinery components that provide the interface between rotating shafts and nonrotating shaft support parts. In most movable bridge applications, the shaft rotates while the support bearing and its housing remain stationary. All rotating members are supported, at some point, on a bearing or bearings. The function of the bearing is to support the applied loads, maintain alignment of the members, permit free rotation of the shaft or pin, and minimize frictional power losses.

The two types of bearings typically present on movable bridges are sleeve and anti-friction or rolling element bearings. Normally the bearing element—either sleeve, ball, or roller bearing—is installed in a housing. This may be inside a speed reducer casing, wheel hub, or crank arm, or a separate assembly known as a pillow block or flange unit. Figure 2.8.2.3-1 shows a shaft supported by a sleeve bearing pillow block.

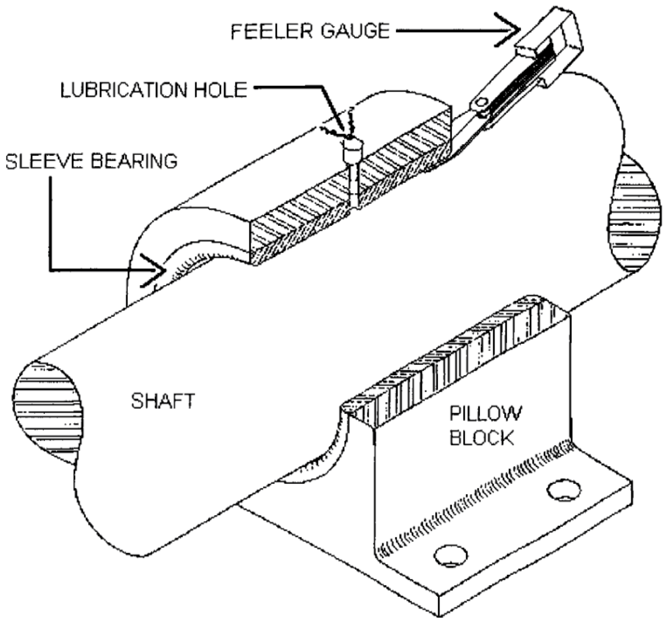


Figure 2.8.2.3-1 – A sleeve bearing pillow block supporting a transverse shaft

2.8.2.3.1 Sleeve Bearings

A sleeve bearing is a cylindrical metal sleeve that fits over its associated shaft, or journal, with a slight radial clearance. Sometimes sleeve bearings are called journal bearings and their housing, journal boxes. The sleeve bearing is held, or fixed, in the housing so that rotation occurs between the bearing inside diameter and shaft surface. The clearance between the shaft outside diameter and sleeve inside diameter is called the radial, or running, clearance and is designed to provide space for lubricant between the two rubbing surfaces.

In most cases, the material of the sleeve bearing was designed to be softer than the shaft material. Typical bearing materials are babbitt, bronze, and sintered metals. Babbitt was used almost exclusively on many older bridges, those built up through the 1930s, when bronze tubes became more available and bronze bearings were more economical to manufacture. Usually the bearing housings were all special and custom made for the application. Recently, however, commercially manufactured standard bronze sleeve bearing units are being used. The preferred material for housings is cast steel, although in some lightly loaded applications, such as support bearings for drive shafts to rotary switches, cast iron may be used.

Often split bearings were used to facilitate assembly in locations where the bearing is positioned between a gear and coupling, or other member, that makes installation and removal difficult. These split units have the same elements as a one piece housing unit except the sleeve bearing and housing are split along the longitudinal center line, as shown in Figure 2.8.2.3.1-1.

C2.8.2.3.1

Clearance on split sleeve bearings is typically accomplished by use of shims. If the bearings are opened, inspectors should exercise care not to misplace or damage the shims and also to match mark shim locations to provide for proper reassembly.

Sleeve bearings must be capable of supporting both radial and axial, or thrust, loads. Figure 2.8.2.3.1-2 shows that radial loads are carried by the cylindrical portion of the bearing and the flanges restrict axial movement of the shaft and resist any thrust loads.

Radial clearance is important in a sleeve bearing. There must be sufficient clearance to provide space to accommodate the lubricant but not so much that the shaft is permitted excessive radial movement. The proper amount varies according to the bearing inside diameter and is usually specified as an RC-6 Fit in accordance with ANSI B4.1, *Preferred Limits for Cylindrical Parts*, although sometimes the original design clearance is specified on the detail drawings. If neither the ANSI specification nor the original drawings are available, suggested clearances of 0.001 in. (0.0254 mm) to 0.002 in. (0.0508 mm) per in. (25.4 mm) of shaft diameter may be taken as an acceptable assumption. Thus for a 4 ½ in. (114.3 mm) ID sleeve bearing, a running clearance between 0.005 in. to 0.009 in. (0.127 mm to 0.229 mm) would be suitable.

In general, bearings which are not subject to load reversal in the shafts they support are able to continue to operate safely with higher bearing clearance because bearing "slap" during reversals is not a consideration.

Sleeve bearings may be lubricated with either oil or grease. Generally speaking, bearings in enclosed housings and designed to operate at higher speeds are oil lubricated, while those in solid or split housings designed to work at lower speeds (possibly not even making a full revolution) are grease lubricated. Examples of oil lubrication are inside speed reducers or electric motors. Grease lubrication examples are transverse and longitudinal span drive shaft support bearings, or crank and lever bearings on wedge drive systems. In most cases, the housings will be equipped with grease fittings or oil cups for replenishing the lubricant. Occasionally, the lubricant is introduced through drilled openings in the shaft and fittings will be located on the shaft's end.

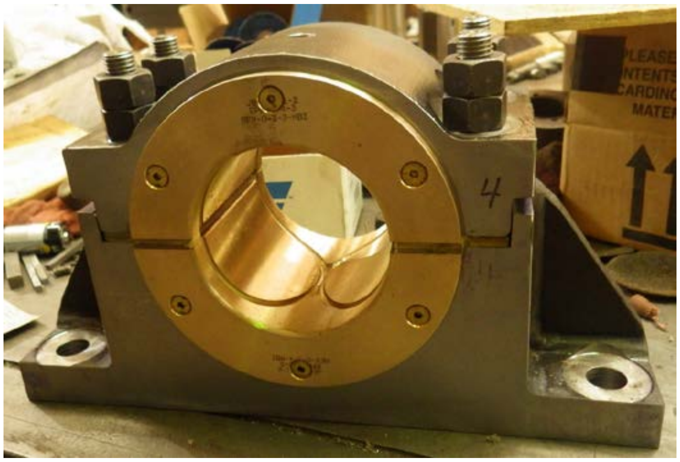


Figure 2.8.2.3.1-1 – A split pillow block (Image Credit: Steward Machine Company)

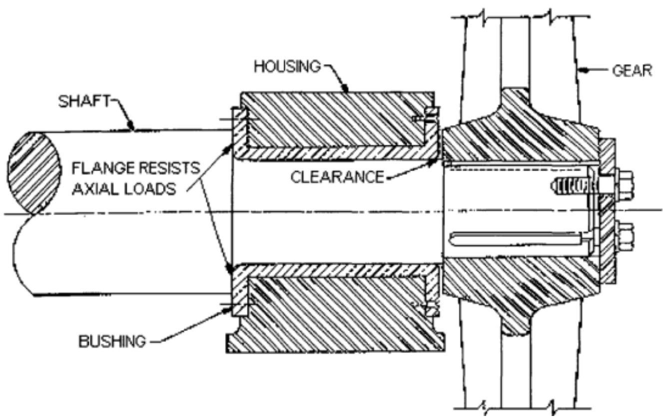


Figure 2.8.2.3.1-2 – Flanges on a sleeve bearing may support axial loads and locate the shaft

2.8.2.3.1.1 Inspection

Before inspecting sleeve bearing units, observe and record the ambient conditions: the presence of dirt, corrosion, foreign material, and excess lubricant. During routine inspections, clean the exterior of the unit and adjacent areas of the shaft and proceed as follows:

- Examine the bearing support for signs of distress or cracking and check all foundation or mounting bolts and nuts.
- Clean and check the entire housing exterior for cracks and/or corrosion and note general overall condition. Make certain the cap bolts and nuts are secure and not deteriorated, cracked, or loose. Observe the lubrication fittings to make certain they are in place and function properly, as in Figure 2.8.2.3.1.1-1. Inspect the fillet areas, in-depth, between the feet and body of pillow blocks and between the flanges and body of flange units, for cracks. At

C2.8.2.3.1.1

See Sections 2.2 and 2.3 for discussion of inspection frequency and required level of effort for routine and in-depth inspections.

Two methods may be used to determine bearing clearances.

Feeler gauges may be used without disassembly. This method would be used during routine inspections on split sleeves and in all cases on solid sleeve bearings.

Disassembly and direct measurement of the ID of the sleeve and the shaft on split sleeve bearings allows accurate measurement with a vernier caliper or micrometer and also permits inspection of the condition of the shaft and sleeve bearing for scoring and damage. This type of times these cracks will be readily visible to the naked eye; however, suspect areas should be checked with dye penetrant, as in Figure 2.8.2.3.1.1-2.

- Examine the bearing sleeve to assure it is not cracked and that it is properly secured in the housing. Inspect the ends and/or flanges for signs of scoring or severe wear. Also carefully look at the shaft as it emerges from the bearing for evidence of wear.
- Determine the existing clearance between the bearing and shaft using feeler gages as shown in Figure 2.8.2.3.1.1-3. Record this clearance and compare it to the original running clearance and to clearances reported from previous inspections (if available) or to nominal values given above. The difference in the two is the amount of wear. In most cases the maximum wear will not be at the top of the bearing, so it will be necessary to move the feelers around the circumference of the shaft to locate the point having the greatest clearance. This maximum radial clearance location should be noted in the report. Additionally, if possible, the location and amount of maximum clearance should be measured at both ends of the bearing, this will assist in determining and evaluating the presence of misalignment or uneven wear in other components such as gear sets, as shown in Figure 2.8.2.3.1.1-4 (A) and (B).
- Feel the bearing housing during and upon completion of an operating cycle to determine if it is overheating. When the shaft has stopped rotating, feel it immediately adjacent to the bearing. If the shaft or bearing feels excessively hot it is best to measure its operating temperature using a surface pyrometer or other temperature gauge.

During in-depth inspections, if the span can be closed to the passage of marine traffic for a sufficient period of time, remove the bearing caps and visually inspect the shaft and bushing surfaces for adequate lubrication and the presence of abrasive or corrosive materials. Clean any loose dirt or foreign material off the shaft and bearing surfaces and make certain the lubrication distribution grooves and passages are open and free of any obstructions before replacing the cap. Note: caution should be exercised when removing bearing caps to insure the shafts do not move, gears disengage or other components be disturbed. Only one bearing cap should be removed at a time and it should be completely reinstalled before opening up another bearing.

inspection will, in some cases, be part of an in-depth inspection. Under no circumstances should such disassembly be undertaken without thorough planning by experienced personnel. Breakage of one irreplaceable special order turned connection bolt can result in a long unacceptable period of movable span down time while waiting for the replacement part.

Bearings should not be disassembled on “locked down” stressed transmission shafting. It is also advisable to support the ends of a swing span before disassembling bearings on end jack mechanisms.

Figure 2.8.2.3.1.1-1 – Corroded pillow block

Figure 2.8.2.3.1.1-2 – Pillow block with complete failure in the fillet area

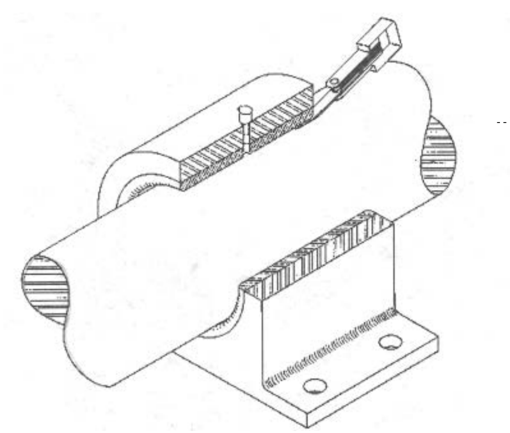


Figure 2.8.2.3.1.1-3 – Measuring internal clearance in a sleeve bearing with feeler gauges

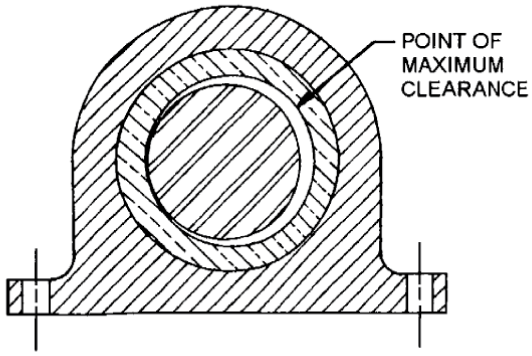


Figure 2.8.2.3.1.1-4A – Maximum clearance is not always at the top of the shaft

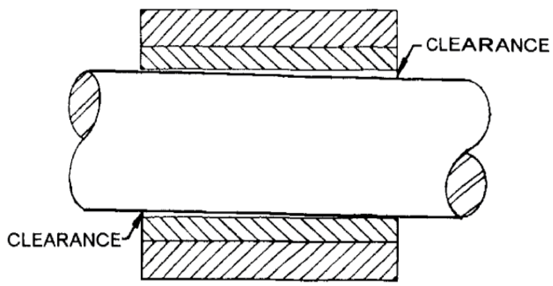


Figure 2.8.2.3.1.1-4B – Checking both ends of the bearing will help in revealing shaft misalignment

2.8.2.3.2 Anti-friction Bearings

Many newer bridges were designed with ball and roller bearing units. These commercially available assemblies are generally self-aligning bearings in sealed housings and require little maintenance other than periodic lubrication. While most applications on the span drive and span locking systems require heavy duty roller bearings, as seen in Figure 2.8.2.3.2-1, lightly loaded applications on electrical control devices, etc., can be satisfied with ball bearing units, as shown in Figure 2.8.2.3.2-2.

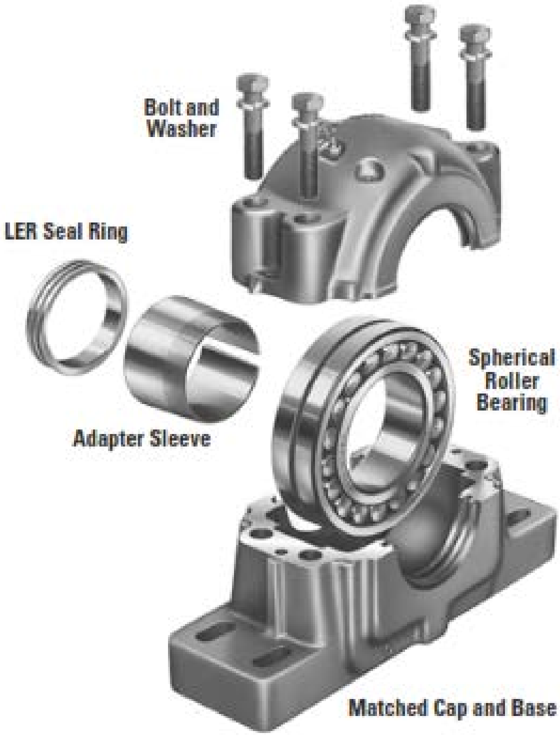


Figure 2.8.2.3.2-1 – A roller bearing pillow block with its bearing cap removed (Image Credit: Torrington)

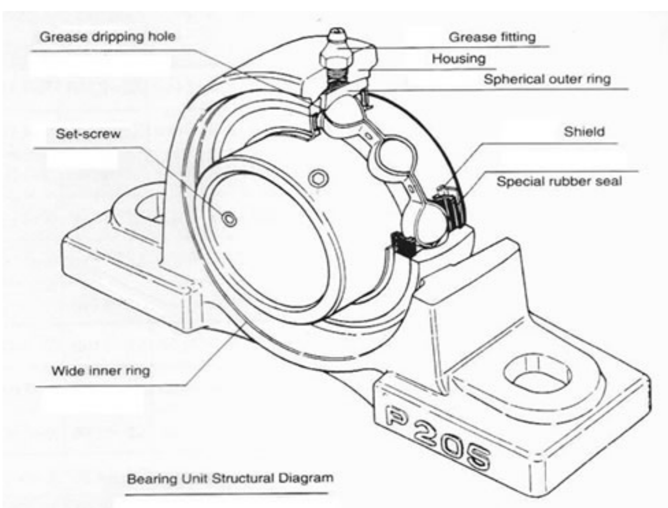


Figure 2.8.2.3.2-2 – A ball bearing pillow block (Image Credit: Sup Bearing)

For the loads and speeds encountered on movable bridges, ball and roller bearings are almost always grease lubricated. An exception to this could be the bearings in enclosed speed reducers that are frequently lubricated with the same oil used for the gears. The housings are equipped with fittings for the purpose of adding lubricant. There should not be an excessive amount of lubricant accumulated around the seals or housing. If there is, the bearing is being over lubricated, which could cause failure or rupture of the seals.

Similar to sleeve bearings, anti-friction bearings may have one piece or split housings and are capable of carrying radial, thrust, or combined loading. Very little wear occurs in anti-friction bearings since the races and rolling elements are made of very hard steel and the units are effectively sealed to prevent the entry of foreign materials that would cause wear. Accordingly, internal clearance measurements are not generally taken by inspectors to determine the amount of wear.

Indications of potential problems or failure of anti-friction bearings are overheating, unusual noises, and shaft or bearing vibration. Some common contributing factors include too much or not enough lubricant; dirt, rust chips or foreign material in the bearing; a faulty ball or roller; seal failure; and loss of clearance or preloading.

2.8.2.3.2.1 Inspection

Before inspecting anti-friction bearing units observe and record the ambient conditions: the presence of dirt, corrosion, foreign material, and excess lubricant. During routine inspections, clean the exterior of the unit and adjacent areas of the shaft and proceed as follows:

- Examine the bearing support for signs of distress or cracking, and check all foundation or mounting bolts and nuts.
- Clean and check the entire housing exterior for cracks and corrosion and note its general overall condition. Make certain the cap bolts and nuts are secure and not deteriorated, cracked, or loose. Observe the lubrication fittings to make certain they are in place and function properly. Inspect the fillet areas, in-depth, between the feet and body of pillow blocks and between the flanges and body of flange units, for cracks. At times these cracks will be readily visible to the naked eye; however, suspect areas should be checked with dye penetrant.
- Feel the bearing housing during and upon completion of an operating cycle to determine if it is overheating. When the shaft has stopped rotating, feel it immediately adjacent to the bearing. If the shaft or bearing feels excessively hot, it is best to measure its operating temperature using a surface pyrometer or other temperature gauge.
- Anti-friction bearings normally run with little discernible noise. Listen to each bearing during operation for any unusual or loud noises. They could be a warning of distress and trouble.
- Carefully inspect the seals to see if they are in place, not damaged, and functioning properly.

- It is generally not a good practice to remove the caps of split housings on anti-friction bearings during the course of inspection since the risk is high that the bearing could be inadvertently damaged or foreign material could enter the bearing chamber. In cases where there are indications of internal bearing problems or grinding noises indicating potential failure, a deficiency report should be filed for corrective action by maintainers and consideration given to an in-depth disassembly and inspection effort.

2.8.2.3.3 Trunnion Bearings

Trunnion bearings are in service on many types of bascule and vertical-lift bridges and may be sleeve or anti-friction units. When used on the trunnion shafts of trunnion type bascules and the counterweight sheave shafts on vertical-lift bridges, the bearings are usually split sleeve type bearings with split pillow blocks, as shown in Figure 2.8.2.3.3-1. The shaft is fixed to the rotating element by a collar and rotates within the two fixed support bearings. A few installations have been fabricated with single sleeve bearings mounted in housings attached to the final rotating member (the bascule girder or the sheave) so that the trunnion shaft is stationary. The loads on these bearings are heavy since the one bearing supports the full dead load of the span and counterweight. Consequently, the trunnion shaft diameters for this type of design are large: anywhere from 10 in. to over 30 in. (254 mm to over 762 mm), depending upon the size of the bridge.

Older bascule and vertical-lift bridges have split type sleeve bearings on trunnion shafts. Many of the more recent installations have been equipped with anti-friction bearings, as seen in Figure 2.8.2.3.3-2.

Various heel trunnion bridges, Strauss and Page types for example, were designed to locate the bearing directly in the structure and normally used sleeve bearings in both the heel and counterweight trunnion locations, as seen in Figure 2.8.2.3.3-3.

Figure 2.8.2.3.3-1 – A bascule bridge split sleeve type trunnion bearing

Figure 2.8.2.3.3-2 – A large diameter roller bearing pillow block on a vertical-lift bridge

Figure 2.8.2.3.3-3 – Trunnion bearing on a Strauss heel trunnion bascule bridge

2.8.2.3.3.1 Inspection

While construction of these units is similar to the sleeve and antifriction types previously described, they are much larger in size and, in the case of vertical-lift bridge sheave shaft bearings, very special in design. It is recommended that routine audiovisual observations of the housing, fasteners, lubrication devices and sealing elements be conducted without disassembly during in-depth inspections, unless audiovisual inspection indicates that there may be "severe" problems that justify the effort, cost and risk of disassembling such large trunnion pillow blocks.

If suspect conditions are revealed and further investigations involving disassembly are required, disassembly should be undertaken only with the advice and assistance of a qualified engineer.

2.8.2.4—Shafts, Couplings, and Brakes

2.8.2.4.1 Shafts

Shafts transmit torque from one rotating part to another: from a coupling to a pinion, from one coupling to another coupling, or from a gear to a pinion mounted on a common shaft. As the shaft speeds are reduced, the magnitude of the torque increases and it is very important that the couplings, pinions, and gears do not slip. Therefore, couplings, pinions, and gears that are not an integral portion of the shaft are usually not only keyed to the shaft but also mounted with an interference, or shrink, fit.

In general, there are few problems with properly designed shafts. When problems do arise, cracking is the most usual defect. Normally cracking originates in an area of stress

C2.8.2.4.1

Inspectors should be knowledgeable of the different types of keys and their attachment. Set screws should be tight. Gib head keys can sometimes work themselves loose. Shaft collars may be required to hold some Gib head keys in place.

concentration, such as a keyway or shoulder where the shaft changes diameter, and propagates as the shaft continues in use. If a keyway ends at a shoulder, an especially high stress concentration can result and cracking is likely. Heavily corroded areas are also subject to cracking as well as surfaces that have deep tool marks or tears remaining from poorly controlled machining operations. Repeated, severe shock loads may also result in stresses high enough to induce cracking.

Shafts were usually conservatively designed and seldom fail when a crack first starts. However, fatigue related cracks are progressive. The cracks start very small and grow slowly at first and then more rapidly until failure occurs. This crack growth process may take many months, or even years, until a crack reaches a size that results in shaft failure, but each crack should be carefully monitored to determine crack propagation rate by direct measurement.

Permanent angular plastic distortion, or twisting, may occur when a shaft is subjected to heavy overloads. Plastic distortion is extremely rare on bridge shafting. Signs of twisting or any form of plastic deformation warrant a "poor" or "severe" condition rating, extra diligence in checking for cracks, and filing of a deficiency report recommending corrective action. A thorough visual examination can generally disclose any existing cracks, particularly if the shaft has been painted because the paint will separate along the strain lines.

2.8.2.4.1.1 Inspection

The importance of detecting a shaft crack early, before it progresses to the point of shaft failure, cannot be overemphasized. During a routine inspection, the inspector should clean and inspect shafts carefully. Inspectors should:

- Visually inspect any localized areas of high stress, such as shoulders or keyways, at close range. Suspect cracks should be further investigated using a nondestructive test method such as dye penetrant, magnetic particle or ultrasonic procedures (see Chapter 2.10).

The dye penetrant NDT method is a simple test that can be performed on shafting by a trained inspector using inexpensive materials that are readily available in kit form. Magnetic particle or ultrasonic inspections are more complicated, require specialized equipment, and should be performed by a trained technician during in-depth inspections (see Chapter 2.10).

- In some cases, the areas to be inspected are not readily accessible and inspection of them would require removing the bridge from service for an extended period of time. If cracks are suspected in such locations the inspector should recommend that further in-depth examination be scheduled as soon as possible. Nondestructive means, such as ultrasonic or radiographic inspections, are frequently used

C2.8.2.4.1.1

Nondestructive testing is discussed at length in Reference 8, Section 4. For the convenience of users of this Manual, portions of the data therein is reproduced in Chapter 2.10 of this Manual. The discussion in this portion of the text is limited to general recommendations specific to the inspection of the shafts, where cracking is a key problem requiring special attention.

to examine areas that are hidden from view. These methods should be performed only by experienced technicians using specialized equipment (see Chapter 2.10).

2.8.2.4.2 Couplings

Couplings are used to join shaft ends together for the purpose of transmitting rotary motion and/or torque from one shaft length to the next. A coupling may be rigid or flexible (self-aligning) or a combination of the two. Uses on bridges include ones that are required to transmit high torques at low speeds on the span drive system, connecting the rack pinion shafts to transverse shafts, for instance; moderate speed, low torque demands as on the motor shafts; and others that merely transmit rotary motion for the purpose registration and control, such as on electrical signal devices, span limit, and overspeed switches.

2.8.2.4.2.1 Rigid Couplings

On many older bridges rigid couplings with no flexible aligning capability were frequently used. Any misalignment caused deflection in the shafts and placed extra loads on the shafts, couplings and bearings. Typically a rigid coupling consists of two halves that are merely flanged steel hubs shrunk and keyed to the shaft ends being connected. The flanges are then bolted together, thereby joining the shafts. Occasionally a rigid coupling is a long one- or two-piece steel sleeve that fits over and is keyed to the ends of both shafts being joined.

There are no moving parts in a rigid coupling, no lubricant is required and wear is not a problem.

2.8.2.4.2.1.1 Inspection

During routine inspections:

- Visually inspect for corrosive deterioration or cracks.
- Check bolts on flanged couplings for condition and tightness.
- Inspect keys and keyways for tightness and cracking.

Note: Observe coupling during bridge operation. Include any coupling that shows excessive movement (wobbling) or unusual noise in a deficiency report to the proper authorities.

2.8.2.4.2.2 Flexible Couplings

No matter how carefully machinery is installed in the field, there is usually some misalignment—however slight—between the machinery components connected by the shafts. Flexible couplings permit some misalignment to exist between the shaft ends and can then still be properly coupled without introducing undue loading and stresses to the shafts, bearings, and couplings. Structural deflections and their effects on the machinery components during operation are also mitigated to a great extent with flexible couplings. The ability to accept misalignment, however, is minimal and shafts should still be aligned as closely as possible even when connected by flexible couplings. All flexible couplings should have clearance between the shaft ends. They are designed with hubs that are mounted on each shaft and a flexible means to connect the hubs together.

There are a great variety of flexible couplings available; however, the ones in the following descriptions are the types found most often on movable bridges. It is recommended the inspector review the manufacturer's literature in the operation and maintenance manuals to determine the type, construction, and lubrication requirements of the couplings to be inspected.

When the coupling is assembled, it should be thoroughly lubricated and it should be periodically relubricated during operation. While most gear couplings are grease lubricated, some require oil. The lubricant is retained and foreign material kept out of the chamber between the hub and sleeve with either a lip type or a labyrinth seal in the sleeve.

Gear couplings are rugged, high torque capacity units and are generally used for connecting all shafts after the motor shaft in the span drive system and the low speed shafts on the span lock system.

Often a flexible coupling half will be used together with a rigid half to create a flex/rigid connection. Such an arrangement is frequently found on floating shafts and their associated speed reducer output and rack pinion shafts on bascule bridges or longitudinal shafts on swing spans and span drive vertical-lift bridges.

2.8.2.4.2.2.1 Gear Couplings

A gear coupling, as seen in Figure 2.8.2.4.2.2.1-1, consists of hubs shrunk and keyed on each of the shafts. Gear teeth have been machined into the OD of each hub; they engage the internal teeth cut into the ID of the sleeves that fit over the hubs and are then bolted together. Since slight movement occurs between the gear teeth in the hub and the sleeve, lubricant is required.

Figure 2.8.2.4.2.2.1-1 – Gear coupling (Image Credit: Falk)

2.8.2.4.2.2.2 Grid Couplings

Figure 2.8.2.4.2.2.2-1 illustrates a grid coupling. Both hubs are shrunk on and keyed to their shafts. Notice the hub ODs have axial slots with a spring type grid inserted to join the hubs. The slots are bell-mouthed at the end adjacent to the mating hub to accommodate some misalignment. No load is carried by the flanged cover; all the load is transmitted by the grid.

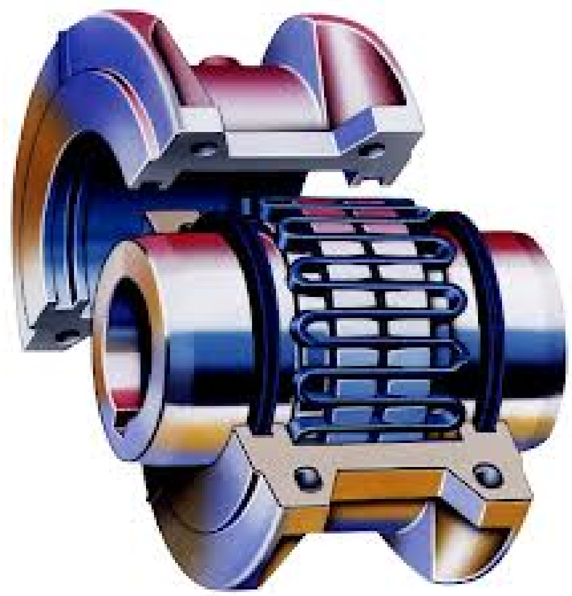


Figure 2.8.2.4.2.2.2-1 – Grid Coupling (Image Credit: Falk)

The sealed cover serves to restrain the grid from flying off due to centrifugal force as well as to retain the lubricant and protect the coupling interior from the entry of dirt, debris, and water. Some grid couplings have covers that are split longitudinally, parallel to the shaft center line.

Grid couplings are most often used to couple the motors to the high speed shafts in the span drive and span lock systems.

2.8.2.4.2.2.3 Chain Couplings

This coupling has hubs with sprockets cut into their ODs, mounted on each shaft end, as shown in Figure 2.8.2.4.2.2.3-1. The hubs are shrunk on and keyed to the shafts. A short, continuous length of double-width roller chain is located over the sprocket teeth; power is then transmitted from one hub to the other through the chain.

Some existing chain couplings do not have covers. It is desirable for them to have protective covers to retain the lubricant and guard the chains from dirt, debris, and moisture. The absence of covers should result in a “poor” condition rating and a recommendation for corrective action.

Chain couplings are used in applications less heavily loaded than those requiring gear couplings and are often present in hand drive units and span lock systems.

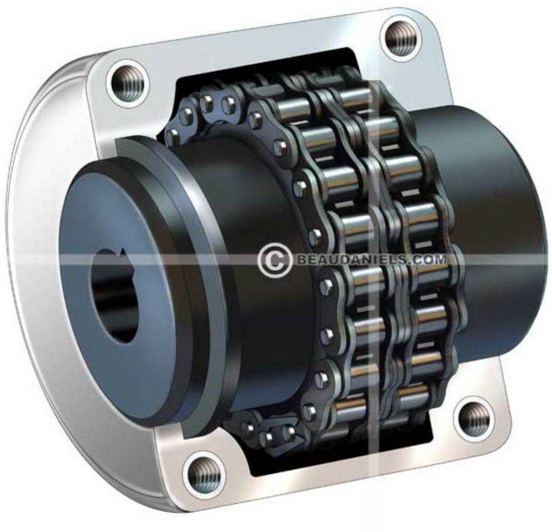


Figure 2.8.2.4.2.2.3-1 – Chain coupling (Image Credit: Beau Daniels)

2.8.2.4.2.2.4 Insert Couplings

A variety of small, light duty couplings are used on shafts of small diameter driving various electric control and signaling equipment. Figure 2.8.2.4.2.2.4-1 illustrates one type that is called an insert coupling.

The hub on each shaft end has protrusions, or fingers, on the end facing its associated hub. A nonmetallic or soft metal insert is positioned between the hubs and engages the finger extensions of both hubs, thus transmitting the rotation. The hubs normally have a sliding fit and are keyed to the shaft. A set screw forced against the key holds each hub in place.

This type of coupling is not capable of transmitting a significant amount of torque as its function is to transmit rotary motion on light components only.

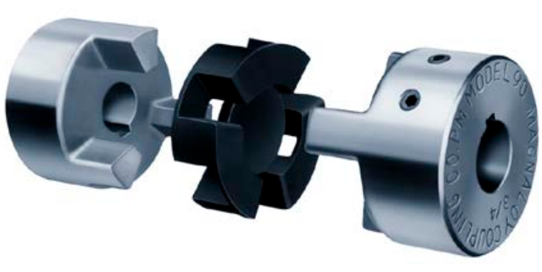


Figure 2.8.2.4.2.2.4-1 – Insert coupling (Image Credit: Magnaloy)

2.8.2.4.2.2.5 Jaw Type Couplings

Jaw type couplings usually consist of two jaw flanges that mesh to connect the shafts. Jaw couplings do not typically require lubrication when in use, but may require lubrication when they are used as clutches that are coupled and decoupled frequently.

Sometimes jaw type couplings are used as clutches for the emergency drive systems, and are used to couple the emergency drive to the gear drive. Figure 2.8.2.4.2.2.5-1 shows a jaw type coupling used as a clutch (shown engaged).

Figure 2.8.2.4.2.2.5-1 – A jaw type coupling (shown engaged)

2.8.2.4.2.2.6 Inspection of Flexible Couplings

During routine inspections:

- Carefully inspect the exterior of the coupling and all seals and gaskets. There should be no lubricant seeping through the mating surfaces of the coupling sleeves of either flange or longitudinally split types.
- Check all flange bolts for tightness and condition. This is important on all couplings but critical on gear types, since the bolts are transmitting the torque and any failure could put the bridge out of service.
- Visually inspect the keys and keyways for any signs of movement or cracking. If there are any indications of cracks, investigate further using dye penetrant.
- On small insert type couplings, make certain they are functional and not so deteriorated they cannot transmit rotary motion. Check the set screws for tightness and confirm that they are not loose on their shaft.
- Visually inspect jaw type couplings for corrosive deterioration or cracks in lugs. Inspect keyways for tightness and cracks.

- When jaw type couplings are used as clutches, make certain that they are adequately lubricated and can be engaged and disengaged as necessary.

Figure 2.8.2.4.2.2.6-1 – Interior of a well-lubricated grid coupling; note broken grids

If the bridge can be removed from service for a short period during in-depth inspections, remove the coupling covers and/or sleeves. Look to see if the unit is properly lubricated and check the lubricant for contamination, foreign material, and other causes of wear. Examine the interior for corrosion and any excess wear or breakage of teeth, grids, or roller chain, as in Figure 2.8.2.4.2.2.6-1. Visually inspect all mating parts. It is difficult to obtain detailed dimensional information about the interior construction from coupling manufacturers and it may be necessary for the inspector to make judgments regarding wear by observation alone. The line of contact on the internal teeth of a gear coupling sleeve does not extend across the full width of the teeth since they are wider than the teeth on the hub. To obtain some idea as to tooth wear, compare the thickness in a worn area to that in an area where no contact has been made, usually at the ends. In a grid coupling, the width of the slots at the narrow end is very close to the original thickness of the grid. If the slots are much wider than the grid at that end, the coupling is worn. On a new chain coupling, the sprocket teeth have nearly the same radius as the rollers on the roller chain. A large tooth radius indicates substantial wear, as seen in Figure 2.8.2.4.2.2.6-2.

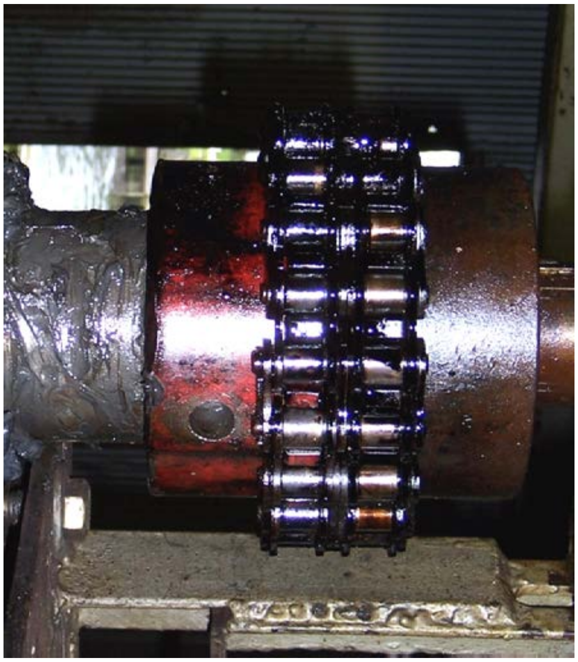


Figure 2.8.2.4.2.2.6-2 – Chain coupling in service without a protective cover

2.8.2.4.3 Brakes

Brakes combine both mechanical and electrical features so both mechnical and electrical inspections are required. A detailed description of brakes and how they function can be found in Chapter 2.8.3.5 and will not be repeated here. The mechanical inspection of brakes is described below and the electrical inspection is described in Chapter 2.8.3.5.4.

Clearances can be checked only when the brake is released. Since most brakes have sheet metal covers that are easy to remove and replace, they should be opened for all inspections. The brake is typically correctly adjusted when the two shoes have equal clearance between the face of the drum and the brake shoes. Normal clearances specified by the brake manufacturer are usually $^{1}/_{8}$ in. (3 mm) or less. To check clearances, energize the brake to release the shoes. Clearances can be determined with feeler gauges. The final determining factors for proper brake adjustment are the applied brake torque when the brake is set and the elapsed time from brake application to full torque (which affects deceleration torque applied to drive machinery). Original design specifications for the span drive machinery should contain data concerning span drive machinery motor acceleration and braking deceleration times which can be verified in the field.

During the routine inspection, check for any portion of the brake shoe surface that is in contact with the brake drum barrel that could cause heating during operation. The shoes should be equally spaced on each side of the drum. If the brake is not centered on the brake drum, proper clearance cannot be obtained.

If a brake shoe rubs on the drum, the brake lining will overheat and develop a glaze on its surface. If this condition is severe, the shoe will overheat and smoke during use. If burning and smoking occur, the shoes should be replaced and the brake shoe clearance adjusted.

Brake shoe wear is an important part of any brake inspection. If shoes are allowed to wear down to the point where the rivets touch the drum, the drum can be damaged and require resurfacing.

Routine inspection includes a visual evaluation of the brake. The drum surface should be clean and smooth. Check for wear or grooves caused by rivet contact on the face. A rusted surface on the drum is an indication that the brake has not been working. Mechanical problems in the mechanism may keep the brake from operating, or the shoes may not be properly adjusted. Verify that the brake wheels are free of oil, water, and dirt.

In-depth inspection should include measurement and recording of the torque settings of all motor and machinery brakes.

2.8.2.5—Buffer Cylinders

Buffer cylinders are used most frequently on bascule and vertical-lift bridges and occasionally on swing spans. Their purpose is to assist in a controlled seating of the span and the elimination of shock loads during closing. Usually buffers are large pneumatic cylinders, although at times hydraulic devices have been used. Typically the cylinder contains a movable piston attached to a piston rod that extends beyond the cylinder body, as shown in Figure 2.8.2.5-1.

On bascule and vertical-lift bridges, they are normally mounted vertically on the movable span. As the span opens, the piston descends and air is drawn into the cylinder through a check valve and filter. During closing, as the leaf descends, the end of the extended piston rod contacts a strike plate on the pier and forces the piston into the cylinder, thereby compressing the air. As the intake port is equipped with a check valve, the compressed air can escape only through the control valve on the outlet port. In this way, controlled air pressure absorbs the shock loads during closing and aids in seating the span softly. Air leakage around the piston is minimal since it is equipped with piston rings conforming to the cylinder ID. The piston rod is guided by a bushing, or sleeve bearing, mounted in the center of the lower cylinder cover.

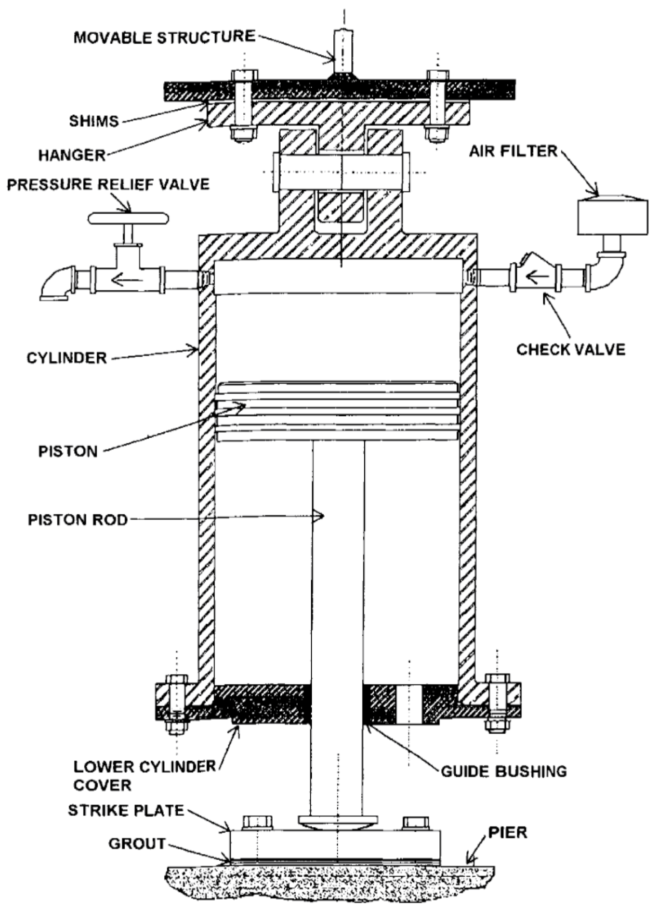


Figure 2.8.2.5-1 – Construction of a typical buffer cylinder

A few bascule bridges have the buffer cylinders mounted in the counterweight pit and are engaged by the counterweight as the span closes; also, some vertical-lift bridges have them mounted on the tower legs, the counterweight, or both to assist during opening and closing of the span.

Horizontally mounted buffers have been used on a few swing spans that open in only one direction. The design of these has to include a means, usually a spring, to cause the piston rod to extend as the span opens since the force of gravity will not do it. A typical design is shown in Figure 2.8.2.5-2.

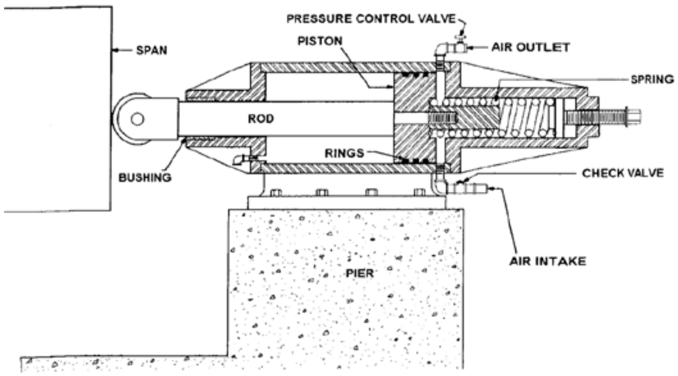


Figure 2.8.2.5-2 – Section of a horizontal buffer

2.8.2.5.1 Inspection

During routine inspections:

- Watch the buffers in operation during cycling of the leaf. The piston rod should withdraw smoothly to the fully extended position as the leaf opens. If it does not, it could indicate the inside of the cylinder is not properly lubricated, the guide bushing is binding the piston rod or is not lubricated, there is foreign material and/or wear that is causing the piston to hang up, the check valve is not permitting air to flow into the cylinder, or, in the case of horizontal buffers, the spring may be broken.
- When the leaf is closing, the piston rod should contact the strike plate somewhere near its center, as shown in Figure 2.8.2.5.1-1. As the piston is forced into the cylinder, air should escape only through the control valve on the outlet pipe. No air should escape through the inlet; if it does, the check valve is not functioning properly. This is important because if the inlet valve is faulty, the cylinder may appear to be working properly but will not be building up any pressure; hence, no retarding force is being generated and shock loading may, of course, result. Note that bridges with modern control systems may not require buffers.
- Check the air filter on the inlet pipe for cleanliness.
- Inspect the piston rod for scoring, rust, and lubrication. If it is rusty and has no lubricant coating, the bushing is probably not being properly lubricated. Scoring of the rod can indicate bushing wear or the presence of grit, metal particles, or both in the lubricant.

Figure 2.8.2.5.1-1 – Buffer cylinder and piston rod; note that the buffer is heavily corroded and not functional

- Observe the pressure built up during operation by installing pressure gauges between the control valve and cylinder on the outlet side, or between the check valve and cylinder on the intake side. This observation should be done simultaneously on all buffers at the end of the leaf or span. Check to assure that the same amount of pressure is built up in each cylinder. One person at each buffer will be required to make and record these observations. If the pressures are not equal, adjust the pressure control valves until they are. On some bridges the buffers on each end of the leaf are piped together so that the pressure throughout the system is automatically equalized.

In either case, the pressure build up should be sufficient to cushion the span when closing but not so great that the span bounces after the piston rods hit the strike plates. If bouncing occurs, the pressure valve should be adjusted to relieve the pressure build up just enough to eliminate the bounce.

During an in-depth inspection:

- The internal parts of a buffer cylinder cannot be inspected unless the bridge is closed down for a period of time. If the buffer is not operating properly, the inspector can perform a quick, cursory check by taking the bridge out of service for a short period and removing the bottom cover plate with the leaf closed. Sometimes the plate may be lowered far enough to see inside the cylinder. **Caution:** Do not attempt to open the leaf with the cylinder cover removed. If the piston is withdrawn sufficiently to allow one or more of the piston rings to emerge, the rings will expand and prohibit reassembly without a compressing strap or other device to compress the rings. Also, with the bottom cover plate removed there is nothing to stop the piston assembly from dropping out of the cylinder and becoming damaged and/or causing an injury.

- If the cause of improper operation of a buffer cylinder cannot be determined without disassembly, it should be removed from the leaf and reconditioned in a shop.
- Measure and record air pressure and bushing clearance of air buffers. The values should be compared with original values and values stated in previous reports. Copies of the measurements should be provided in the report.

2.8.2.6—Live Load Shoes

Live load shoes are simple devices that perform a very important function when the movable leaf is in the closed position. They allow vertical positioning of the closed span and support the weight of traffic (the live load) passing across the bridge. While trunnion bascule and vertical-lift bridges usually have live load shoes, other means such as wedges or end lifts are often used on swing spans to support live loads. Rolling lift bascules do not usually require live load shoes since the live loads are supported by the track plates. Some trunnion bascules are designed without live load shoes.

A live load shoe consists of the shoe, mounted on the movable leaf, and a strike plate secured to the pier or another portion of the fixed structure as shown in Figure 2.8.2.6-1. Notice that the bottom of the shoe has a slight curvature that prevents edge contact due to slight misalignment or leaf deflection. The size of the shoe is determined by the magnitude of the live load to be supported. Accordingly, short span, two-lane bascules will have small live load shoes while large vertical-lift bridges and double-deck bascules will have larger, cast or fabricated shoes and strike plates or bases.

Regardless of their size, the shoes are typically mounted on the main girders and the strike plates on the piers so that they engage when the leaf is closed. They are properly adjusted when the shoes are in firm contact with the strike plates when the span is closed, locks driven, and brakes set. Correct adjustment of the live load shoes is obtained by the use of shims between the shoe and girder. Improper adjustment of live load shoes can transmit loads to machinery components and to structural components that significantly exceed their design loads, and can result in failure. Maladjusted live load shoes or wedges should be rated “poor” or “severe,” and a critical deficiency report should be filed.

C2.8.2.6

On trunnion and rolling lift bascule spans, live load shoes may be located channelward of the trunnion, center of roll at the bottom of the main span girders, or at the back of the counterweight on top of the main girders. In either case, live load shoes are typically found on both types of bridges. On Chicago type (simple trunnion) and some Strauss bascules (heel trunnion, overhead counterweight type), live load shoes are located both channelward and at the rear of the counterweight.

Live load shoe clearances, if any, are generally given in the design plans and should be verified. In the absence of plan information that indicates there should be a specific gap under dead load only, inspectors should assume that the presence of a gap requires further investigation by an evaluator as part of an engineering evaluation of the stress caused by the gap.

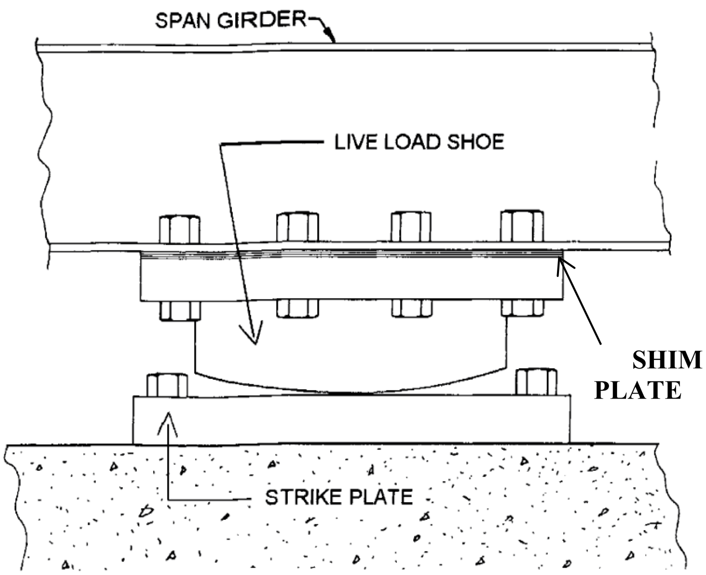


Figure 2.8.2.6-1 – Live load shoe and strike plate

2.8.2.6.1 Inspection

During routine inspections:

- See that all fasteners are tight and corrosion free.
- Inspect for any deterioration of the shims between the shoe and girder and the grout between the strike plate and pier.
- Check the surfaces of the shoe and plate for severe deformations or cracks.
- Make certain the shoes and strike plates are in firm contact when the leaf is closed and no traffic is on the bridge. Gaps that permit a significant amount of vertical motion under the passage of traffic are potentially hazardous due to overloads on other areas of the leaf structure and machinery.

2.8.2.7—Threaded Fasteners

Machinery components are usually secured to concrete and steel structures using various types of threaded fasteners. Those used when mounting to concrete are called anchor, or foundation, bolts and those for attaching to structural steel are high strength steel, turned bolts. Their function is to hold the machinery securely in place, and not let it work loose during operation permitting the parts to become misaligned and experience accelerated wear and possibly premature failure. It should be understood that as the rotational speed of shafts is decreased, torque, or force upon the equipment, increases proportionately. These tremendous loads are ultimately resisted by the fasteners; thus, their importance cannot be overemphasized. Any loose, deteriorated, or otherwise unsatisfactory fasteners can quickly allow the machinery to wear excessively or fail and put the leaf out of service.

2.8.2.7.1 Anchor Bolts

Anchor bolts are long threaded rods embedded in concrete with their threaded ends extending beyond the surface of the concrete. Machinery elements and supports are positioned over them, leveled, and bolted into place. Subsequently, grout is inserted in the remaining voids to prevent water and foreign materials from accumulating.

Sometimes the upper ends of the anchor bolts are encased in a pipe sleeve, also embedded in the concrete, as seen in Figure 2.8.2.7.1-1. This pipe should be filled with grout after aligning the machinery so water does not collect and promote bolt deterioration by corrosive action.

Since anchor bolts usually have a clearance fit with the bolt holes in the machinery, the only force that resists horizontal movement is friction between the machinery surfaces and the concrete. Therefore, it is essential that the nuts be securely tightened.

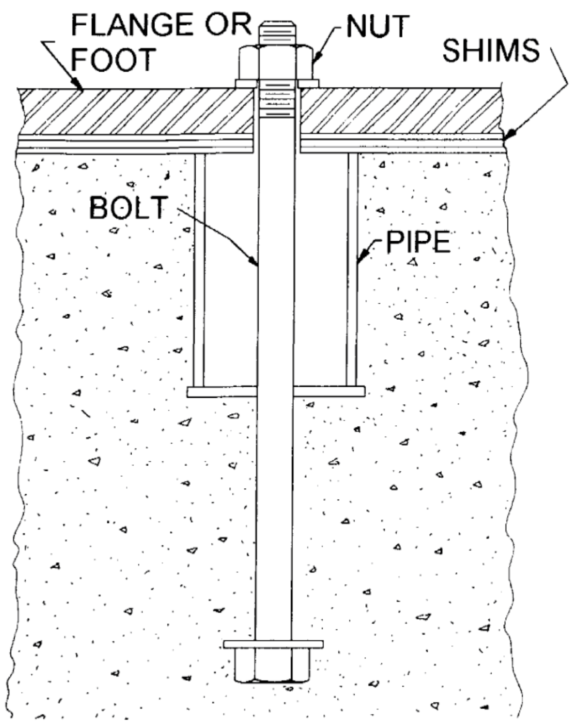


Figure 2.8.2.7.1-1 – Sleeved anchor bolt

2.8.2.7.2 Turned Bolts

Bolts with accurately machined bodies are known as turned bolts. In bridge work they are used when mounting machinery components to steel structures or supports. Generally, the finish drilling of the bolt holes is accomplished after positioning and aligning the machinery so that a very accurate fit is achieved between the bolt and bolt holes in both the machinery and steel supports. Correct positioning of the machinery base from the steel support surface is accomplished by use of shims that permit adjustment to within one-half the thickness of the thinnest shim, as shown in Figure 2.8.2.7.2-1.

Horizontal movement is resisted by the turned body of the bolt bearing against the sides of the bolt hole. Movement perpendicular to the support surface is stopped by the nut. Accordingly, it is necessary that the nut be correctly tightened when installed and that correct torque be maintained at all times.

C2.8.2.7.2

Turned bolts should have tight precision machined fit and clearance should be as per plans. The clearance is rarely more than a few thousandths of an inch. The threaded portion of the bolt should be well clear of any potential shear planes.

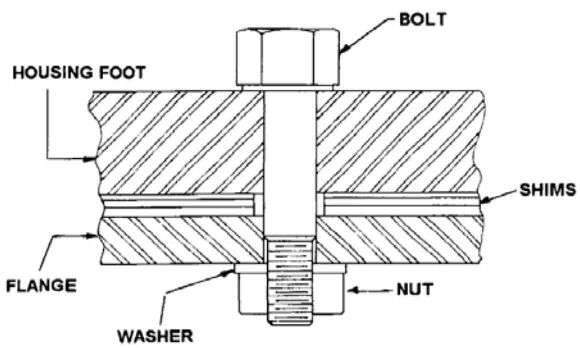


Figure 2.8.2.7.2-1 – Turned bolt

2.8.2.7.3 Inspection

During routine inspection, check the following:

- Carefully inspect fasteners for corrosion, as it is the worst enemy of bolts, especially anchor bolts.
- Check nuts for tightness. Bolts can become stretched from overloads or work loose from vibrations caused by traffic and leaf operation.
- Inspect the concrete around anchor bolts, particularly those embedded into pedestals, for any signs of cracking and spalling due to severe horizontal forces carried through the bolts.
- It is a good practice for the inspector to examine fasteners on a piece of machinery as a particular component is being inspected. It saves time and often will avoid the necessity of returning to the site later to finish an incomplete job.

During an in-depth inspection, an attempt should be made to perform the above checks on all machinery anchor bolts, and a significant sampling of other fasteners in fastener groups that contain a large number of fasteners.

2.8.2.8—Emergency and Manual Drives

2.8.2.8.1 Emergency Drive Engines

Gasoline or diesel engines are often used for emergency power on movable bridges. In addition, some owners utilize permanently mounted air drive or hydraulic motors, or may use air motors or electric tools to turn emergency “manual drives.” The engine may drive the machinery directly or be used in conjunction with a generator that supplies electric power to either the normal drive motors or smaller, auxiliary motors. All machinery operates in the usual manner, although almost always at a reduced speed.

2.8.2.8.2 Manual Drives

Most bridges have provision for hand operation when all power sources, the utilities and emergency generating equipment, fail. These hand drives are, in effect, hand cranks tied into the gear drive system. In most cases, it doesn't take a lot of force to turn the machinery, but it does take a long time to fully open or close the leaf, as seen in Figure 2.8.2.8.2-1.

Figure 2.8.2.8.2-1 – Manual drive on a swing bridge

2.8.2.8.3 Inspection

Emergency drives must deliver the same torque as the normal drive system, but as they are infrequently used wear is generally not a problem. Emergency drives, clutches and brakes are often found to be inoperative for many reasons: for example, heavy corrosion, overabundance of paint, lost cranks and other parts, or general abuse (see Figure 2.8.2.8.3-1).

The inspector should observe and report such neglect and be sure the emergency drive system is capable of satisfactory operation.

Due to the gear ratio needed to allow personnel to drive a span by **not** using a T-bar, capstan, or hand held tools; operation of the normal drive would present a potential hazard to workers near or holding the manual drive elements. On any manual drive, it is important that engaging the manual drive should automatically lock out the normal span drive.

- Check each emergency drive for proper operation. The bridge operator should know the location of hand cranks, chains, and other removable components of the system.
- Install them and confirm they fit.
- Engage and disengage all clutches and cutout couplings and make certain the system is capable of moving the leaf.
- Have the bridge operator start up the auxiliary engine and operate the bridge using emergency power. If the emergency system has recently been used, the inspector may review the associated operations log in lieu of performing an emergency test operation during the inspection.

C2.8.2.8.3

If specialized proprietary air, hydraulic, or unusual other types of emergency drive systems are present, inspectors should obtain specific manufacturer recommendations for inspection procedures. Hydraulic systems should be checked as per Chapter 2.8.2.12. Air-based systems operate similar to a hydraulic system, but leaks are somewhat more difficult to detect. The system can be operated and soap solutions used around fittings that are suspect. Formation of bubbles in the soap solution indicates an air leak. Pressure monitoring and other methods involving installation of pressure gauges as discussed for hydraulic systems in Chapter 2.8.2.12 also are effective.

Caution: Do not attempt any operation of the hand or emergency drive system without the absolute certainty the normal drive system cannot be activated. Usually there are electrical safety interlocks that preclude energizing the normal drive motors while the emergency drive is active. Confirm the safety devices are in working order before installing any cranks, chains, or other components of the hard drive.

Figure 2.8.2.8.3-1– Manual span brake, inoperable due to corrosion and excessive paint

2.8.2.8.4 Air Motors

There are two basic types of air motors that are readily available and that might be found on emergency drive systems of existing movable bridges.

Radial piston motors generally operate at low speeds and have more low speed torque than vane type motors. They are generally designed to operate in only one position (with the drive shaft horizontal). Piston motors up to 30 horsepower (22.37 kW) are available, running at speeds between 800 and 2,000 rpm.

Vane motors are smaller, simpler, and cost less than piston motors and can be operated in any position. Multi-vane motors up to 10 horsepower (7.46 kW) are available, generally running at speeds between 2,000 and 4,000 rpm.

Either type of motor may be built as reversible or nonreversible. Speed is generally controlled by an air throttle or “governor.” Most air motors are designed to function at an air pressure of 90 psi (621 kPa).

Reversible motors should be installed with valves that open in four directions to prevent blockage of the secondary exhaust port (which is opposite to the port being pressurized), if a permanent air piping system is used. It is possible to use quick connect fittings and hoses on emergency drives, if this is the case, some means of venting the offside exhaust port must be present. One of the most likely causes of power loss in an air motor is restriction of the intake or exhaust air flow.

Air motor construction, configuration, inspection, and maintenance are similar to hydraulic systems. The vane type and piston type construction is similar to the views shown for hydraulic motors and pumps of similar types. Air motors are lubricated by oil mixed with the air and may leak oil, air, or both.

2.8.2.8.4.1 Inspection

During routine inspection, check the following:

- Check mounting bolts, structural supports, and base castings for looseness and cracks.
- Check the function of the system through one full operating cycle and monitor system pressure; check for leaks and unusual sounds or behavior. Verify that the system runs at an appropriate speed without major speed variations and that valves, filters, regulators, and oiler assemblies are present and functional per the system plans. Lubricators should always be present and are generally installed at the inlet side of the motor. Since it is undesirable for oil laden air to exit freely to the environment, it is generally necessary for a two stage liquid separator filter to be present on the motor outlet side. On reversible motors,

these requirements lead to either duplicate lubricators and filters or a complex inlet/outlet piping configuration to run air in alternating directions through a single filter and lubricator.

- Check that hoses, fittings, valves, and piping are tight and free from deterioration that could lead to an air leak or a line failure during operation.

During in-depth inspections, disassembly by trained air motor mechanics may be appropriate to permit internal inspection if internal problems are believed to exist. If no evidence of internal defects exists, the in-depth inspection should not include disassembly, but should attempt to performance test the system thoroughly and apply soap solution to suspect fittings and piping connections to test for leaks.

2.8.2.9—Shrink Fits With and Without Clamping Sleeves

Coupling attachments (and many other attachments to shafts) often include keyways machined in the shaft longitudinal dimension in the OD of the shaft and the ID of the fitted part hub. The usual design involves a key that is a separate piece fitting into the longitudinal grooves machined into the shaft hub. The fit and finishing requirement of the hub, shaft slots, and keys is as specified in the contract plans, but subject to recommended minimum requirements published in Reference 6 and also to manufacturers' recommendations that may at times exceed Reference 6 or contract plan requirements.

One common installation procedure is to cool the inner part (the shaft) with the keys already in place and to heat the outer part (in this case, the coupling) to provide clearance to place the part properly. When the parts reach equal temperature, the result is a tight interference fit that will provide rigid nonslip performance.

The routine inspection of shrink fit attachments on couplings and other components is the same as for other looser fit keyed shafts. Check for signs of slip or cracks at keyway slots and other reentrant shoulders or irregularities that cause stress concentrations.

One newer procedure on recent movable bridge rehabilitation machinery designs is the use of keyless positive clamping force split sleeve connections for external contracting (or internal expanding) part fits as a method for installing new couplings onto existing shafts in the field. The shrink fit procedure is best done with parts in the shop, and may be difficult or impossible in the field due to rapid heat transfer to large adjacent metal parts, and interferences to access. The split sleeve type coupling connections should be checked for rotational and longitudinal slip, loose fasteners, and stress cracks as for other bolted parts during routine inspections.

2.8.2.10—Machinery Coding Recommendations

Due to the proprietary nature of some design data for mechanical components, it may be difficult to precisely quantify the criteria for numeric condition evaluation coding on individual mechanical components. The following general guidelines are intended to assist in coding the condition of mechanical components. "Excellent" and "good" are usually obvious, need no further explanation, and are not discussed.

Open gearing: Open gearing that exhibits excessive wear, cracked teeth, or any of the signs of impending tooth failure described in Chapter 2.8.2.1 should be coded "severe." Defects that have the potential to cause drive machinery failure should receive the highest priority for corrective action. If failure is unlikely in the immediate future, the component may be coded "poor." Lack of covers, lack of lubrication, or signs of accelerated tooth wear should be coded as "poor."

Enclosed gearing: Minor rusting or signs of moisture in the oil, minor wear, a clogged filter, misalignment, or spalling of one or two gears would be coded "fair" because they are unlikely to cause failure in the near future. A cracked enclosure, broken or loose anchor bolts, significant corrosion, misalignment, wear or spalling of many teeth, or signs of impending seal failure would be either "poor" or "severe" depending on the inspector's opinion on how imminent failure may be and the urgency of any recommended corrective actions.

Bearings: Sleeve bearings that exhibit excessive radial clearances, or are broken or loose in their journal boxes, should be coded "severe" because bearing metal is generally unable to withstand impact or uneven loadings and it is difficult to predict remaining life. At times, a sleeve bearing may crack and lose a piece of the sleeve that reduces the bearing area. Any fractured bearing sleeve should be coded as "severe" regardless of the percentage of lost surface area.

Frictionless bearings that show excessive wear, make grinding noises, where individual rollers or ball bearings are not free to roll, where the outer or inner bearing face is scored (not normally visible) or loose, or where the bearings are running in excess of 200°F (93°C) should be coded "severe."

Shafts and couplings: Cracked shafts should be considered "severe," irrespective of the rate of propagation of the crack. A cracked shaft that fails may render the bridge inoperable. The inspector should file a "severe" deficiency report the same day to initiate timely follow-up testing, assessment, correction measures, or some combination of the three.

If found by assessment to be "non-severe," cracks should be closely monitored to determine the rate of crack propagation and the owner should prepare contingency plans to be implemented in the event of shaft failure. Such contingency

C2.8.2.10

The actual severity of shoe and wedge vertical movements will vary due to the design details of the individual structure. On some structures, a vertical "pumping" movement will prove to have minor effects on stresses. Owners may, at their option, develop their own maximum permissible vertical gap guidelines based upon the nature of the movable bridges in their inventory.

plans should remain in force until the cracked shaft(s) are replaced or repaired.

Couplings exhibiting distress, lack of proper lubrication, or wear of individual parts should be considered “poor” unless these conditions have led to looseness or damage that appears likely to cause a failure. In such cases, they should be coded as “severe.”

Buffer cylinders with air escaping from areas other than the outlet pipe should be coded “poor” or “severe” depending upon the inspector's evaluation of the potential consequences of cylinder failure.

Live Load Shoes or Wedges that show signs of vertical span movement under heavy live loads should be coded “poor.” If the relative movement at the shoes or wedges creates a vertical gap in the support that exceeds one-fourth of an inch ($^1/_4$ in.) (6.35 mm), the shoes or wedges should be coded “severe” until rating calculations are performed to determine that the imposed stresses on primary members do not represent a hazard. If calculations are available, a case-specific maximum permissible vertical deflection to cause a rating of “severe” should be added to the bridge file for each type of shoe or wedge.

Fasteners that show signs of movement should be checked for nut tightness, cracks or breaks. Loose fasteners that are on structural parts are less likely to be “severe” than if they are turned machinery bolts. Cracked, broken or loose fasteners should be coded “fair,” “poor,” or “severe” based upon the percentage of the fasteners that are not functional.

Table 2.8.2.10-1 – Fastener condition coding guide

Percentage of Ineffective Fasteners	Condition Code
≤10 percent	Fair
>10 and <20 percent	Poor
≥20 percent	Severe[1]

[1] *Any questionable fasteners that comprise a percentage loss of connection effectiveness exceeding 20 percent should be coded “severe” until actual calculations are performed to rate the connection for imposed loads. Once calculations are made, the coding can be revised based upon engineering judgment.*

Manual and emergency drives that do not function should be rated “severe.” If such drives are functional with difficulty, and leave doubt of their continued ability to function after testing, they should be coded “poor.”

Air motors that exhibit leakage should be coded “poor;” systems which fail to run reliably or are unable to run at a steady speed should be coded “poor” and be scheduled for further investigation. The existence of either leaks or speed variation warrants filing a deficiency report. Systems with fittings, hoses, or piping that is deteriorated should be coded "poor" or "severe" based upon the likelihood of a line failure during use.

2.8.2.11—Special Machinery

The inspection of mechanical components common to movable bridges is covered in Chapter 2.8.2. The inspection of special machinery and mechanical components that are unique, either in function, location, or appearance, to one specific type of movable bridge is covered in this section. Section 2.8.2.11.1 addresses machinery specific to bascule bridges, Section 2.8.2.11.2 addresses machinery specific to swing bridges, and Section 2.8.2.11.3 addresses machinery specific to vertical-lift bridges. In general, unique or uncommon movable bridge types, such as floating pontoon bridges, share machinery components addressed in the following sections.

2.8.2.11.1 Bascule Bridges

The following special machinery components are unique to bascule bridges:

- trunnions
- segmental girders, track girders, and tread plates
- bascule centering devices
- span locks
- Hopkins frame

2.8.2.11.1.1 Trunnions

A trunnion shaft assembly is typically mounted on each side of the bascule leaf. There are two basic types in common use: asymmetric and symmetric (Figures 2.8.2.11.1.1-1 and 2.8.2.11.1.1-3). When the leaf is raised, its entire weight is supported by the trunnion bearings. The trunnions of both types are on a common horizontal center line that forms the horizontal axis of rotation of the leaf.

The trunnion shafts of asymmetric trunnions are mounted through holes in the trunnion and bascule girders. Hubs are shrink fitted and keyed to the shafts and then bolted to the girders. Steel rings are often bolted to the girder web to add rigidity. (See Figures 2.8.2.11.1.1-2 and 2.8.2.11.1.1-4).

The small end of each asymmetric trunnion shaft is usually mounted in an eccentric assembly. After assembling the span and mounting the trunnions, final alignment of the two trunnions is obtained by rotating both the outer eccentric and the inner eccentric until the trunnions are in line (see Figure 2.8.2.11.1.1-2).

The symmetric type of trunnion bascule has equal size trunnions mounted on fixed supports, which are typically piers

C2.8.2.11.1.1

The trunnion assembly described is a special type, and applies only to trunnion bascule bridges. Generally, the term "trunnion" means any large shaft, such as the sheave trunnions on a vertical-lift, or the trunnions used on heel trunnion bridges. The most common types of trunnion bascules typically have trunnion bearings on both sides of the main girder.

or steel assemblies, such as A-frames or rigidly framed towers. (see Figure 2.8.2.11.1.1-3).

One uncommon type of trunnion bascule uses a large single trunnion bearing, mounted on the bascule girder, which turns on a fixed shaft supported by fixed collars on each side of the bascule girder.

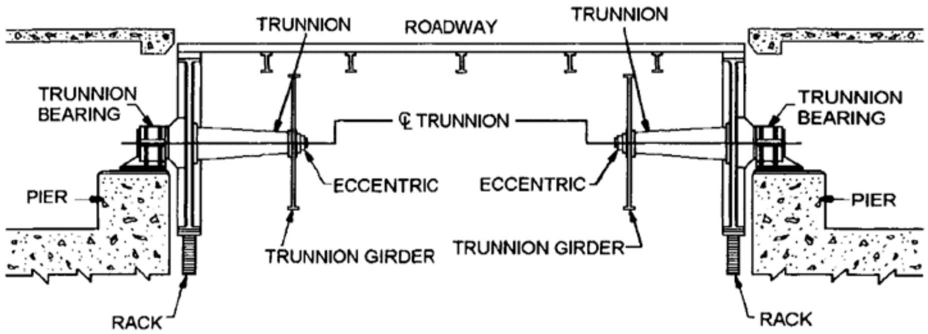


Figure 2.8.2.11.1.1-1 – Asymmetric trunnion assemblies

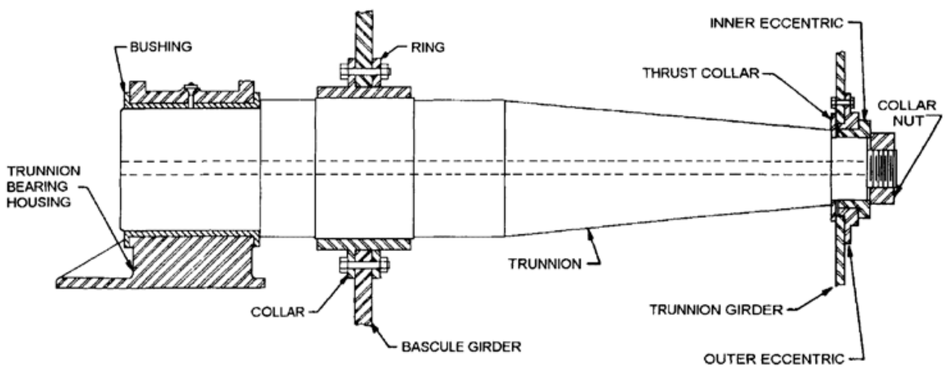


Figure 2.8.2.11.1.1-2 – Sectional detail of an asymmetric trunnion shaft assembly with an adjustable eccentric type inner bearing; the term "asymmetric" refers to a lack of symmetry about the centerline of the bascule girder

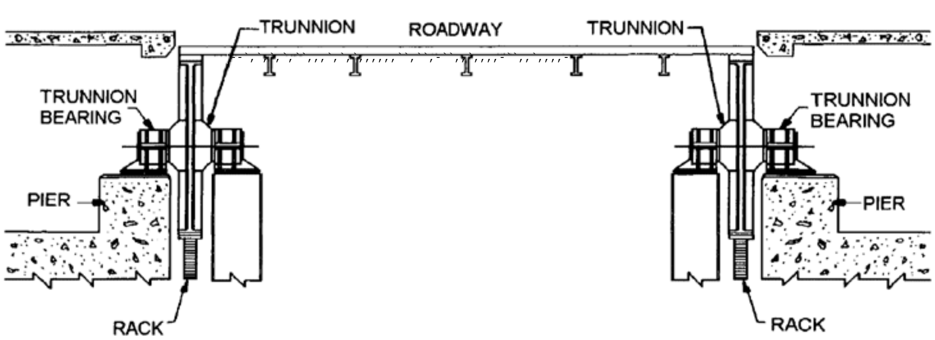


Figure 2.8.2.11.1.1-3 – Symmetric trunnion assemblies

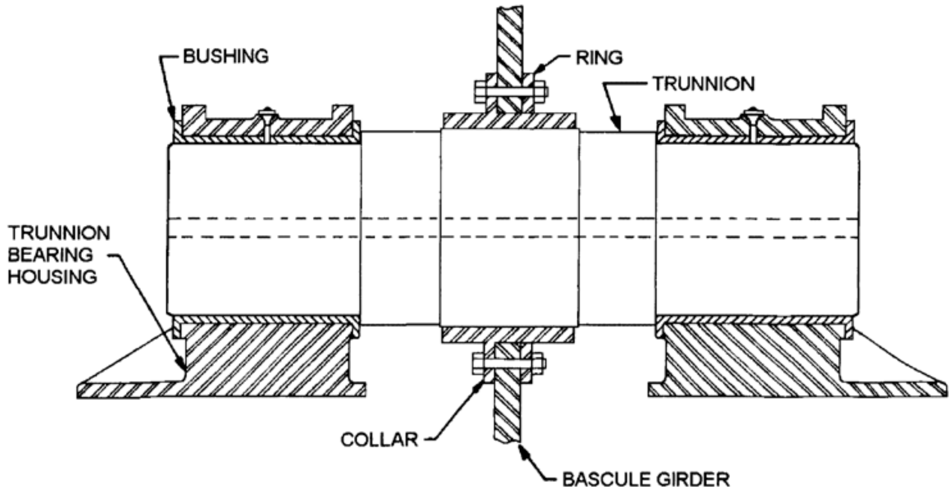


Figure 2.8.2.11.1.1-4 – Sectional detail of symmetric trunnion shaft assembly

2.8.2.11.1.1.1 Inspection

During routine inspections:

- Carefully inspect all bolts, hubs, rings, and fasteners that hold the shafts in the trunnion and bascule girders. Check for rust, abrasion dust, corrosion, and cracking. Check the condition of the girder webs around the shafts. Carefully inspect all asymmetric type trunnion eccentric lock nuts to be sure they are all in place and tightened securely to prevent rotation of the eccentric.
- Listen for any noise coming from shaft assemblies as the leaf is raised and lowered.
- Check trunnion bearings as outlined in Chapter 2.8.2.3.3.

During in-depth inspections:

- Perform a visual check of the shaft alignment. Trunnion shafts must be in the same horizontal line and the webs of all the bascule girders must be perpendicular to that line in the horizontal and vertical planes, or the leaf will not rotate properly. The weight of the entire leaf is transmitted through the trunnion shaft to the trunnion bearings. Shaft misalignment will cause unsymmetrical loadings on the bearings and their supports. Eccentrics mounted on the small end of the shaft allow for precise alignment of the shaft (Figure 2.8.2.11.1.1-2).

During special inspections:

- Current practice is to check the trunnion alignment using a laser based bore alignment system using the boreholes in the trunnions. An older method to check trunnion shaft alignment is to run a piano wire through the drill holes (if present) at the center of both trunnions (Figure 2.8.2.11.1.1.1-1). The wire must be tight to minimize sag. Attach one end of the wire to a bar, which should be held

1.0 in. (25.4 mm) out from the end of the trunnion to allow centering of the wire. This can be accomplished by inserting 1.0 in. (25.4 mm) blocks between the bar and the trunnion. Center the wire by measuring from it to the OD of the trunnion in several places, and adjust it until each measurement is the same.

- The other end of the wire is attached to a turnbuckle, which must be held far enough from the end of the other trunnion to allow for tightening and centering the wire. The wire should be stretched as tight as possible manually, before attaching it to the turnbuckle.
- Sight down the wire to see if there is any appreciable sag, as it may be necessary to consider the catenary deflection of the wire. If the sag cannot be eliminated, measure how much sag exists. At the small end of each shaft, measure from the shaft OD to the wire.

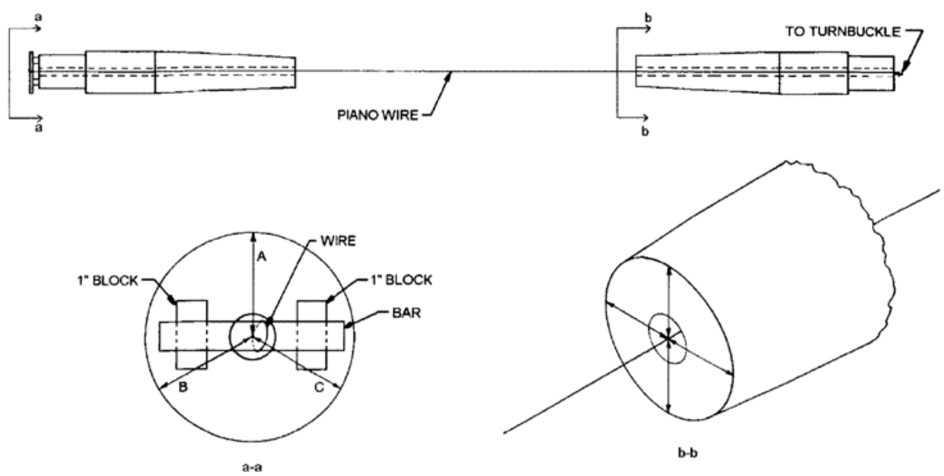


Figure 2.8.2.11.1.1.1-1 – At large end of the trunnion on side a-a, a piano wire is secured around a bar resting on 1.0 in. (25.4 mm) blocks. The other end of the wire is attached to a turnbuckle, which can be mounted on a railing or any other fixed point. Measure the horizontal and vertical dimensions, as shown in b-b, with the leaf in the open and closed positions.

- Taking into consideration any sag in the wire, the shaft eccentricity, if any, can be determined. Measure the vertical position and the horizontal position of the wire with respect to the out-to-out of the shaft. Check the shaft alignment once with the span closed and again with the span open to see if there is any variation. If there are no holes in the trunnions, an offset wire may be possible or a precise survey may be required.

2.8.2.11.1.2 Segmental Girders and Tread Plates

On rolling lift bascules, each leaf is supported in the open position by curved segmental girders that are in turn supported by track girders embedded in the substructure. The segmental and track girders have heavy tread plates at the planes of rolling contact that carry the full weight of the structure in line bearing while rolling. The segmental girders are constructed with square or circular pockets in the bottom flange that receive the corresponding lugs or pintels on the top flange of the tread plate. These mated pockets and lugs serve to maintain proper alignment as the bridge rolls into the open position, as shown in Figure 2.8.2.11.1.2-1 and Figure 2.8.2.11.1.2-2.

Figure 2.8.2.11.1.2-1 – Segmental girder and tread plate of track girder (the girder is embedded in the pier concrete)

Figure 2.8.2.11.1.2-2 – Segmental girder and tread plate of track girder

2.8.2.11.1.2.1 Inspection

Routine inspection of these components should be performed as follows:

- Check the mating surfaces of the segmental girder and track girder tread plates to be sure there is uniform contact during bridge operation.
- Check the pockets and lugs for evidence of wear or plastic flow on the sides (e.g., shiny surface, abrasion dust, or evidence of fine metal shavings). If evidence of wear is present, the sides of the lugs and pockets are in contact during span opening, and the span is misaligned.
- Look for fatigue cracks near the base of lugs and at the corners of the pockets. If the lugs are not one piece with the tread plate, check the lugs for relative motion and/or broken fasteners.
- Check for loose or sheared bolts on the tread plates.
- Check for signs of plastic flow or cracking of the tread plates, see Figure 2.8.2.11.1.2.1-1.
- Check for cracks in the fillet of the bottom flange angle of the segmental girder.
- Check the bottom flange angle of the segmental girder for squareness.
- The track girder tread plate top surface should be completely flat and provide a true horizontal plane. Check for out of plane areas in both horizontal axes.

Figure 2.8.2.11.1.2.1-1 – Longitudinal crack in track girder tread plate

C2.8.2.11.1.2.1

Figure 2.8.2.11.1.2.1-1 shows a severely cold worked track girder tread plate on the structure shown in Figure 2.8.2.11.1.2-1. The line bearing stresses on this structure were excessive, leading to plastic flow of the treads longitudinally and transversely. These effects, coupled with excessive wear, caused the track girder tread plate to crack open longitudinally over the web plate of the track girder.

The crack in the fillet of the bottom flange angle of the segmental girder is due to high line bearing stresses, and is typically found on the segmental girders of rolling lift bascule bridges.

2.8.2.11.1.3 Bascule Centering Devices

To insure span locks and sockets are properly aligned, centering devices are installed at the forward end of the leaf. On a single-leaf bascule, a tapered centering guide on the leaf fits into a pocket on the substructure. On double-leaf bascules, tapered guides on one leaf mesh with tapered slots on the other leaf as the bridge approaches the closed position.

2.8.2.11.1.3.1 Inspection

The routine inspection procedure for bascule centering devices is as follows:

- Observe the device during its complete operational cycle.
- Make sure the tapered guide on the bascule span is properly aligned with the guide pocket or the mating tapered slots. Any deformation of the guide or polishing of the inside surface of the guide pocket may indicate misalignment of the bridge. Polishing or plastic flow on one side indicates the span is out of alignment in that direction or the girder or pocket has shifted.
- Check for debris buildup in the guide pocket.
- Check for adequate lubrication in the guide pocket.

Check fasteners for corrosion, deterioration, and tightness.

2.8.2.11.1.4 Span Locks

Span locks are used on trunnion bascule spans to hold the span securely closed. They are always located at the toe end of the span. On a single-leaf bascule bridge, the lock bar operator, mounted on the toe end of the span, slides the lock bar into a socket on the substructure. On a double-leaf bascule, the socket is on the toe end of the second leaf (see Figure 2.8.2.11.1.4-1). Frequently, locks are also mounted on the counterweight end of the span and are referred to as tail locks or heel locks. The tail lock bar operating mechanism is mounted on the leaf and the socket on the substructure or a fixed span.

The conventional lock bar machinery is shown in Figure 2.8.2.11.1.4-2. A motor drives a speed reducer; and the power from the reducer is transmitted through shafts, cranks, and connecting rods to the lock bar. The lock bar slides through two span mounted guides and engages a socket mounted on the substructure (for single leaf bascules), or the other leaf (on a double-leaf bascule).

Many rolling lift double-leaf bascules have rigid non-moving intermeshing jaw type span locks. These rigid span locks consist of a tongue and groove arrangement wherein tongues are provided on one leaf to intermesh with grooves provided on the other leaf. The bottom portion of the groove extends further than the top portion. When the leaves are lowered, the leaf with

C2.8.2.11.1.4

Many different types of span lock devices are used. Most often, mechanically operated locks, interlocking jaw type, or self-contained electric motor driven types locks are used on bascule bridges. Only the conventional mechanical type or the self-contained type provide positive locking of the spans.

Some bridges may have hydraulically activated lock bars. The operation of lock bars is usually very simple and the study of the operation manual or the installation should give an indication to the inspector of the operation mechanism and likely points of wear on the lock bars and lock bar operators. Inspection of hydraulic components is provided in Chapter 2.8.2.12.

On double-leaf bascules, a loose lock bar fit can be discovered by closely observing the floor break between the two leaves on either side of the channel. Relative vertical motion of one leaf compared to the other will generally indicate loose fit. If the lock the grooves is lowered first and is stopped before it fully seats. The leaf with the tongue is lowered until it comes in contact with the projecting part of the groove. The locks intermesh as both the leaves are subsequently lowered further till both leaves are completely seated.

Figures 2.8.2.11.1.4-3 and 2.8.2.11.1.4-4 show a self-contained lock bar operator. The lock bar operator performs the same function as a conventional lock bar, but it has its own drive motor, brakes, and limit switches. Torque from the motor is translated into linear force by the gear and acme screw.

Self-contained lock bar operators are increasingly being used to replace the obsolete conventional lock bar machinery. These units are easier to install and maintain than the conventional units.

The lock bar is usually of rectangular cross section, with its end slightly tapered so that it can easily slide into the guides and socket even if the spans are slightly misaligned. The lock bar should move freely through the guides and sockets, which usually have bronze liners with lubrication fittings. If the leaves are properly aligned, a small clearance should be noticed on the top and bottom, with slightly larger clearances on the sides. When the leaves are closed and traffic is passing over the bridge, the lock bars are subject to top and bottom loads. With proper clearance and alignment, very little span movement should occur during traffic movement over the span, and there should be no side loads on the lock bar.

bar area is accessible, the mechanism can be operated and the bar and receiver measured with a vernier caliper with the span closed. If the structure is not accessible, then inspectors can sometimes use a manlift or ladder to climb the open structure and stand on the web of the end floorbeam to take measurements of the bar and receiver.

Rigid intermeshing type span locks are prone to mechanical damage and wear, and should be checked for loose fit and damage by methods similar to those discussed above.

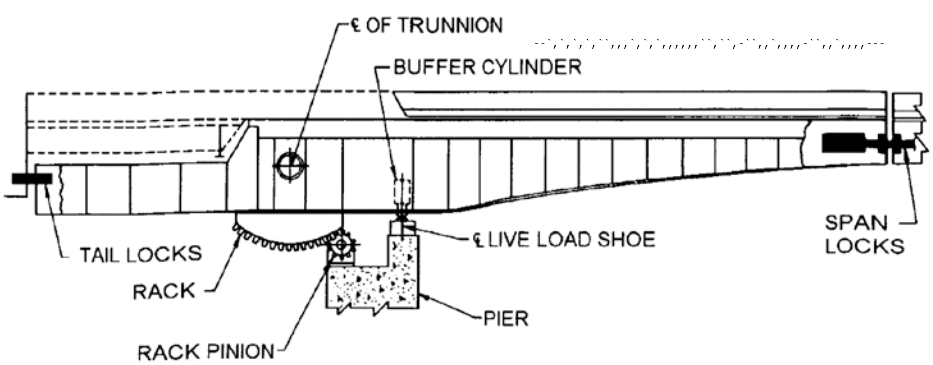


Figure 2.8.2.11.1.4-1 – Operating components of a double-leaf bascule bridge

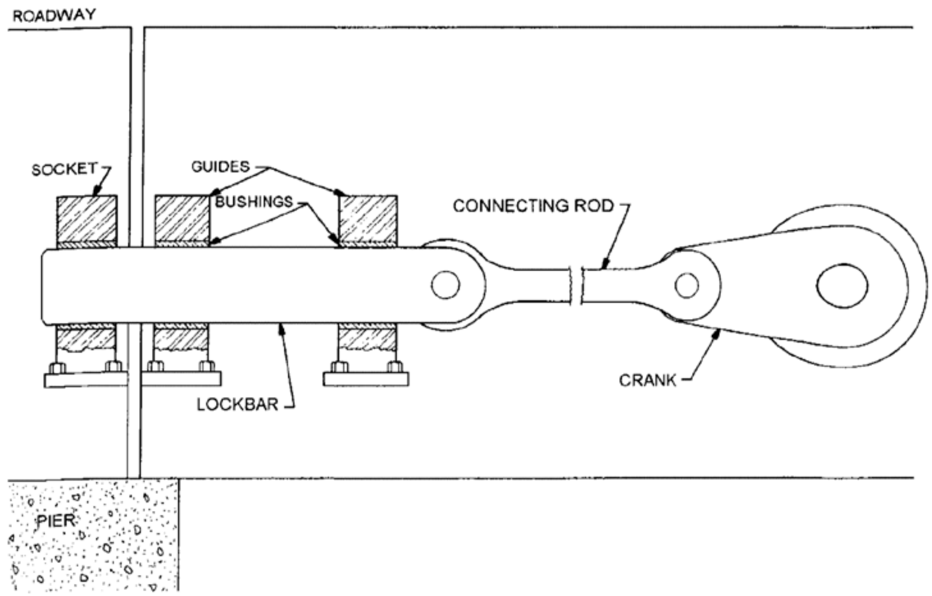


Figure 2.8.2.11.1.4-2 – A conventional lock bar assembly

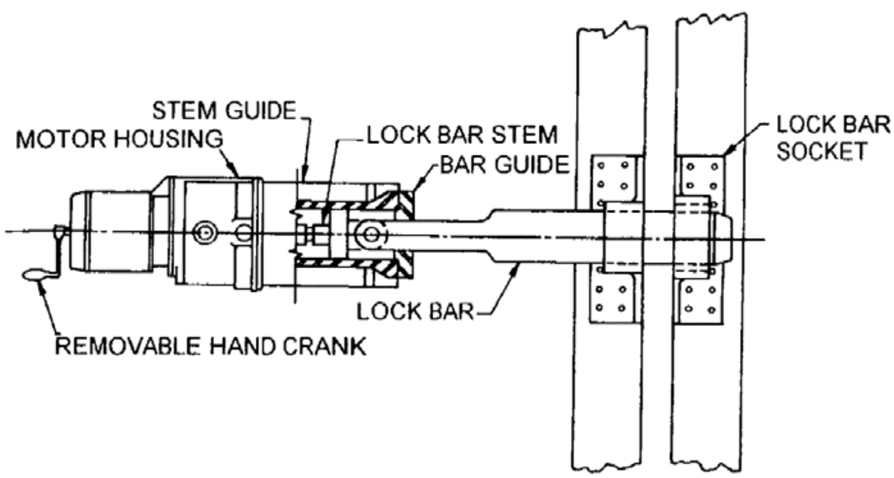


Figure 2.8.2.11.1.4-3 – A cutaway view of a self-contained lock bar operator

A limit switch, driven by a gear or line shaft, is interlocked with the operating controls, preventing over-travel of the lock bar or operation of the bridge before the lock bar is withdrawn.

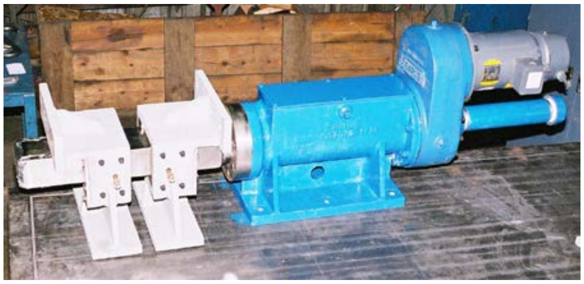


Figure 2.8.2.11.1.4-4 – Lock bar operator

2.8.2.11.1.4.1 Inspection

During routine inspections, check the following:

- Observe the device during its complete operational cycle.
- Measure the clearances between the bar, the guides and the sockets. It may be necessary to have the bridge operator raise the leaf slightly to make these parts more accessible.
- Inspect individual drive components such as gears, bushings, motors, and hydraulic systems as per Chapter 2.8.2.1 through 2.8.2.10 and 2.8.2.12.
- For a self-contained operator, check the acme threads for wear and proper lubrication.
- For rigid jaw type locks, check the jaws (tongue and groove) for wear, corrosion, and damage. Damage can occur while intermeshing the tongue into the groove. Also, observe the floor break between the two leaves for relative vertical motion under live load. A relative vertical motion indicates a loose fit, and would require shimming during maintenance.

During in-depth inspections, the following should be checked:

- Measure the dimensions of the bronze liner in the socket and inspect for wear. If excessive wear is noted, it should be either adjusted or replaced. Make sure the lubrication system is working and all fasteners on the sockets are secure.
- Measure bar dimensions and compare with the design or as-built dimensions. Check the bar closely for evidence of top, bottom, or side wear. If bar or socket exhibit an abnormal amount of wear, the span may be misaligned or the guides and sockets may have shifted.

2.8.2.11.1.5 Hopkins Frame

On many bridges, the speed reducers, bearings, brakes, and other components are mounted directly on the concrete substructure or structural members while on others these components are assembled on steel frames and supports. Frequently a group of components are shop mounted on a common frame that is subsequently installed in the field. Regardless of just how the assemblies are completed, all the forces acting on the machinery components are ultimately transmitted through the supports to the pier or superstructure.

The Hopkins drive, shown in Figure 2.8.2.11.1.5-1, is a special drive unit assembled on the machinery frame that is found only on certain trunnion bascule bridges. The frame is mounted vertically and pinned to the pier with clevises. The upper part of the frame is held in position by two links. The links extend from the drive pinion shaft to a link shaft. The link shaft is fastened to the bottom of the movable leaf on a common center line with the trunnion shafts.

Figure 2.8.2.11.1.5-1 – Hopkins drive and frame

Supports and mounting frames that are not wearing parts are often overlooked during a machinery inspection. These supports do suffer distress and occasionally fail, resulting in damage to other parts as well as interruption of service. Therefore it is important to carefully clean and inspect all machinery supporting structures. Routine inspection of the frame should include the following:

- Check the frame for cracks, especially where gears, racks, and pinions are attached. Check for loose or missing bolts at these locations.
- Check to see that the frame is mounted securely, that all connections are tight into the pier, and that clevises are free of cracks.
- Observe the supports while the leaf is operating to see if movement occurs between the substructure or superstructure and the support or between the machinery component and support. Any movement could indicate loose fasteners, cracked concrete, or deteriorated steel members.

Carefully watch for any apparent deflection of the support. Noticeable deflection can result from improper fit of the bolts in their bolt holes or cracks around the mounting flanges near bolt holes, fillets, welds, or severely deteriorated steel. If any of these conditions exist, they will be readily apparent during leaf operation. However, suspected cracks may require further investigation using dye penetrant or other nondestructive testing means.

Supports which are partially embedded in concrete are particularly susceptible to severe corrosion at the concrete interface. Any corrosion of this type should be promptly treated and corrected to avoid substantial weakening from continued corrosion and deterioration.

2.8.2.11.2 Swing-span Bridges

Several special machinery components are found on swing span bridges. These are listed below, and guidelines for their inspection are presented in the subsections that follow:

- Center bearings
- Balance wheels and track
- Tapered rollers
- Wedges, end-lift jacks and shoes
- Swing span centering latches
- Drum girder

C2.8.2.11.2

The large majority of swing span bridges are symmetrical, having equal arms on either side of the center swing pier. This symmetry creates a naturally balanced system eliminating the need for counterweights.

A small number of bobtail swing bridges having unequal arm lengths exist. The inspection of the counterweight systems used on this type of swing span should be performed as described in Chapter 2.8.1.

2.8.2.11.2.1 Center Bearings

The center bearing is the most important wearing part on a swing span bridge. When the wedges are withdrawn and the bridge is being rotated, all of the dead load weight of the bridge is supported on the center bearing. This special machinery component is also the most difficult part to inspect. Figure 2.8.2.11.2.1-1 shows a typical cross sectional drawing of a center bearing. The steel top plate is attached to the bottom of the span, and it bears on the bronze top disc of the bearing. The top disc has a boss in the center that engages a counterbore in the top plate to provide positioning. Pins pressed into the top plate engage holes in the bronze disc to prevent rotational slippage between the two pieces.

The top disc rotates with the span; the bottom disc remains stationary. Oil grooves are machined into the spherical surface of the bronze disc to assure proper lubrication of the bearing surface. The oil box is split vertically, and is bolted to the bearing base. The bearing is lubricated by being submerged within the oil box. If any center bearing swing bridges are encountered with no oil box present, one should be installed as soon as possible. If the oil in the box is low or contaminated, it should be refilled or replaced. If any of the above three defects are discovered, or if the inspector has a reason to believe the center bearing is damaged due to noisy operation or other evidence, the span will need to be jacked up and the bearing surface should be inspected.

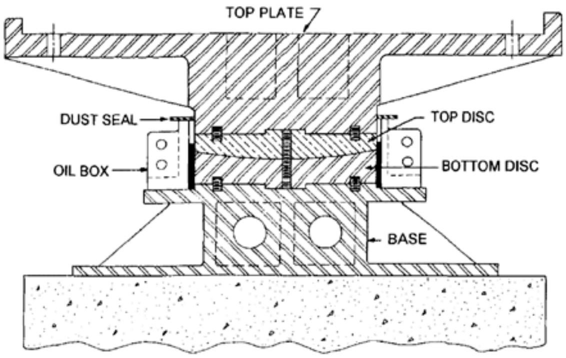


Figure 2.8.2.11.2.1-1 – Cross-sectional view of a center bearing; a split circular oil box surrounds bearing. Notice that none of the discs or plates are bolted together.

2.8.2.11.2.1.1 Inspection

The disc would normally be inspected only during in-depth inspections, since it is impossible to inspect the center bearing thoroughly without jacking the bridge up several inches to expose the bearing surfaces. Jacking can be done in either the open or closed position, but it is considerably easier to jack the bridge up in the closed position, since equipment and personnel can be easily moved on and off the bridge. Figure 2.8.2.11.2.1.1-1 shows a new spherical bronze center bearing for a swing bridge.

Jacking the span is a major project, and should be done only by experienced personnel using proper equipment. Gasket material should be on hand to insure the oil box can be reassembled in an oil-tight condition. Hand scrapers, emery cloth, and crocus cloth should be available to remove and polish any score marks found on the bearing surfaces. Solvent and rags will be needed to clean parts before reassembly. New oil should be on hand for the bearing.

To jack the bridge in the closed position, place jacks at each end of the span and in the center. Substantial cribbing should be used to support the span on all three piers. Usually, lifting the center of the span approximately 3.0 in. (75 mm) will allow the bearing to be inspected and the discs removed (if necessary). The oil can be drained and the oil box removed anytime after the bridge has been removed from service. The span should not be rotated after the oil has been drained.

When the span is raised, the top disc may either rise with it or remain on the bottom disc; there is no positive means to hold the top disc to the span. If the disc does rise with the span, be sure that no one reaches into the bearing. The top disk could drop down at any time.

Figure 2.8.2.11.2.1.1-1 – A new spherical bronze center bearing for a swing bridge

After jacking the movable span, the inspection should be carried out as follows:

- Remove the top disc from the bearing.
- Check top of bronze disc for scoring, worn boss, enlarged dowel holes, and worn or sheared dowels. Worn dowels should be replaced. If the boss shows any wear, measure its outer diameter and the inner diameter of the counterbore of the top plate. There should be no clearance. Wear on boss or dowels may indicate the bridge was operated with a dry or poorly-lubricated bearing. If boss is egg shaped or out of round, bridge may be operating under excessive wind load.
- Check spherical bottom surface of disc. It should have a mirror finish, and oil grooves should be open and free from foreign matter. If the bronze top disc or steel bottom disc have any score marks and no replacement is available, score marks should be polished out before returning the bridge to service.
- Clean all parts thoroughly before returning to operation. Be certain that no foreign matter enters the bearing prior to or during reassembly.

Apply a thin coat of lubricant to bearing surfaces. Be sure that the oil box is filled to proper level before operating bridge.

Routine inspections of center bearings should be based primarily on performance testing, listening for noises, and checking the effectiveness of the method of lubrication. If a center bearing has an oil bath lubrication box, the oil should be sampled and sent for analysis as per the method for hydraulic oil in Section 2.10. If it does not have an oil bath lubrication box, then inspectors should ask that the center bearing be lubed in their presence to permit sampling of the excess that extrudes during lubrication.

2.8.2.11.2.2 Balance Wheels and Track

As the bridge is rotated, the balance wheels provide stability from tipping for unbalanced loads, either due to dead loads or wind effects. Balance wheel assemblies are mounted to the bottom of the span. Figure 2.8.2.11.2.2-1 illustrates a typical balance wheel assembly. In this figure, the wheel bearing is located in the hub of the wheel and the shaft is stationary. In some cases, the wheel may be mounted on a shaft that rotates with the wheel. Two shaft bearings will then be found in the frame. Figure 2.8.2.11.2.2-1 shows an installation with a separate rail. Some installations have a rack machined onto the curved track as shown in Figure 2.8.2.11.2.2-2.

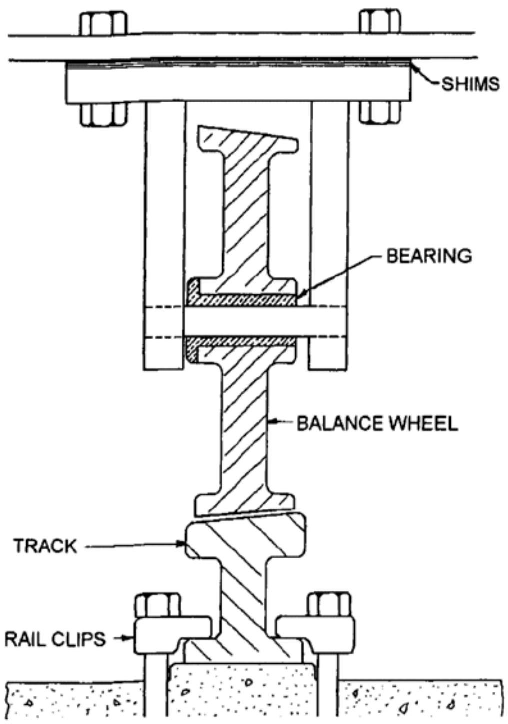


Figure 2.8.2.11.2.2-1 – A balance wheel assembly in which the wheel rotates on a stationary shaft

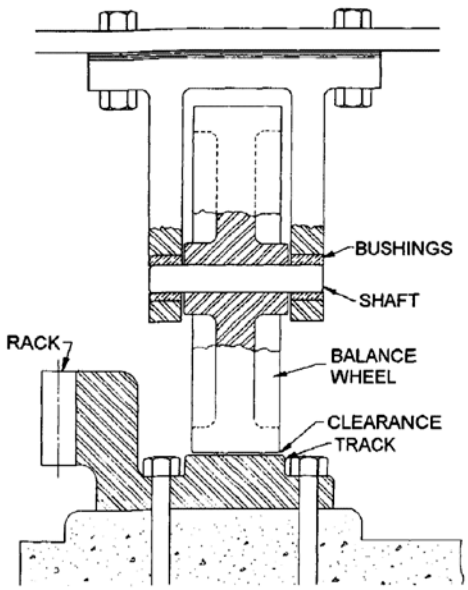


Figure 2.8.2.11.2.2-2 – A balance wheel assembly where the rack teeth have been machined into the curved track

2.8.2.11.2.2.1 Inspection

During routine inspections, check the following:

- When the wedges are driven, no balance wheel should be in contact with the rail. The distance between the rail and the wheels should be the same for each wheel. The drawings should indicate the design clearance. If no drawings are available, 0.050 in. (1.27 mm) can be used, as seen in Figure 2.8.2.11.2.2-1.
- If there is no wind when the wedges are withdrawn, the clearance under the wheels should remain until rotation begins. If the span tilts and brings some wheels into contact with the rail, it is probably unbalanced.
- Try to rotate balance wheels with the wedges driven. Check the clearance between wheel and rail.
- Check the bearing clearances on the wheel shaft. If the wheel shaft is stationary and the bearing is in the hub of the wheel, it is not possible to check the clearance with feeler gauges. A dial indicator can be mounted to check vertical movement of the wheel and a pry bar used to raise and lower the wheel. Any vertical movement greater than design clearance indicates wear in the bearing and or shaft.
- Check the outer diameter of the wheel and the track surface for irregularities.
- Check rail clips, foundation bolts, and set screws for tightness and corrosion.

Figure 2.8.2.11.2.2.1-1 – Close-up of balance wheel with excessive clearance

2.8.2.11.2.3 Tapered Rollers

A rim bearing swing span has a large number of heavy tapered rollers supporting the span, instead of a center bearing. The cross section in Figure 2.8.2.11.2.3-1 illustrates tapered roller components and Figure 2.8.2.11.2.3-2 shows the rim bearing assembly. As the rollers travel around the track, the center ring to which the radial rods are attached rotates on the span. A sleeve bearing is pressed into each roller. A thrust washer bearing is also used between each roller and the outer roller space ring.

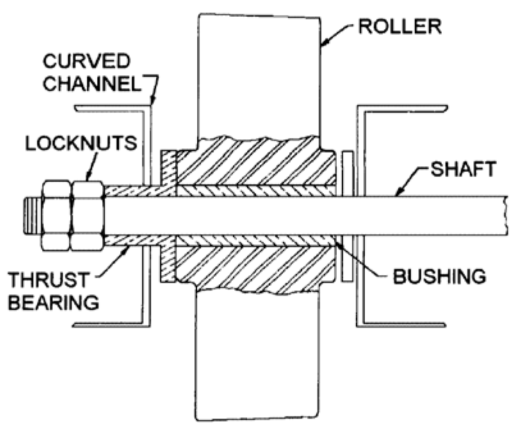


Figure 2.8.2.11.2.3-1 – A typical tapered roll. Lock nuts on shaft can be tightened to bring the roller into contact with both rails.

Figure 2.8.2.11.2.3-2 – Layout of rim bearing assembly

2.8.2.11.2.3.1 Inspection

During routine inspections of the tapered rollers, check the following:

- Observe the roller assemblies while the span rotates. See that rollers rotate properly, and that the center ring rotates smoothly.
- Listen for noise coming from the rollers, the center ring, or the center-pivot bearing. Watch to see if the rollers try to skew as they roll.
- Check the outer diameter of the rollers and both upper and lower track surfaces for irregularities.
- Check radial rods and fasteners for tightness, corrosion, and deformation.

During in-depth inspections, check the following:

- The thrust bearing should be checked on each roller. If it is worn, the roller will move away from the center of the span, and there will be clearance between the roller and the upper track. If possible, the thickness of the thrust bearing should be measured to determine wear.
- The sleeve bearings in the rollers are normally inaccessible. A complete inspection can be done on these bearings only when the bridge is out of service.

2.8.2.11.2.4 Wedges, End-lift Jacks, and Shoes

When a span is closed, it must be firmly supported at several points in order to support live loads. This firm support is accomplished by live load shoes or wedges. The wedges are driven into position between the substructure and the span

C2.8.2.11.2.4

Wedges, end lifts, and shoes may be actuated by either mechanical (such as shaft or chain driven muscle powered), electromechanical, or hydraulic devices.

bottom. End wedges (or end supports in general) also support a portion of the superstructure dead load. The amount of dead load supported needs to be adequate to prevent uplift at the ends under traffic. Center wedges/supports generally are not intended to support more than a small amount of dead load. Center wedges/supports should be driven just enough to ensure that are in firm contact. The center wedges/supports are there to stabilize the center of the span to carry traffic and to help relieve it of a portion of the live load. When positioned, the wedges transmit live loads from the span to the substructure (Figures 2.8.2.11.2.4-1 and 2.8.2.11.2.4-2). Before the span is opened, the wedges are withdrawn.

A typical wedge operating machinery layout is shown in Figure 2.8.2.11.2.4-3. A motor drives a primary reducer, which is coupled by longitudinal shafts to secondary worm-gear reducers at the ends of the span. The worm-gear reducers drive spur gear sets on the four corners of the span. The gears rotate cranks that drive wedges through adjustable connecting rods. The wedges slide in T-slot guides attached to the bottom of the span (see Figure 2.8.2.11.2.4-4). The wedge seat is on the substructure, and wedge machinery is identical at both ends of the span. Pivot-pier wedges are driven by a third worm-gear reducer and operate in the same way as the end wedges.

The types discussed at length herein are electromechanical. Inspection of hydraulic systems is covered in Chapter 2.8.2.12. The components of the hydraulic drive of the wedge, shoes, or end lift should be inspected as described therein. The inspection of mechanical and electromechanical systems should be based upon the principles described in Chapters 2.8.2.1 through 2.8.2.10.

Out of adjustment turnbuckles on toggles can cause lift timing between corners to be out of synchronization. This may cause a crank to operate past top-dead-center and partially retract. If this situation occurs, other toggles may take more than their share of the load. Hence, actuation between corners should be equal. See Figure 2.8.2.11.2.4-7.

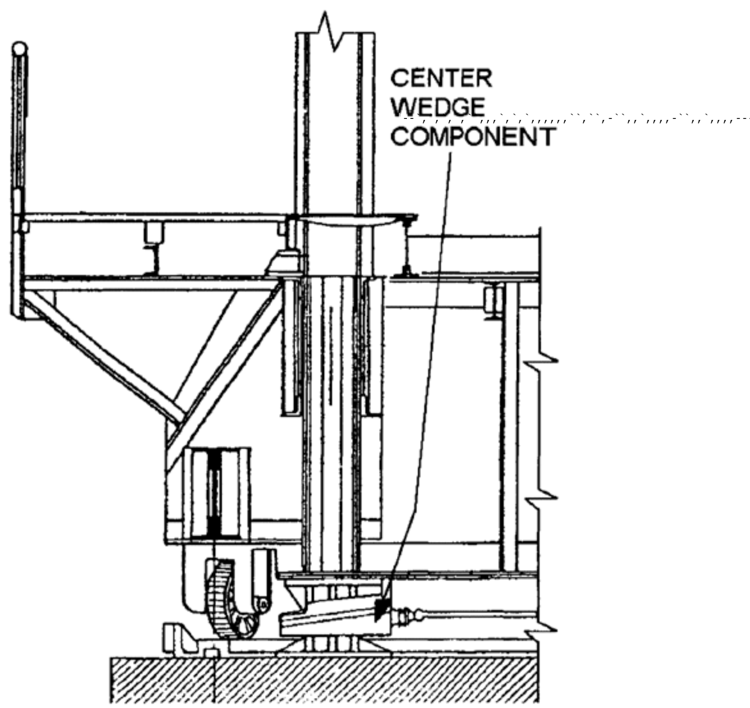


Figure 2.8.2.11.2.4-1 – Center wedge component

Figure 2.8.2.11.2.4-2 – End wedge, crank, and turnbuckle

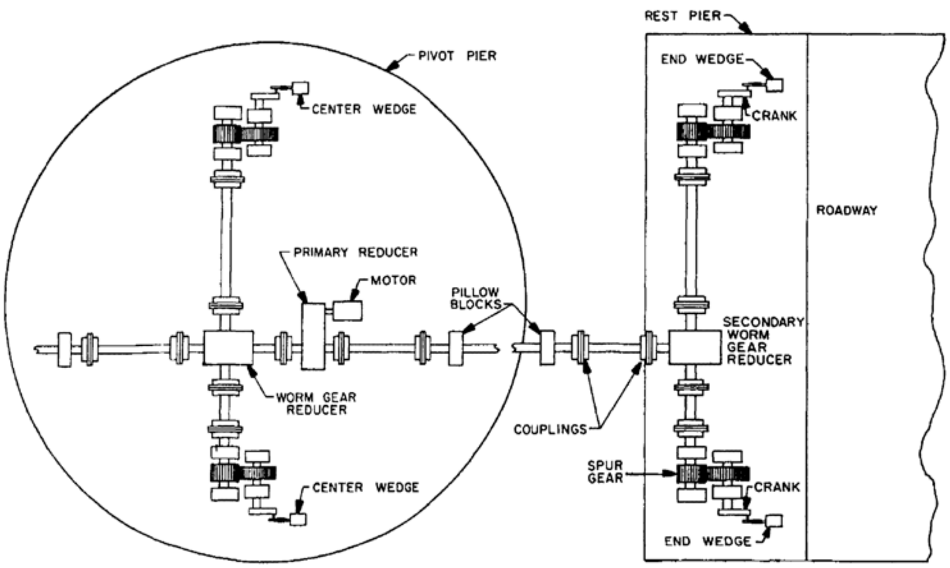


Figure 2.8.2.11.2.4-3 – Wedge drive machinery

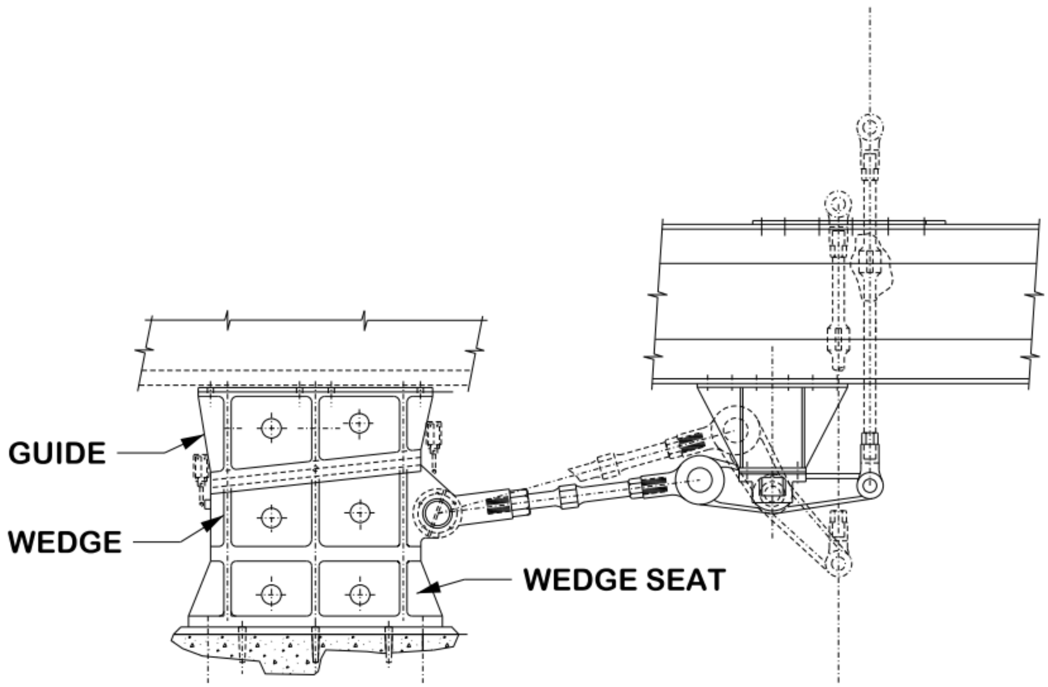


Figure 2.8.2.11.2.4-4 – Wedge components

Wide spans may have additional wedges at the ends to provide more support and limit deflection across the end of the span. Regardless of the number of wedges, they are driven in the same manner—through cranks, shafts, couplings, and gears—to operate in unison.

A typical emergency drive for the wedge operating machinery is shown in Figure 2.8.2.11.2.4-5. The emergency drive is designed for operation from roadway level. A hole in the deck is provided for a T-bar, which engages the emergency drive shaft. This vertical shaft is supported by pillow blocks mounted on a bridge girder. A bevel pinion is mounted on the lower end of the shaft, and drives a bevel gear mounted on a horizontal shaft. A square-jaw clutch is disengaged during normal operation of the wedge machinery. During failure of the electric motor or electrical controls normally used to operate the wedges, the brake can be released manually and the square-jaw clutch engaged for the emergency drive. If the motor rotates freely, it need not be disconnected. If it does not rotate freely, the coupling between the motor shaft and the input shaft of the reducer is disconnected. With the square-jaw clutch engaged and the brake released (or the motor coupling disconnected), the T-bar can be turned manually to operate the wedge drive machinery. A similar emergency hand drive can be used to rotate the span and operate other equipment on the bridge. Hand drives are time consuming and laborious, but are necessary during emergencies when the bridge must be operated during power outages or other adverse conditions.

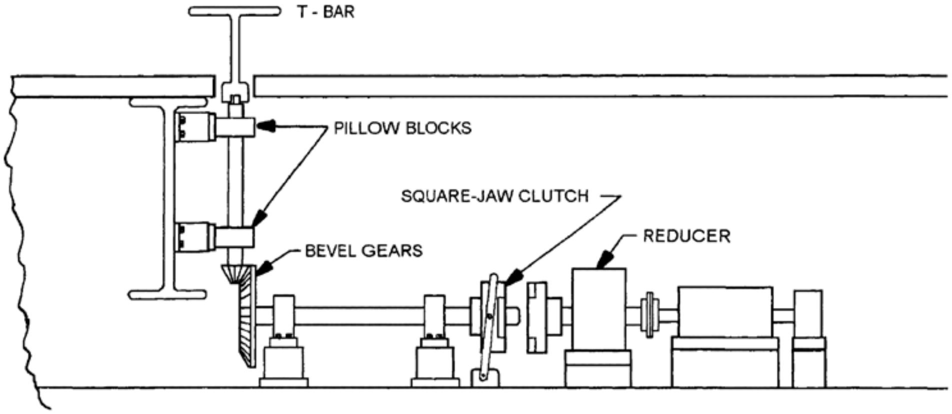


Figure 2.8.2.11.2.4-5 – Elevation of manual drive components

Most swing-span bridges are relatively rigid and deflect little when load supports are withdrawn. Some, however, are quite flexible, and deflect several inches when load supports at the ends of the span are disengaged. Since the limited height of the wedges cannot accommodate such large deflections, jacks and shoes are used instead. Shoes operate in the same manner as wedges, but are flat instead of tapered, and slide in horizontal T-slots (see Figure 2.8.2.11.2.4-6). When the span is closed, it sits upon the shoes at each corner. The shoes bear on seats mounted on the substructure, transferring the live load and some of the span's dead load to the substructure. When the span is to be opened, jacks raise the ends of the span slightly to remove the weight from the shoes. While the span is elevated, the shoes are withdrawn. When the jacks are lowered, the entire weight of the span is transferred to the center pier. The jack machinery is normally mounted on the span, driven by the same motor that operates the shoes, or has separate motor drives. Toggle, link-and-roller, and screw arrangements have all been used for elevating drives. A toggle-lift drive is shown in Figure 2.8.2.11.2.4-7. Note when the elevating bar is raised and the shoe withdrawn, the span is completely supported by the center pier. In Figure 2.8.2.11.2.4-8, the elevating bar has raised the end of the span, and the shoe is positioned over the seat. When the elevating bars are retracted, the span will be lowered slightly to road level and rest on the shoes. Figure 2.8.2.11.2.4-9 shows a link-and-roller device for raising and lowering the ends of the span. It operates in the same manner as the toggle lift but instead utilizes a link and roller arrangement. The load shoes are not shown.

Figure 2.8.2.11.2.4-6 – Live load shoes on a swing-span bridge

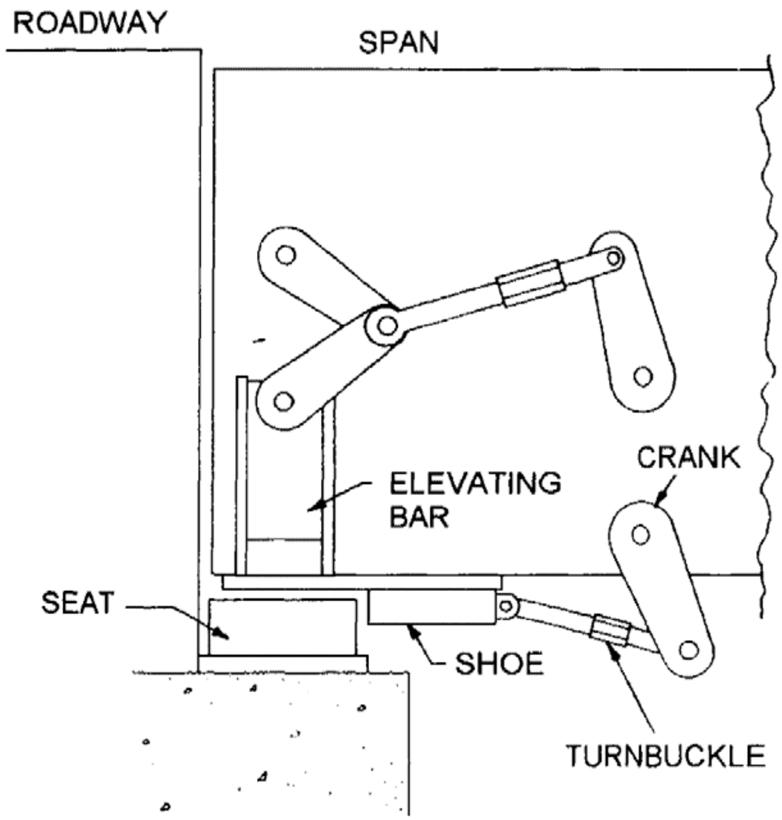


Figure 2.8.2.11.2.4-7 – Toggle elevating drive—bar is raised and shoe withdrawn; span is free to rotate

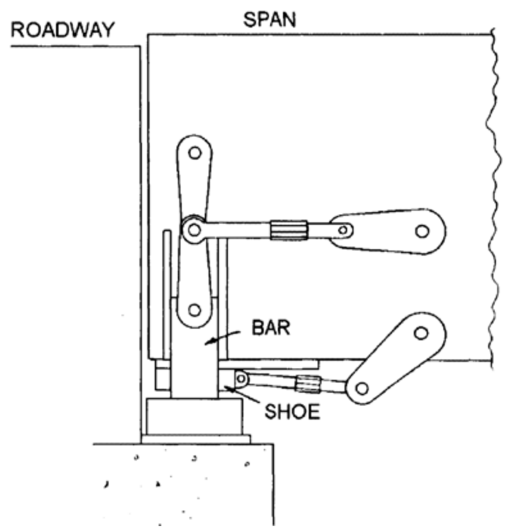


Figure 2.8.2.11.2.4-8 – Elevating bar fully extended and shoe in place; when the bar is raised, the span will rest on the shoe

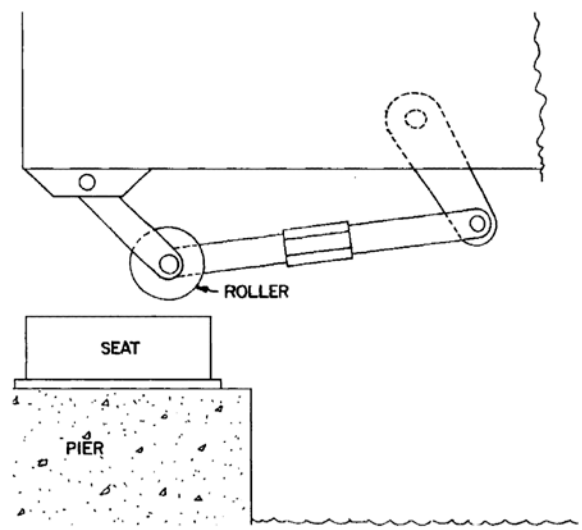


Figure 2.8.2.11.2.4-9 – Link-and-roller end lift (live load shoe not shown)

2.8.2.11.2.4.1 Inspection

The inspection of the drive machinery gears, shafts, and bearings is discussed in Chapter 2.8.2.1, 2.8.2.2, and 2.8.2.3. The routine inspection of the remaining components of the live load support assemblies should be as follows:

- Observe components during a complete operational cycle.
- Check wedges, jacks, and shoe bearing seats for deformation, settlement, and deflection.

- Check each crank to be sure it is tightly keyed to the shaft on which it rotates.
- Check clearance between all pins and bushings either with a feeler gauge or by observing relative motion between the pin and bushing.
- Be sure both lock nuts on turnbuckles are tight. Look for corrosion on exposed turnbuckle threads.
- Where jacking devices are used, see that they are elevating the span enough for free movement of the live-load shoe in and out of its supporting position. Check guide slot and lifting bar for side clearance.
- Check guide slots on shoes and wedges for excessive clearance. Be sure wedges or shoes seat fully when span is closed, as shown in Figure 2.8.2.11.2.4.1-1.

Figure 2.8.2.11.2.4.1-1 – Improper bearing of live load shoe

- During the inspection, check straightness of shafts and connecting rods. Be sure rotating and sliding parts are well-lubricated, and that bolts and fasteners are tight and free from corrosion and rust.
- Verify the amount of lift provided at the ends of the swing span. This amount should be that defined in the existing plans, if available. If insufficient raising of the span is provided, the live load on one end of the swing span can cause the other end to raise up off the wedge causing impact forces.

- Verify that the vertical alignment of the roadway is maintained when the end wedges are driven.

2.8.2.11.2.5 Swing-span Centering Latches

When the span is closed, it must be lined up with the fixed roadways and walkways. One way to achieve the required alignment is through the use of an end latch, also called the centering latch (Figure 2.8.2.11.2.5-1). One such centering device is located at each end of the span.

The latchbar has a roller attached to its lower end that fits into the centering pocket attached rigidly to the substructure. When the span is to be opened, the latch is raised by the wedge drive crank shaft attached to a pawl on the latchbar. The span can then rotate.

When the bridge is being closed, the roller on the lower end of the latch rolls up the ramp and drops into the pocket, positioning the span.

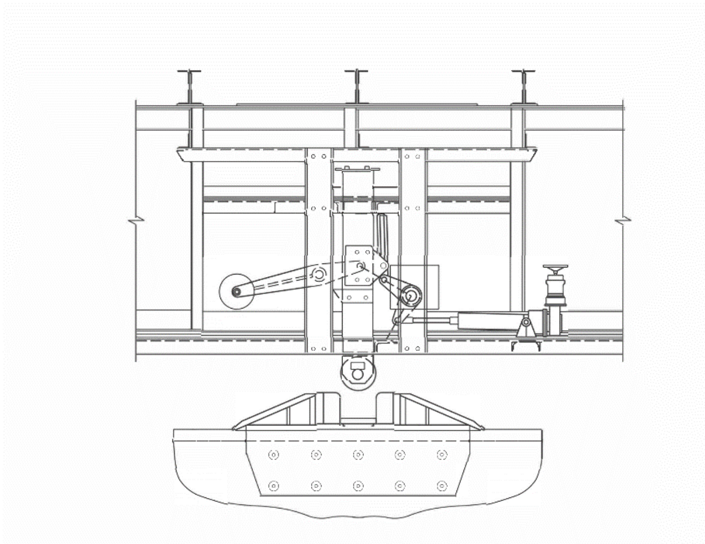


Figure 2.8.2.11.2.5-1 – End elevation of span showing location of centering

2.8.2.11.2.5.1 Inspection

During routine inspections, check the following:

- Observe the operation of the latch bar during the opening and closing of the span. Check the height of the wheel when it is raised out of the recess in the pocket to be sure that it can roll up the ramp properly when the span begins to rotate. Make sure the latch bar pawl disengages the pin and allows the latch bar to drop to the lowered position as the wheel rolls down the ramp.
- Watch the latch bar operation as the span closes. The span should slow down and nearly stop before the latch bar drops

into the pocket. Be sure the latch bar drops completely into the pocket (see Figure 2.8.2.11.2.5.1-1).

- Look for movement between the pocket and the substructure. Check the bar and the guide for deformation due to over travel as the span closes.
- See that the pin that engages the pawl contacts it near the center of the curved end. Check the pawl, pawl support bracket, and pin for deformation and wear. Be sure the pawl swings freely.
- Check the system for proper lubrication. Inspect fasteners for tightness and corrosion, especially the bolts on the latch bar guide and pocket.

Figure 2.8.2.11.2.5.1-1 – Latch bar engaged in pocket

2.8.2.11.2.6 Drum Girder

The drum girder found only on rim bearing swing bridges, is typically a built up riveted or bolted circular girder. The bottom flange of the drum girder is attached to the upper track of the rim bearing rollers. It serves to uniformly distribute the structural dead load and portion of the live load from the distribution girders to the center pier. It also serves to stabilize the structure during opening and closing operations as it rotates on the tapered rollers.

Routine inspection of the drum girder components should include the following:

- Inspect the drum girder as a whole for pitting, cracks, corrosion, and section loss; loose, missing or broken fasteners; and signs of buckling of the web plate.
- Inspect the drum girder bottom flange for fatigue cracks projecting from rivet or bolt holes in the horizontal leg at the flange angle fillet.

- Inspect the drum girder/distribution girder connection for impacted rust; loose, missing or broken fasteners; and section loss.
- Check for impacted rust between the horizontal leg of the bottom flange angle and the upper track.
- Check to make sure the drum girder is correctly aligned on the tapered rim bearing rollers.
- Observe the motion of the drum girder during opening and closing operations for smoothness of movement. Make note of and investigate any unexpected noises.
- Inspect the drum girder bracing for corrosion, loose connections, and proper alignment.

Inspect the distribution girder/loading beam interface for loose, missing or broken fasteners; impacted rust; and section loss.

2.8.2.11.3 Vertical-lift Bridges

The following special machinery components are usually found on vertical-lift bridges:

- Wire ropes and sockets
- Sheaves and drums
- Trunnions
- Tension adjusting devices
- Span guides
- Balance chains
- Span leveling devices
- Centering devices
- Span locks

2.8.2.11.3.1 Wire Ropes and Sockets

Steel wire ropes are used to lift the movable spans of vertical-lift bridges. The wire ropes are fitted with sockets at each end so they can be connected to the structure. The socket is attached to the structure either by pinning it directly to the member, or through the use of eye bolts that permit adjustment of tension after installation.

There are three main causes of wire rope problems: fatigue, abrasive wear, and abuse.

Fatigue is recognized by the appearance of small cracks in the individual wires. Cracks occur predominately at points of rope finity which are at the tangent point of the counterweight sleeve and the end of the rope at the lifting girder.

Abrasion and abuse result from the presence of foreign matter, rust, corrosion, and inadequate lubrication (see Figures 2.8.2.11.3.1-1, 2.8.2.11.3.1-2, and 2.8.2.11.3.1-3). Abrading will also result if the sheave grooves are not the proper size.

Abrasive wear is identified by location of flattened area on the outside surface of rope. It is usually caused by abrasive wear between rope and pulleys, or between successive layers of rope.

Another kind of abrasion occurs between individual strands within a rope. This type of wear results in abrasion dust and gives a rusty appearance to the rope. On the other hand, corrosion of the wire rope can be identified by uniform degradation of steel along all the exposed surfaces. Lack of proper lubrication accelerates the abrasive wear and corrosion of wire ropes. Abrasive wear is typically most pronounced in the area of ropes just below the span side of the sheaves with the span in the closed position, since this is the acceleration and deceleration zone of the ropes.

Abuse due to presence of foreign matter, inadequate lubrication, impact by a heavy object, mishandling, and rubbing of the rope against a static structure can cause mechanical damage. This is identified by extensive plastic deformation of steel, or nicks and cuts in the wire strands.

Figure 2.8.2.11.3.1-1 – Flattened areas on the wire rope indicate abrasive wear

Figure 2.8.2.11.3.1-2 – Heavily corroded wire ropes; ropes with deterioration from corrosion should be evaluated for removal from service

Figure 2.8.2.11.3.1-3 – Broken wire on a wire rope

2.8.2.11.3.1.1 Inspection

During routine inspections, check the following:

- Observe the rope during a full operational cycle. Note if the rope contacts any portion of the bridge structure during the cycle. Prioritize inspection of the portion of the rope that is tangent at the tangent point on the counterweight sheave and the end of the rope at the lifting girder area when the movable span is closed, since these are the highest-wear areas of the rope.

C2.8.2.11.3.1.1

While written for Underground Mining Hoists, the Code of Federal Regulations, section 30 CFR §77.1434 Wire Rope Retirement criteria is recommended as the most applicable standard for determining when to retire wire ropes for movable bridges. These standards provide quantitative criteria for rope replacement based on deterioration, including (a) & (b)

- Closely examine individual wires for cracks or breakage. List the number of broken wires in one rope lay for each strand. The number of broken wires is a significant factor in determining the remaining life of the rope.
- Look for flat areas on the rope. These are areas indicating abrasive wear. Also note the length along the wire of the flattened portion of the wire, as it is a significant factor in determining the remaining life (based on industry standard guidelines) of the rope. The criteria for determining the remaining life of a wire rope can be obtained from the wire rope manufacturers.
- Measure the diameter of the rope. Reduction of the diameter is an indication of problem within the interior of the rope.
- Check for dirt and foreign matter in the lubricant, and note the adequacy of the lubrication.
- Check the sheaves to be sure the rope is properly seated in the sheave groves.
- Observe the wire rope for any distortion such as kinking, crushing, main strand displacement or core protrusion.
- Check for corroded or broken wires at end connections.
- Measure and record the tension in all wire ropes.
- Tension values should to be compared with original and previous report values. The tension can be estimated by timing the natural frequency $f = \frac{1}{2L}\sqrt{T/m}$ or by the use of an electronic rope tension meter.

  T = tension in rope (lbs.)
  m = mass/unit length of rope = lbs/ft/32.2 ft/sec^2
  f = frequency (cycles/second) that can be estimated or measured using a smart phone with a vibration app.

2.8.2.11.3.2 Sheaves and Drums

Sheaves are large-diameter, annular-grooved drums over which the ropes connecting the span and counterweight pass. Sheaves are mounted on trunnion bearings that usually have a split bushing. The bottom half of the bushing is generally bronze, and since there are no upward forces on the sheave, the top half of the bushing could be made of a variety of materials: bronze, babbitt, or simply a dust cover. Clearance between the bushing and shaft should be checked only if the top half is a bearing material.

Although similar in appearance to sheaves, operating drums are located on the span. They are grooved in a spiral fashion, and rotate in bearing assemblies. Operating drum bushings are usually the split bronze type, and the clearance should be checked.

the number of broken wires within a rope lay length, (c) the loss of diameter of outer wires, (d) rope deterioration due to corrosion, (e) distortion of the rope, (f) heat damage, (g) diameter reduction of the rope, or (h) loss of more than ten percent of rope stress as determined by testing.

Rope manufacturers, as well as the U.S. Navy, publish manuals with standard inspection procedures and analysis techniques which can be helpful in determining the remaining strength and life of ropes.

On lift spans at windy sites, the length of standing cables, the configuration and alignment of the sheaves on moving cable and the socket grooves on standing cables can be critical factors in the service life of cables. Long vertical cables may be subject to wind induced vibrations that can cause rubbing against sheaves or spreader socket grooves that do not provide proper flared, radius entries for the cable. Sharp edges in such areas can cut the wires or lead to rapid abrasion that drastically lowers the service life. The grinding of the sharp edges, addition of chafe protection such as wire or leather should investigate the entry and exit points of cables from sheaves, sockets and spreaders carefully during routine and in-depth inspections. wrapping, and addition of wind vibration dampers or clamps should be considered in such cases to extend service life.

2.8.2.11.3.2.1 Inspection

During routine inspections, check the following:

- Check rope grooves for signs of rust or corrosion, and the presence of any abrasive material.
- Look for indications of rubbing between ropes and grooves.
- Check the condition of the lubrication on the grooves, and examine it for foreign matter.
- If practical, check trunnion bearing clearance.

During in-depth inspections, the following should be added:

- Remove bearing cap and inspect shaft. It should have a mirror finish (see Figure 2.8.2.11.3.2.1-1). If it is scored, recommend that it be polished. Do not operate the bridge with the bearing cap off.
- Inspect grooves with the use of groove gauges.

Figure 2.8.2.11.3.2.1-1 – Scored sheave shaft; while not visible in this photo, shaft has bronze imbedded in the surface, indicating "severe" wear on bushing

2.8.2.11.3.3 Trunnions

Sheave and drum trunnions are similar in construction to the symmetric type trunnion assemblies described for trunnion bascules and should be inspected by the methods presented for trunnions and trunnion bearings in Sections 2.8.2.11.1.1.1 and 2.8.2.3.3.1. (See Figure 2.8.2.11.3.2.1-1.)

2.8.2.11.3.4 Tension Adjusting Devices

Tension adjusting devices are provided to remove slack and ensure uniform tension in the operating ropes. These special machinery components are located on the tower columns, and serve as the anchors for the uphaul and down-haul ropes. There are several designs for adjusting devices, including long, threaded eyebolts with turnbuckles and hand operated worm wheel mechanisms. Data for proper tension, usually given in the design plans, should be checked before making adjustments.

2.8.2.11.3.4.1 Inspection

During routine inspections, rope sockets, eye bolts, turnbuckles, and worm wheel adjusting devices should be inspected for corrosion, wear, and proper lubrication.

2.8.2.11.3.5 Span Guides

Span guides and rollers are commonly used to restrict lateral and longitudinal movement of the span during operation. The rollers, which are located on the span, travel on vertical tracks or plates mounted on the tower columns. Sliding guides are also occasionally used, and operate in the same manner. A typical span guide arrangement is shown in Figure 2.8.2.11.3.5-1. Note that only one corner of the span is restricted in both directions, allowing for longitudinal expansion and contraction of the span. The guides, located on the four corners of the span, maintain a close clearance (in the range of $^1/_4$ to $^5/_8$ in.) (6.350 to 15.875 mm) over guide rails located on the tower columns.

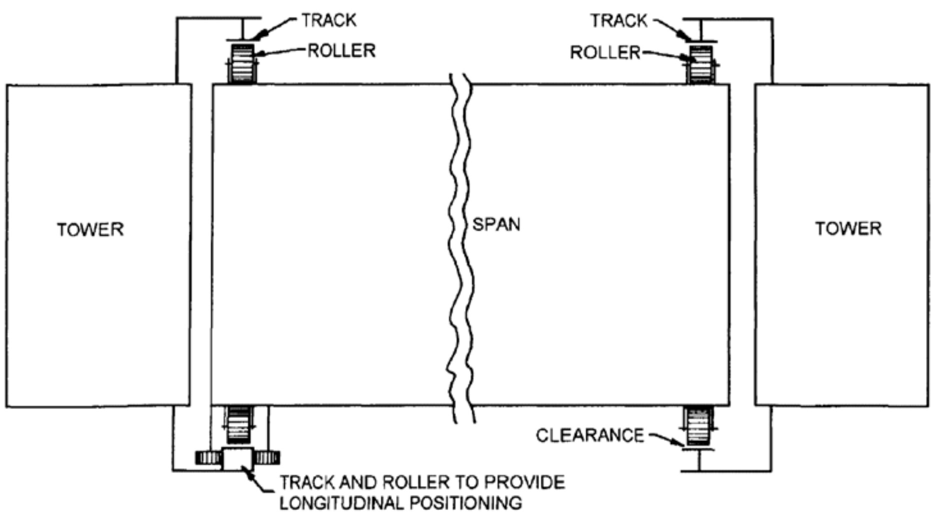


Figure 2.8.2.11.3.5-1 – Schematic of typical span-guide rollers; sliding-type guides are also used

2.8.2.11.3.5.1 Inspection

During routine inspections, check the following:

- Have the bridge operator raise span a few feet and check clearance at all four corners. Check clearance again with span 1.0 ft. (0.3 m) from the top. Be sure proper clearance is maintained for the entire length of travel of the span. Temperature should be recorded, as this can affect clearances.
- On roller-type guides, be sure the rollers rotate freely.

- On sliding guides, be sure tracks are adequately lubricated for their entire length. Proper lubrication is essential on this type of guide.

2.8.2.11.3.6 Auxilary Counterweights/Balance Chains

The purpose of counterweights is to offset the weight of the span. If the span and counterweights are in perfect balance, the load on the drive machinery is minimal. If there is severe imbalance, additional loads are put on all operating components. Lift spans should be balanced to have a small positive dead load reaction (i.e. slightly span heavy) at the supports when closed.

An unbalanced condition can result from the weight of counterweight ropes as they pass from one side of the sheave to the other. On smaller bridges with only a few ropes the imbalance is not significant. However, on large bridges, the counterweight ropes can weigh several tons [(KiloNewtons (kN)]. An imbalance of this magnitude would overload the bridge operating machinery.

Auxilary counterweights or balance chains are installed on some bridges to compensate for the weight of the ropes. The auxiliary counterweights are typically steel supported on wire ropes. The chains, made of heavy links pinned together, are connected to the tower and the bottom of the counterweight.

The operation of balance chains is illustrated in Figures 2.8.2.11.3.6-2A and 2.8.2.11.3.6-2B. In Figure 2.8.2.11.3.6-2A, the span is raised and most of the rope is on the counterweight side of the sheave. In this position, the balance chain is supported by the tower.

When the span moves down (see Figure 2.8.2.11.3.6-2B), the rope is transferred to the span side. At the same time, the balance chain is raised, adding weight to the counterweight and maintaining the balance of the system. The auxiliary counterweight operates in a similar fashion to offset the weight of the ropes as the span moves up (see Figures 2.8.2.11.3.6-3A and 2.8.2.11.3.6-3B).

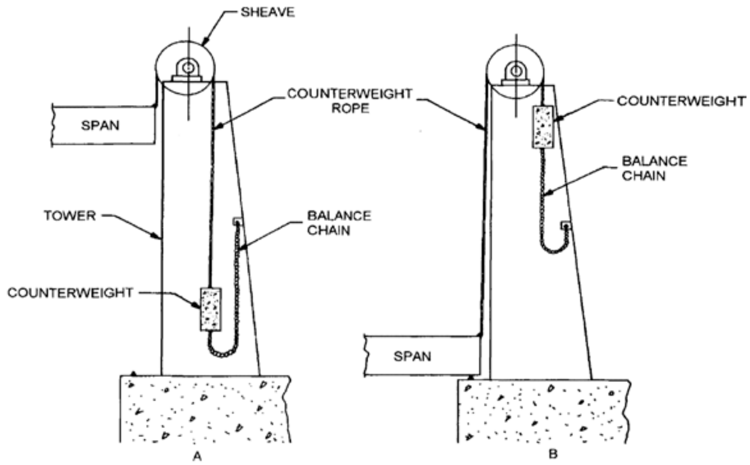


Figure 2.8.2.11.3.6-2A & B – Operation of balance chains

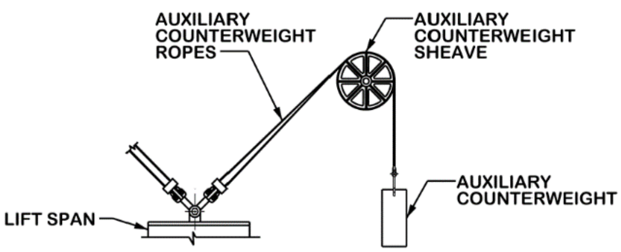


Figure 2.8.2.11.3.6-3A – Operation of auxiliary counterweight

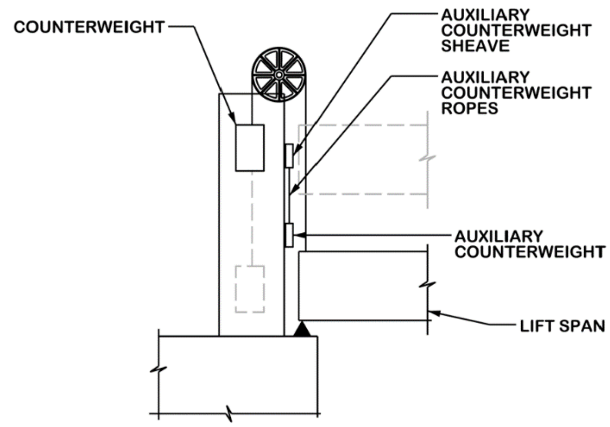


Figure 2.8.2.11.3.6-3B – Operation of auxiliary counterweight

2.8.2.11.3.6.1 Inspection

During routine inspections, check the following:

- Each link is pinned to its adjacent link and should not bind or undergo irregular movement during operation of the bridge, as seen in Figure 2.8.2.11.3.6.1-1. Pins and links should be well-lubricated and free from corrosion and foreign material.
- Check connection of the balance chain to the tower and the counterweight for corrosion and loose, broken, and missing fasteners.

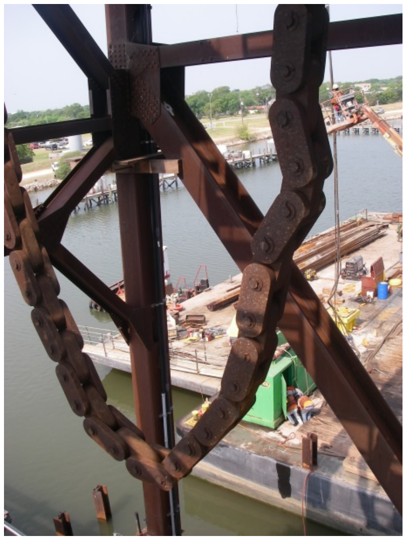


Figure 2.8.2.11.3.6.1-1 – Binding of links in balance chain

2.8.2.11.3.7 Span Leveling Devices

After prolonged operation or severe conditions of unbalance, slippage between counterweight ropes and sheaves could prevent proper seating of the span. Vertical-lift bridges are equipped with special machinery to adjust the span if one side seats before the other.

The simplest leveling device is the adjustable coupling (Figure 2.8.2.11.3.7-1). It is usually a single engagement gear coupling with large diameter plates bolted to each coupling half. A large number of holes are drilled near the circumference of each plate, and one plate has fewer holes than the other.

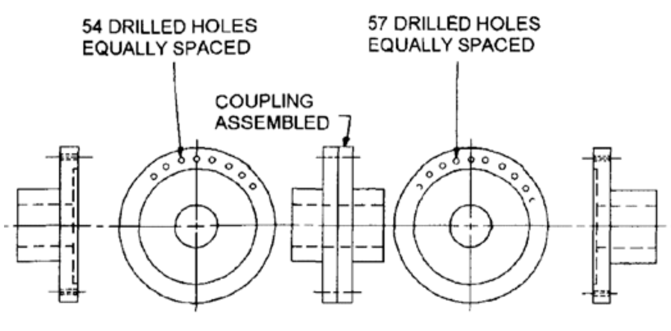


Figure 2.8.2.11.3.7-1 – An adjustable coupling for span leveling

Since there are an unequal number of holes, most of the holes are offset. However, since the number of holes in each plate is divisible by three, three holes spaced 120° apart will line up. Removing the bolts and rotating one of the plates very slightly will bring another set of three holes into alignment.

Some vertical-lifts have a locking clutch at each end to level the span. It is often located in a special differential primary reducer. As long as the clutch is engaged, both sides are driven equally. Release of the clutch will allow the side with the least resistance to move first. When a corner does not seat, the clutch is disengaged, permitting that corner to properly seat. Normally this type of clutch is electrically released by a thruster, interlocked to operate only when one corner of the span is within a few inches (centimeters) of the seat.

2.8.2.11.3.7.1 Inspection

During routine inspections, check the following:

- The inspector should check the bolts to be sure they are tight and free from corrosion.

Since clutch mechanisms of this type are seldom used, wear is not a problem. However, the inspector should visually check the external condition of the clutch and associated machinery. If practical, have the bridge tender operate the clutch to check proper clutch function.

2.8.2.11.3.8 Lift Span Centering Devices

Centering devices are provided to insure that the roadway on the movable span is properly aligned with the fixed spans. Normally centering devices are located on the substructure, beneath the roadway (Figure 2.8.2.11.3.8-1). Provision is made on long spans to accommodate thermal expansion and contraction by fixing one end of the span and permitting the other end to expand or contract.

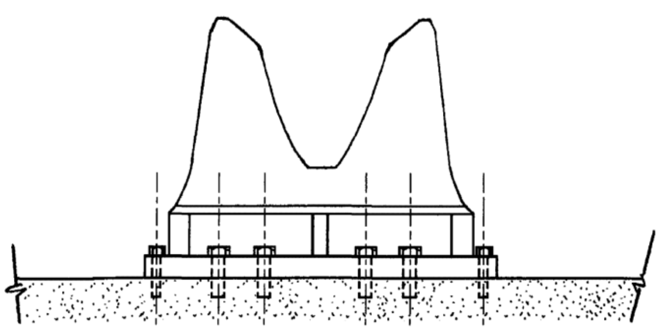


Figure 2.8.2.11.3.8-1 – Centering pocket for a vertical-lift bridge

2.8.2.11.3.8.1 Inspection

During routine inspections, check the following:

- Make sure the tapered guide on the lift span is properly aligned with the guide pocket. Any deformation of the guide or polishing of the inside surface of the guide pocket may indicate misalignment of the bridge. Polishing or plastic flow on one side indicates the span is out of alignment in that direction.

- Check for adequate lubrication in the guide pocket.
- Check fasteners and bolts for corrosion and deterioration, and check bolts for tightness.

2.8.2.11.3.9 Span Locks

The locks that hold the span securely against vertical movement consist of horizontal steel bars, inserted through guides on the span into receiving sockets on the towers. Sometimes, a latch type span lock is also used. The lock bars are withdrawn from the sockets, or the latches disengaged before the span is moved. Electrical interlocks prevent the span elevating drive from starting until the lock bars are completely withdrawn. One lock on each end of the span is normally sufficient to secure the span.

The span locks shown in Figures 2.8.2.11.3.9-1 and 2.8.2.11.3.9-2 are used only on vertical-lift bridges.

In the wedge shaped lock (Figure 2.8.2.11.3.9-1), a jacking mechanism delivers the thrust for the wedge to be driven through the guide, rigidly attached to the pier, and the socket, attached to the lift span. The jacking system may be either an electric motor driven mechanical jack or a hydraulic jack.

In the latch type of lock bar (Figure 2.8.2.11.3.9-2), an actuator moves the latch which engages a bracket attached to the movable span.

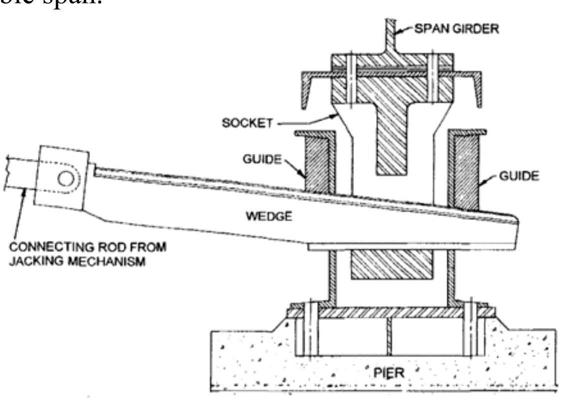


Figure 2.8.2.11.3.9-1 – A wedge shaped lock used to hold a vertical-lift span rigidly in place

C2.8.2.11.3.9

There are many types of devices used to lock the movable span in the open and closed positions. Most are mechanical, but some are hydraulic or spring-activated. Although more widely used on bascule bridges, self contained electric motor driven, dead-bolt type span locks are also used on vertical-lift bridges. The description and inspection of the self contained and the conventional lock bar machinery is covered in Sections 2.8.2.11.1.4 and 2.8.2.11.1.4.1.

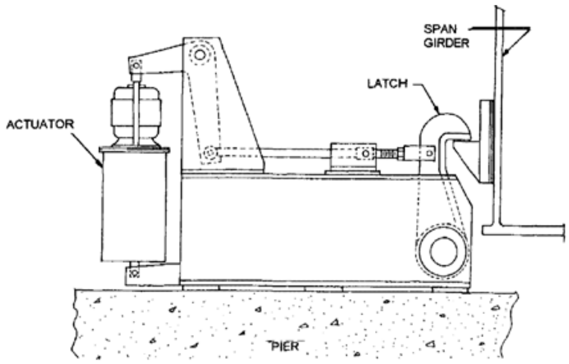


Figure 2.8.2.11.3.9-2 – A latch type lock used on vertical-lift bridges

2.8.2.11.3.9.1 Inspection

During routine inspections, check the following:

- Measure dimensions of the bronze liner in the socket, and inspect for wear. If it has excessive wear, it should be either adjusted or replaced. Make sure there is adequate lubrication and that fasteners on the sockets are secure.
- Measure bar dimensions and compare with the design dimensions.
- Check the bar closely for evidence of top, bottom, or side wear. If bar or socket exhibit an abnormal amount of wear, the span may be misaligned or the guides and sockets may have shifted.
- Measure the clearance between the bar and the guides, and the bar and the sockets. It may be necessary to have the bridge operator raise the span slightly to make these parts more accessible.
- Inspect individual drive components such as gears, bushings, motors, hydraulic systems etc. as per Chapters 2.8.2.1 through 2.8.2.10 and 2.8.2.12.
- Span lock hand cranking and all necessary hand cranking tools should be inspected.

2.8.2.11.4 Special Machinery Component Coding Guidelines

As discussed in Section 2.8.2.10, some design data for mechanical components is proprietary, making quantitative assessment of defects difficult. This section presents general guidelines to assist in coding "poor" or "severe" conditions in special mechanical components.

2.8.2.11.4.1 Bascule Components

Trunnions: Trunnions are primary support system components that must be able to carry applied loads in the open

C2.8.2.11.4.1

Trunnions are vital components that can be "severely" damaged in a relatively short and closed positions and during leaf motion without distress. Noises of any kind emitted by the trunnion bearings should be interpreted as evidence of serious distress. Noises should be coded “poor” or “severe” depending on the inspector's interpretation of the cause of the noise. Trunnions that knock, thump or bang are in all likelihood experiencing high torque stresses due to stick-slip phenomena caused by damaged bearing surfaces, abrasive particles in the lubricant, or other potentially hazardous causes. These conditions should be coded “severe” and an immediate deficiency report filed. If a follow-up engineering investigation including disassembly or borescope evaluation of the bearing surfaces concludes that the trunnion is serviceable, the coding can then be based upon engineering judgment interpreting the evaluation report. Lack of lubrication or signs that the lubrication passages may be plugged with hardened lubricant or debris should be coded “severe” and should cause filing of an immediate deficiency report.

Trunnions that are misaligned or show signs of support structure distress, excessive deflections of the pin or support structure, or continuing settlement or movement of the bearing supports should be coded “severe” unless an engineering study and/or capacity analysis shows that the components affected are serviceable.

Excessive bearing clearances should be coded “poor” unless noises, motion, or other evidence of bearing distress are present.

Segmental girders, track girders, and tread plates: These rolling lift bridge components are often found to exhibit signs of overstress, especially in older bridges. Cracking, signs of severe wear or plastic flow of the tread plates, deformation of tread plates and/or stiffeners and tread connection angles, fastener breakage, and various other signs of distress may be found. Any such defect that gives evidence of overstress should be coded “severe” unless an engineering study has disclosed that the condition does not adversely affect the short-term serviceability. The long-term solution to such observed defects usually involves rehabilitating the structure and replacing the plate. In the short term, after performance of an engineering study, the distressed components may be coded “poor” provided that a program of interim inspections of the defect is instituted that will provide timely detection of potentially hazardous changes in condition.

Bascule centering devices: Centering devices on bascules are holdovers from design of railroad type bascules, where precise alignment of the rails is critical to safe operation. They are only necessary on highway bridges insofar as they may serve to provide proper alignment for live load shoes, rests, and/or span locks. Wear and minor misalignment of centering devices on bascules should be coded “poor,” not “severe,” unless the condition presents a hazard to the traffic safety or problems with the alignment of span locks, live load shoes, period of time by lack of lubrication. Owners should develop QC/QA procedures to verify that trunnions and other critical components are properly lubricated on the required schedule. The owner should assign the responsibility for verifying that lubrication logs are being maintained and that field observations are consistent with the log contents. The assigned inspectors or evaluators should regularly evaluate the lubrication record keeping. Is a lubrication chart present in the machinery space? Is a copy of the lubrication log present in the operator's house or machinery space?

rests, or other vital components are also present.

Span locks: Span locks that show signs of vertical movement under heavy live loads should be coded "poor." If the vertical movement exceeds ½ in. (12.7 mm), the locks should be coded "severe" until rating calculations are performed to prove that the imposed stresses on primary members do not represent a hazard. If calculations are available, a case specific maximum deflection to cause a rating of "severe" should be developed and added to the bridge file for each type of lock.

Hopkins frame: Frames or components that are cracked should be coded "severe" unless analysis calculations have been performed to determine that the cracks are self arresting (or arrested by corrective action) and have an adequate safety margin against brittle fracture.

Frames or frame supports are subject to the same evaluation methods for corrosion losses as other structural components as discussed in Section 3.2. The individual pins, motors, brakes, shafts, bearings, couplings and other components of a Hopkins Frame are subject to the coding guidelines presented for those individual components elsewhere herein.

Signs of excessive frame deflection or movements at connections or supports during movable bridge leaf operation should be coded "poor" or "severe" based upon the inspectors evaluation of the causes and potential consequences of such motion. Deflection or motion of frame components or supports exceeding ⅛ in. (3.2 mm) should be coded "severe" unless calculations have been performed that determine larger motions are acceptable.

2.8.2.11.4.2 Swing Components

Center bearings: The coding guidelines for center bearings are similar to those presented under Section 2.8.2.11.4.1 for trunnion bearings. Signs of vertical or horizontal movements of any magnitude should be coded "severe" on a center bearing, pending further investigation.

Balance wheels and track: Rollers of balance wheels that show signs of dragging instead of rolling should be coded "severe." Balance wheels that squeal or emit other noises such as grinding, snapping, or banging when rolling should be coded "poor" unless the inspector believes that they may lock prior to the next inspection, in which case they should be coded "severe." In any such event, a deficiency report should be filed recommending cleaning and lubrication of wheels and track. The balance wheel track should be level and provide a surface that allows the balance wheels to roll freely. If this is not the case, then the track should be coded "poor" or "severe" based upon the inspector's assessment of likely consequences of the observed conditions.

Tapered rollers: Rim bearing rollers support the vertical loads from the swing span and are primary members in the support system for a rim bearing type swing bridge. Individual rollers that do not turn during span motion, that exhibit excessive bearing clearances or signs of damaged axle bearings or axle rotation due to dragging of the wheel bearing roll should be coded "severe." If more than 25 percent of the rim bearing rollers are individually rated "severe," then the entire rim bearing assembly should be rated "severe" until rating calculations are performed to provide a basis for coding based upon engineering judgment.

Wedges, end lift jacks, and shoes: Swing span wedges and end lift and support devices contain a number of unique mechanisms that are not typical to other types of movable bridges, but they are subject to the same coding guidelines presented in Section 2.8.2.10 for live load shoes or wedges. Wedges, jacks and shoes should be evaluated for percentage of full bearing of the bearing surfaces in contact when driven. Coding should be based on Table 2.8.2.11.4.2-1 unless calculations are performed to allow coding based on engineering judgment.

Table 2.8.2.11.4.2-1 – Wedge, jack, and shoe bearing area condition coding guide

Measure bearing contact area length and width in contact when the wedge, jack or shoe is fully driven. Divide computed actual bearing area by available contact area surface of smaller component. Compute percentage of actual versus available contact area and code condition rating as follows.		
Percentage Bearing	Condition Coding	Comments
100%	GOOD	Bearing surface clean - no pitting
90% to 100%	FAIR	Minor pitting over <10% of actual
75% to 90%	POOR	Pitting may be present over <20% of actual
< 75%	CRITICAL	Pitting over > 25% of actual contact area is a separate cause for coding critical

Swing span centering latches: Swing span centering latches should be primarily evaluated based upon performance. Latches that do not reliably achieve centering when the span is closing should be coded "poor" or "severe" based upon the percentage of opening/closing sequences in which they fail to function. A latch that functions properly for a percentage of openings during the time period evaluated should be coded as shown in Table 2.8.2.11.4.2-2. The time period evaluated may vary, but should not represent less than 400 openings or ten percent of the number of openings per year, whichever is the lower number.

Table 2.8.2.11.4.2-2 – Swing span centering latches condition coding guide

Functioned properly during the stated percentage of opening	Condition Coding
More than 90 percent	"Good"
Between 75 percent and 90 percent	"Fair"
Between 60 percent and 75 percent	"Poor"
Less than 60 percent	"Severe"

Other "poor" or "severe" condition ratings may also be present based on structural condition (see Section 3.2) or excessive deterioration of individual mechanical or electrical components as discussed elsewhere for such components. These ratings should be modified by judgment based on their anticipated impact on latch operation.

Drum girder: Drum girder structural coding should be based on the requirements of Section 3.2. Tapered roller treads should be coded based upon the requirements for rolling lift tread plates and balance wheel treads herein. Any signs of cracks, holes, vertical or horizontal motion of the drum girder relative to the rollers or support structure should be coded "severe" until an engineering study is performed to allow coding based on the engineering judgment using the result of the study.

2.8.2.11.4.3 Lift Span Components

Wire ropes and sockets: ANSI replacement standards have been developed for running and standing wire rope fittings on various types of cranes and hoists. The presence of wear and abrasion in running wire ropes and the presence of kinks, cracks in wires, and breaks in wires for running or standing wire ropes should be coded "poor" or "severe." ANSI standards AIO.4 and AIO.5 for hoists and B30.2 through B30.8 for various types of cranes, derricks, and hoists indicate that a wire rope should be replaced based upon the number of broken wires and a number of other criteria. Wire rope that is categorized by any of the following criteria is recommended therein for replacement:

- is crushed or flattened
- shows evidence of jammed, high strands or unlaying of strands or wires; bird caging; severe internal corrosion; excessive stretching; core protrusion; heat damage; torch burn; or arc strikes

- has kinks, bulges, gaps or excessive clearance between strands or wire

For movable bridges the presence of such conditions should be coded "fair," "poor," or "severe" based upon the number of wires affected or as presented in Table 2.8.2.11.4.3-1.

The table assumes a minimum factor of safety of 4 was used for design of standing ropes and a factor of safety of 6 for the design of running ropes.

Table 2.8.2.11.4.3-1 – Wire rope coding criteria

	Number of wires broken or damaged in two strand lays			
	In running wire ropes		In standing wire ropes	
	In entire rope	In one strand	In entire rope	In end connection
"Fair"**	2 or less	1 or less	1 or less	N/A
"Poor"**	3,4, or 5	2	2	1 or less
"Severe"*	6 or more	3 or more	3 or more	2 or more

*based on ANSI replacement specifications
**developed from ANSI replacement data

Sockets and Other Fittings: Sockets and other fittings that are severely corroded, cracked, bent, worn, or improperly applied should be coded "severe" unless an engineering study finds that they are serviceable.

2.8.2.12—Hydraulic Components

Some movable bridges' functional systems may employ hydraulic components to create controlled appropriate motion. The purpose of this section is to discuss inspection of hydraulic components. It is intended for specially trained inspectors and maintainers. The coordination of inspection and maintenance efforts, as discussed in Section 2.8.2, is applicable to hydraulic components as well. Chapters 2.8.2.1 through 2.8.2.10 cover mechanical components and the general statements about the purposes of mechanical components therein also apply to hydraulic systems.

Leaks in high pressure hydraulic systems are potentially hazardous to personnel. Eye protection is necessary at all times when inspecting hydraulic components and it is extremely inadvisable to check for leaks with bare fingers or hands. High pressure oils are capable of causing severe injury if a leak develops. Use a tool, such as a clean paint stirrer stick or other

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See Section 2.4 for inspector qualifications. Individuals who disassemble hydraulic system components should be properly trained as hydraulic specialists. Disassembly of hydraulic components can be hazardous.

Since many types of hydraulic components are available, it is not feasible to provide specific data pertinent to disassembly and troubleshooting of specific brands. Inspectors and maintainers should obtain copies of manufacturer's data for specific components to be inspected or disassembled and review it prior to performing any inspection or maintenance work on hydraulic components.

device, to verify the location of pinhole leaks or other leaks that produce a high pressure jet of fluid.

Inspectors and maintainers should be properly trained hydraulic specialists. Manufacturer's catalogue cuts and recommended inspection and maintenance procedures for individual components should be obtained by the inspectors/maintainers.

Routine inspection should, in general, not include any disassembly of components, but should be based upon close visual inspection for leaks, operational performance testing, and verifying system pressures. In-depth inspection should include all the items done for routine inspection and also disassembly and special testing as necessary. A schematic diagram for the hydraulic system should be reviewed before attempting any disassembly for inspection purposes. Disassembly should be done during in-depth inspections or if previously noted problems indicating internal defects must be investigated. Disassembly should be done only by experienced, qualified personnel.

2.8.2.12.1 Hydraulic System Basic Principles

One of the basic theories behind hydraulic systems can be reduced to the following equation:

$$F = PA \qquad \textbf{Equation 2.8.2.12.1-1}$$

where:

F = Force, in any units (pounds, kips, or kN)
P = Pressure, in units consistent with F and A, e.g., in psi (MPa) if F = lbs. (N) and A = in^2 (mm^2)
A = Area on which the pressure acts, in units consistent with pressure, e.g., A = in^2 (mm^2) if P = psi (MPa)

This static equation indicates how mechanical advantage is gained in a hydraulic system (more area = larger force). The simplest form of a hydraulic system, a basic hydraulic jack, shown in Figure 2.8.2.12.1-1, can be used to illustrate the principle.

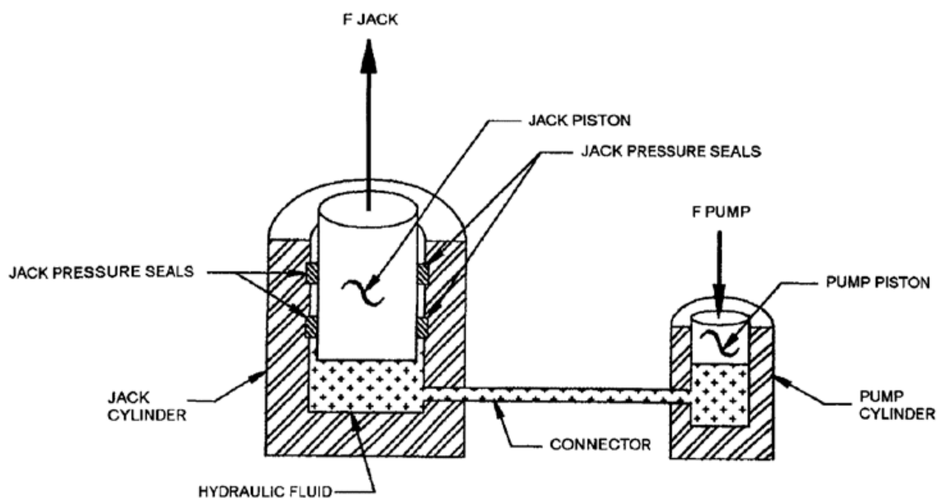

Figure 2.8.2.12.1-1 – Basic hydraulic jack, which illustrates basic hydraulic principles

By applying Equation 2.8.2.12.1-1 to Figure 2.8.2.12.1-1, assuming that the hydraulic fluid is incompressible and that the pressure in the jack and the pump cylinders is equal (i.e. no pressure loss in the hose or pipe between the cylinders) the following relationship results:

$$P_{pump} = \frac{F_{pump}}{A_{pump}} = \frac{F_{jack}}{A_{jack}} \qquad \textbf{Equation 2.8.2.12.1-2}$$

$$\text{or} \quad F_{jack} = F_{pump} \times \frac{A_{jack}}{A_{pump}}$$

Using Equation 2.8.2.12.1-2, the mechanical advantage between the force applied at the pump piston and the force developed by the jack is the ratio of the piston areas. If the area of the jack piston is ten times the area of the pump piston, then the hydraulic system mechanical advantage is ten to one. One pound (Newton) applied to the pump piston will provide ten pounds (Newtons) of force at the jack piston.

Hydraulic motors may also use torque multiplier principles as explained in Appendix A for gear systems. Hydraulic system design is a complex task that should be performed by a certified fluid power engineer. However, for the purposes of basic inspection, the above simplistic model should suffice.

2.8.2.12.2 Hydraulic Components on Movable Bridges

Hydraulic systems used on movable bridges are more complex than the above example. The large distances between the pump and the jack lead to pressure losses in the system. In addition, the speed of motion and force at the jack must be controlled. In general, fluid pressure controls force and fluid flow rate controls speed. On a hydraulic jack, speed is controlled by the person pumping the lever that applies force to the pump piston. On a movable bridge, the motion is usually controlled by valves that regulate the line pressure, direction of flow, and/or fluid velocity of hydraulic fluid from the pump to the jack, hydraulic cylinders, or other hydraulic devices that provide motion. Figures 2.8.2.12.2-1 and 2.8.2.12.2-2 illustrate a simple typical hydraulic system schematic layout and simplified piping and component layout. Additional complexity is added by the inclusion of the mechanical pumps used to pressurize the hydraulic fluid. The valves used to control flow or pressure are not usually as sensitive as a hand on a jack lever, so a means is needed to smooth out instantaneous pressure surges that can occur in an incompressible hydraulic fluid when a pump suddenly starts or stops, or a valve opens or closes quickly. This phenomenon is equivalent to a “water hammer” type pressure spike in potable water piping systems.

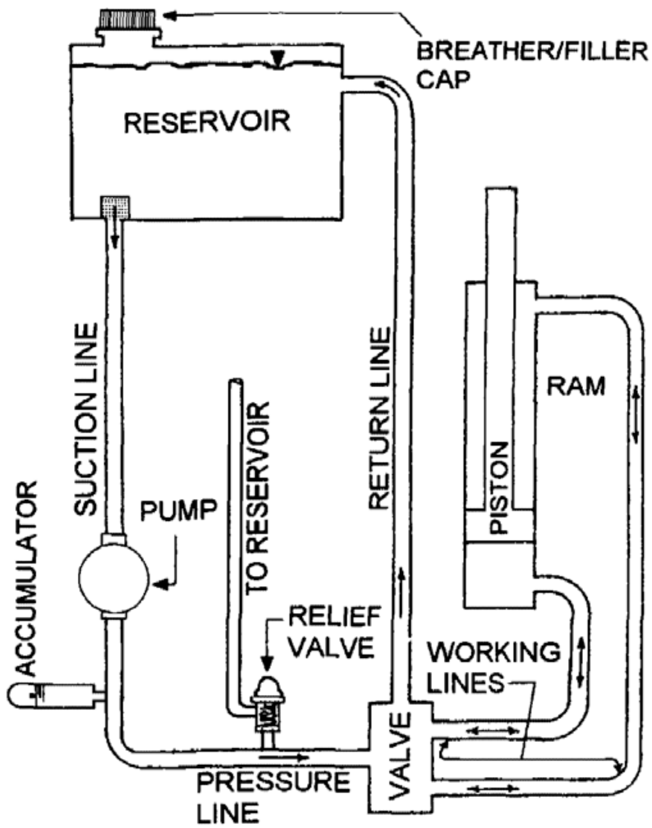

Figure 2.8.2.12.2-1 – Typical double-acting hydraulic system layout

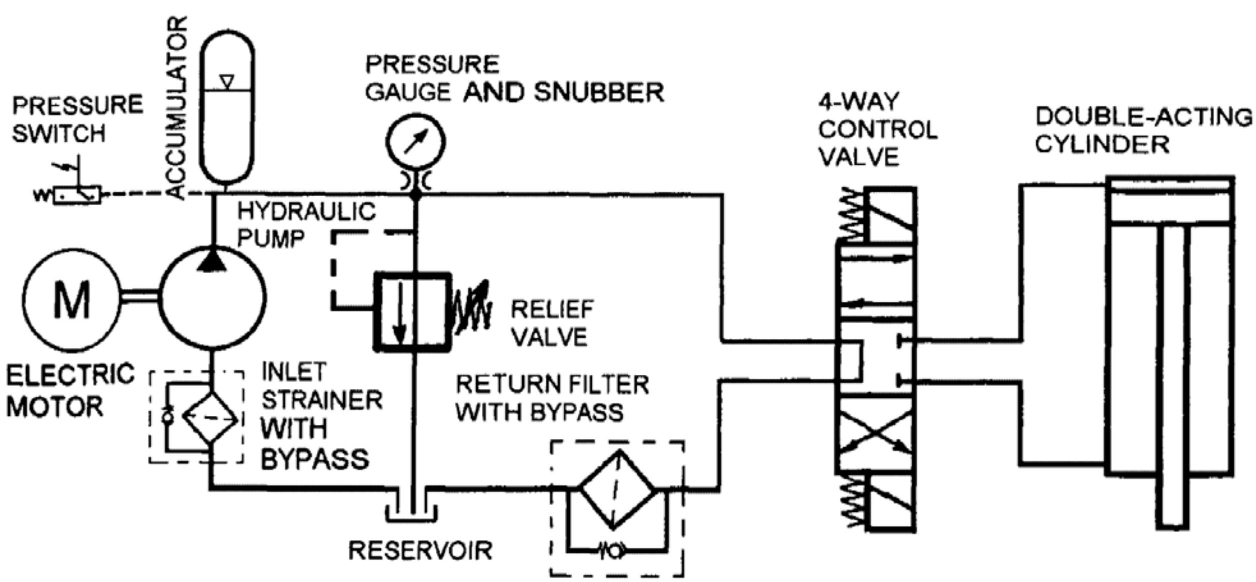

Figure 2.8.2.12.2-2 – Simplified hydraulic schematic circuit layout

2.8.2.12.3 Accumulators

An accumulator is a simple pressure tank containing a compressible inert gas or an elastomeric membrane bladder in contact with the hydraulic fluid, as seen in Figures 2.8.2.12.3-1 and 2.8.2.12.3-2.

The main reason for incorporating an accumulator in the system design is to serve as an energy storage device that reduces the power requirements and required pump size. The accumulator also serves to smooth out operating pressures so the pumps do not cycle on and off rapidly or run continuously during system operation. The fluid level rises and falls to absorb pressure spikes or "hammer" that might otherwise damage hydraulic system components.

Not all hydraulic systems utilize accumulators. A simple pressure relief valve, which allows fluid to escape to the tank, and numerous other devices can be designed to control overpressure "hammer" or other overpressure conditions.

On a movable bridge, the consequences of the failure of a hydraulic system component are typically quite severe. Petroleum products are not permitted to be discharged into navigable waterways. Hydraulic fluid leakage is therefore generally unacceptable. If existing hydraulic systems are encountered on movable bridges that do not have accumulators, and the system has a history of leaks and hydraulic line breaks, it may be appropriate to consider designing a retrofit incorporating accumulators.

Accumulators should be inspected during routine inspections for leaks and for the fluid level inside the tank. Insufficient inert gas cushion can be a major problem. Inspectors should listen to the accumulators during system operation and sound the tank with a hammer handle or mallet to determine fluid level during system operation and at rest, and mark them on the tank for future reference. Bladder type accumulators are more difficult to sound, but they are generally more reliable since the inert gas cushion cannot escape as bubbles in the fluid. One likely sign of inadequate inert gas cushion is rapid on/off cycling of the pumps. Other potential causes (e.g., a major leak, improperly set pressure switches, reduced actuator speeds) should be investigated prior to identifying the cause of rapid pump cycling as insufficient gas cushion in the accumulator.

An accumulator application has a specified gas pressure, based on the application. If pressure precharge is lower than specified due to valve leak, broken bladder, or small transfer of gas through membrane over time, then performance is affected. It is common to check and replenish precharge as necessary, similar to checking air in car tires. Inspectors need not disassemble the accumulator, but only check for gas pressure with a gauge to determine the need to replenish gas or to detect a broken bladder.

C2.8.2.12.3

The relationship between the fluid pressure and fluid temperature is given by the law of Gay-Lussac. The law of Gay-Lussac states that when the volume of a gas is held constant, the pressure of the gas varies directly with the absolute temperature of the gas, as graphically depicted in Figure C2.8.2.12.3-1. The law can mathematically be expressed as:

$$\frac{P}{T} = Constant$$

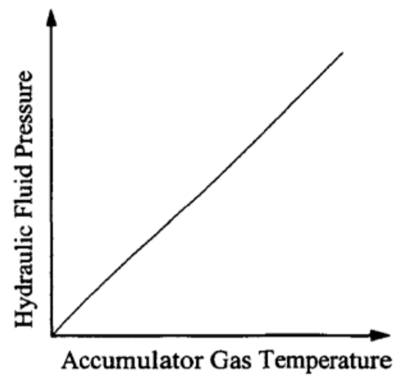

Figure C2.8.2.12.3-1 – Gay-Lussac's Law

Since accumulators are not to be disassembled by inspectors, further discussion of the various design types not included.

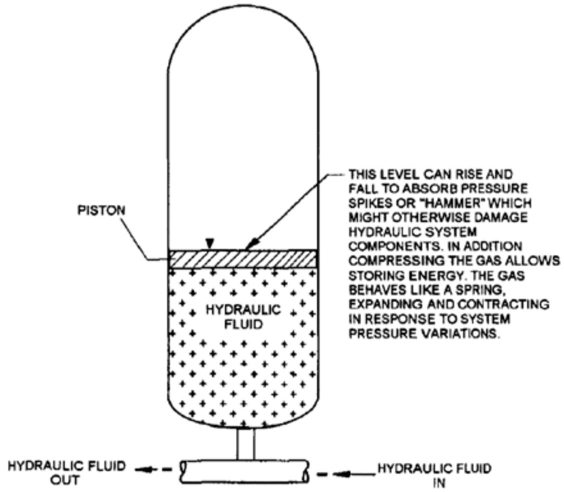

Figure 2.8.2.12.3-1 – Hydraulic piston type accumulator

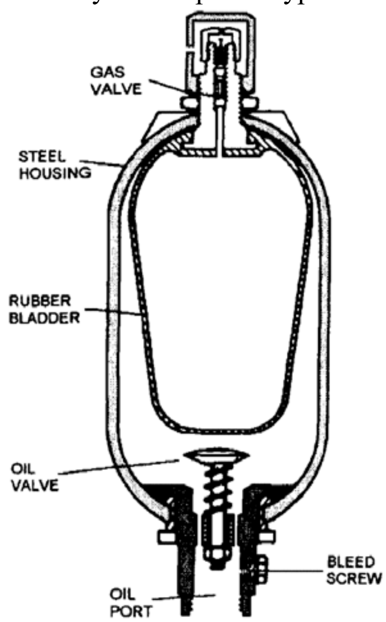

Figure 2.8.2.12.3-2 – Bladder type accumulator

2.8.2.12.4 Valves

There are three basic types of valves used in hydraulic systems:

Pressure control valves: Control pressure by opening in an overpressure condition (relief valves) or change the pressure from one part of the hydraulic system to another (pressure reducing valves). Sequence valves direct flow depending on the pressure.

Pressure control valves limit the pressure (and force) imposed on system components and hydraulic lines. Motion control or counterbalance valves provide smooth starts/stops of actuators.

Directional control valves: Control the direction in which hydraulic fluid flows through the lines. They can be one way (check valves), valves that allow flow only in one direction, or operator controllable valves that shunt fluid flow into different lines in response to control input. Operator controllable valves sometimes permit flow control as well as direction.

Flow control valves: Allow the operator to control the amount of fluid through the valve, and are used to regulate the flow rate of hydraulic fluid through the lines to control the speed of cylinder or hydraulic motor operation. One specialized type of flow control valve is an “equalizing” or “flow divider” valve that is used to confirm that two or more cylinders operate at the same speed.

Figure 2.8.2.12.4-1 shows a schematic of a basic pressure reducing valve, Figures 2.8.2.12.4-2 and 2.8.2.12.4-3 show two stage pilot operated and spool type pressure relief valves, while Figure 2.8.2.12.4-4 shows a check valve.

Directional valves on movable bridges are often remote solenoid actuated types. A four way, three position solenoid operated directional control valve is shown in Figure 2.8.2.12.4-5 and a two stage, four way, three position directional control valve is shown in Figure 2.8.2.12.4-6.

Manual ball valves are typically used as component isolators to allow disassembly for inspection, maintenance, or replacement of individual components. Modern valves often are complex electromechanical assemblies incorporating microswitches and sensors that can control system flow or system pressure.

C2.8.2.12.4

There are many different valve designs and functional mechanisms designed into valves available from various manufacturers. Inspectors and maintainers should obtain catalogue cuts, and inspection and maintenance data from operating or maintenance manuals or from the valve manufacturer to understand the design features and potential internal defects of individual valves. For the purposes of inspection, the questions to be answered are relatively simple:

- What is a valve supposed to do?
- Does the valve work?
- Does it leak?
- Is it likely to stop working or start leaking before the next inspection?
- Is the valve operating at the intended pressures (check pressures)?
- For pressure reducing valves, are the high and low pressures correct?

Relief valve operation should be verified during in-depth inspection.

The intended function of a pressure relief valve is of vital importance. Pumps are typically positive displacement which means that as long as the flow and load is constant, the pressure is constant. If the flow decreases or load increases, the pressure will increase to keep equilibrium. When flow stops, pressure increases rapidly and hose damage can occur. When a pump drives a cylinder, the pressure is constant as the piston extends. When the piston dead heads, the pressure rises quickly. The pressure relief valve or bypass valve redirects flow to the reservoir, thereby lowering pressure buildup.

The bypass pressure should be a specific set amount above dead head pressure and should be tested.

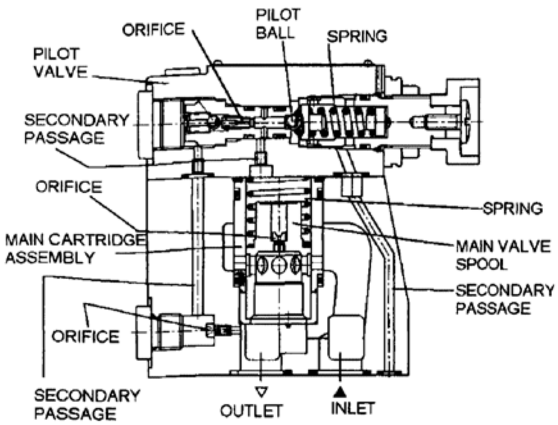

Figure 2.8.2.12.4-1 – Functional diagram of pressure reducing valve

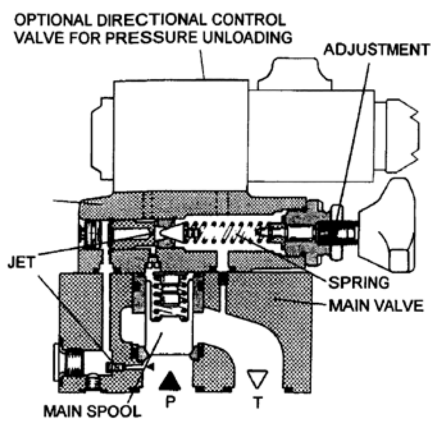

Figure 2.8.2.12.4-2 – Two stage pilot operated pressure relief valve

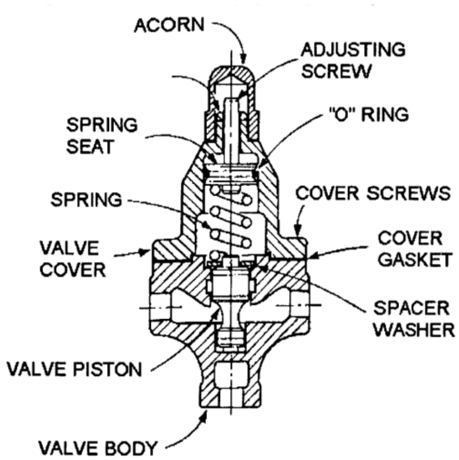

Figure 2.8.2.12.4-3 – Spool type pressure relief valve

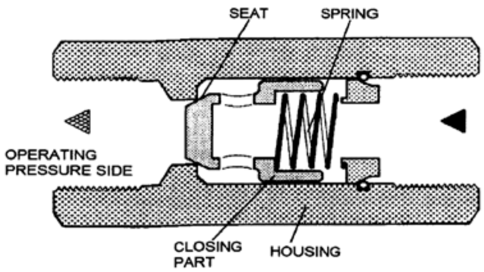

Figure 2.8.2.12.4-4 – Check valve

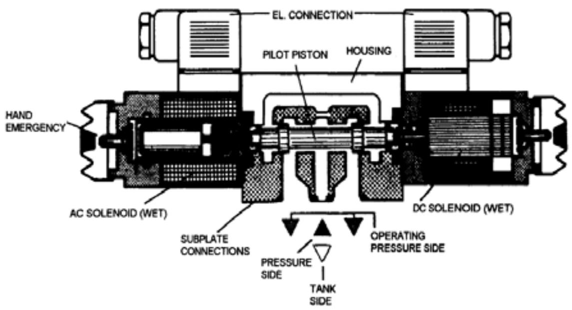

Figure 2.8.2.12.4-5 – Four-way, three-position (4/3) solenoid operated, directional control valve

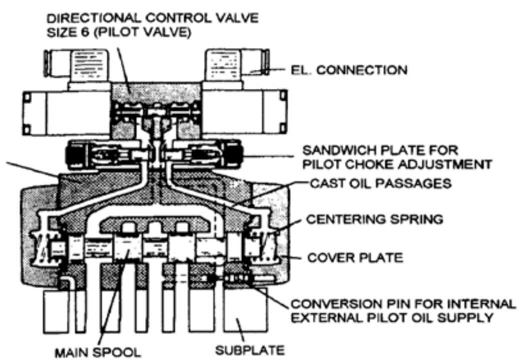

Figure 2.8.2.12.4-6 – Functional diagram of two-stage, 4/3 directional control valve.

Valves contain numerous seals and fittings that can wear out and/or leak. Inspectors should check valve function during routine inspections during operation by watching for unusual cylinder motion, jerking, or chattering, and in the lines during operation. Valves should be checked for leakage and the wiring of solenoid valves should be checked for wire and wire terminal connection condition. Manual control valves should be performance tested in all positions for sensitivity and operator "feel." If it is not possible for a skilled operator to "feather" the operation of a component controlled by a valve to avoid banging against the stops, corrective action should be recommended. Solenoids on solenoid type valves should be inspected as described for other types of solenoids in Chapter 2.8.3.

2.8.2.12.5 Hydraulic Cylinders

Inspectors should be aware of four factors that are most likely to reduce cylinder life: cylinder misalignment, high working pressure, high or low operating temperatures, and contamination of the fluid or seals. Abrasive grit or other harmful substances in the fluid or seals can score the polished surfaces of the cylinder assembly and/or damage the seals.

It is not enough to check for leaks and faulty operation as done for valves. Inspectors should check for conditions that can lead to rapid deterioration and should report such conditions for corrective action by deficiency report during routine inspections.

Side loads due to cylinder misalignment can cause rapid wear of bearings and cylinder bores. The least likely type of mount to have alignment problems is a fixed mount that carries loads on the cylinder centerline (if it is installed properly). Pivot mounts that carry loads along the cylinder centerline are also less likely to have misalignment problems. Misalignment is most likely in a fixed type side mount that is asymmetric and does not carry load along the centerline of the cylinder. Misalignment is least likely in the pivot mount or the standard construction machinery type cylinder that has clevis pin mounts at both ends (see Figure 2.8.2.12.5-1 for illustration of mount types and Figure 2.8.2.12.5-2 for a typical cylinder).

Pressure must be maintained within the manufacturer's recommended working levels. Inspectors should check working pressure at the cylinders by means of the working pressure gauges during system operation. If gauges are not present, they should be installed or inspectors should have portable gauges.

Fluid temperatures should be checked by inspectors during routine inspections before system operation, during operation, and again after running the system through several cycles to check for heat buildup. Individual cylinders should be checked by hand for heating, and if they seem too warm should be checked with a thermometer and the cylinder temperature and air temperature recorded for monitoring. Temperatures above 200°F (93°C) or below 44°F (7°C) are not generally acceptable unless specifically permitted by design. Current AASHTO specifications (Reference 6) require a maximum temperature of 140°F (60°C) in the reservoir, and this is the preferred maximum temperature to prolong seal working life. Temperatures above or below this range may cause operational problems. Systems installed in cold climates should be fitted with thermostatically controlled fluid immersion heaters, and the lines insulated, fitted with heat tapes, or provisions made to circulate heated fluid periodically to maintain acceptable temperatures. Extreme heat or cold can cause valves to malfunction, seals to fail, localized system overpressures due to frozen water contamination, or valve malfunction due to ice or varnish accumulation, or some combination of these. Cylinders should be checked for leaks and for scratches, corrosion, or other marks on the shaft that might cause rapid seal wear.

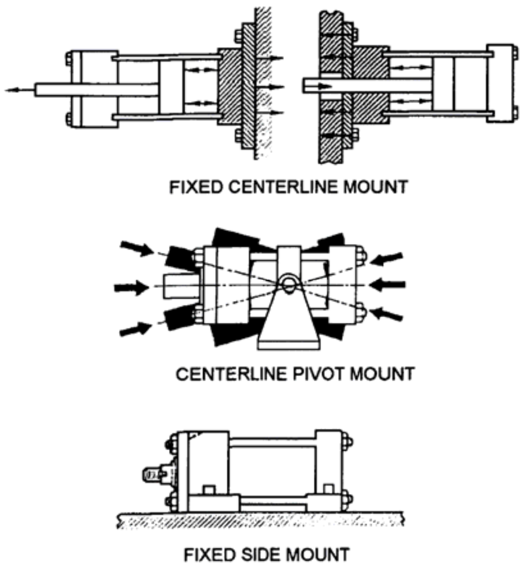

Figure 2.8.2.12.5-1 – Typical types of mounts

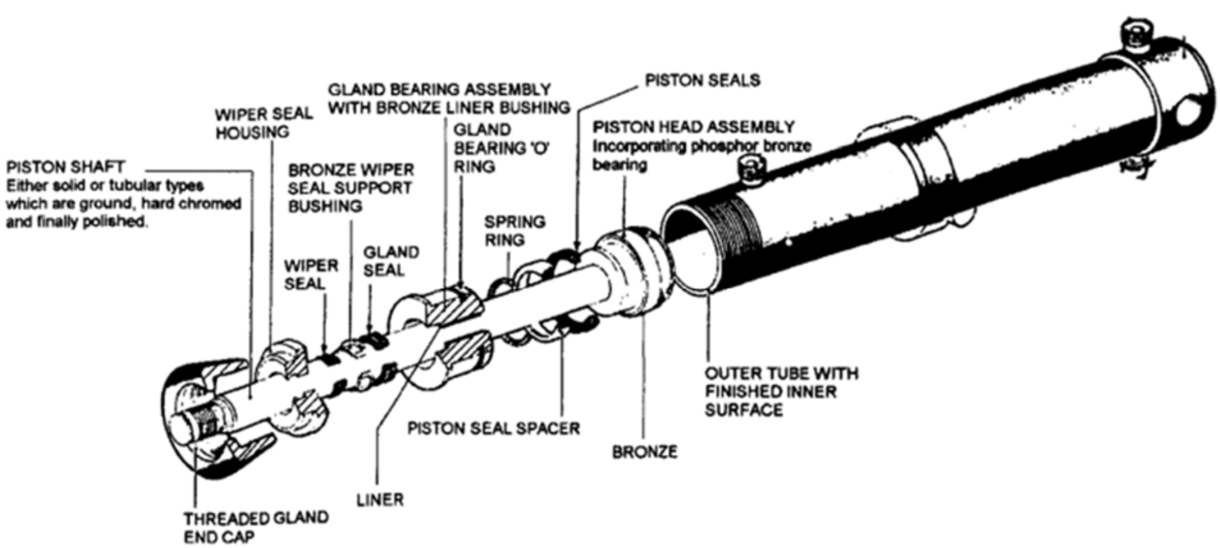

Figure 2.8.2.12.5-2 – Typical double acting hydraulic cylinder

3.8.2.12.6 Hydraulic Pumps

Pumps for hydraulic systems are available in three basic types, as follows:

- Vane pumps, as seen in Figure 2.8.2.12.6-1
- Gear pumps, as seen in Figure 2.8.2.12.6-2
- Piston pumps, as seen in Figures 2.8.2.12.6-3 and 2.8.2.12.6-4

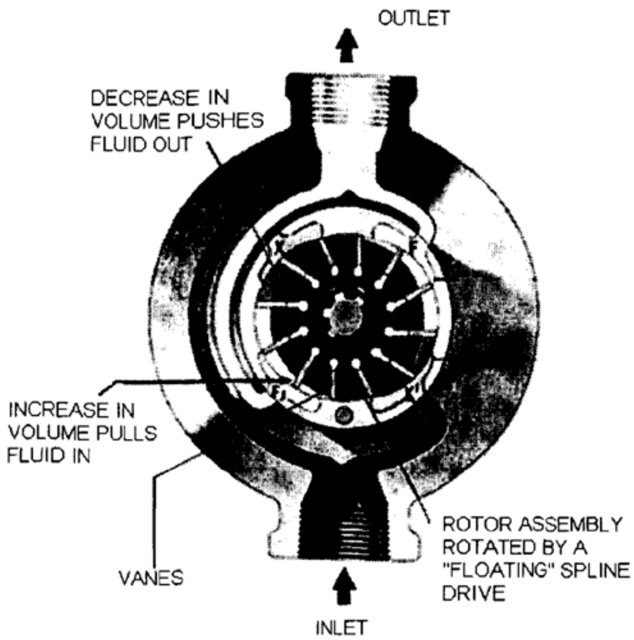

Figure 2.8.2.12.6-1 – Vane type fixed displacement pump

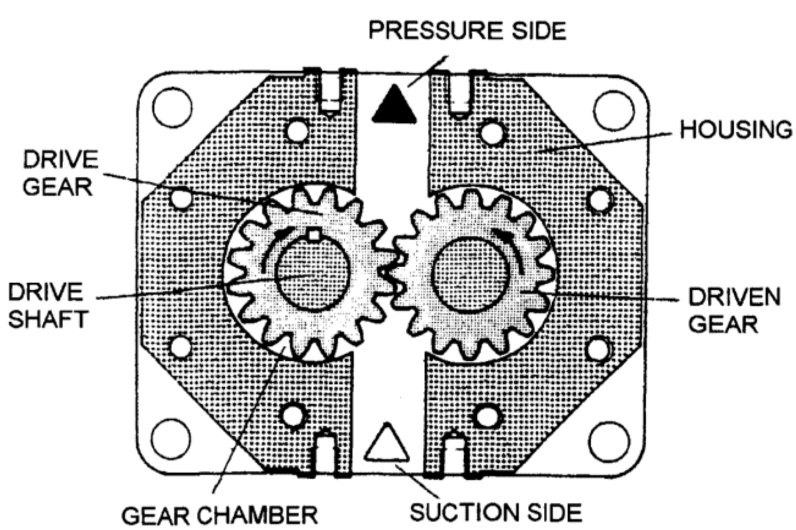

Figure 2.8.2.12.6-2 – Gear type pump

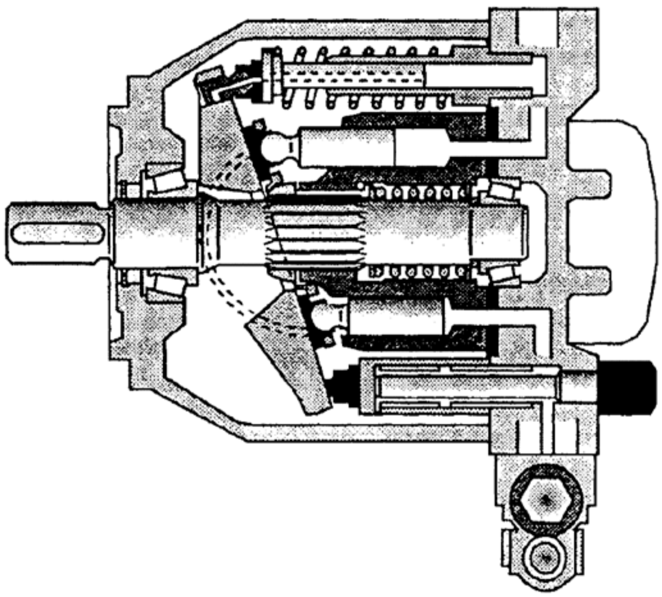

Figure 2.8.2.12.6-3 – Variable displacement axial piston pump (swash plate type)

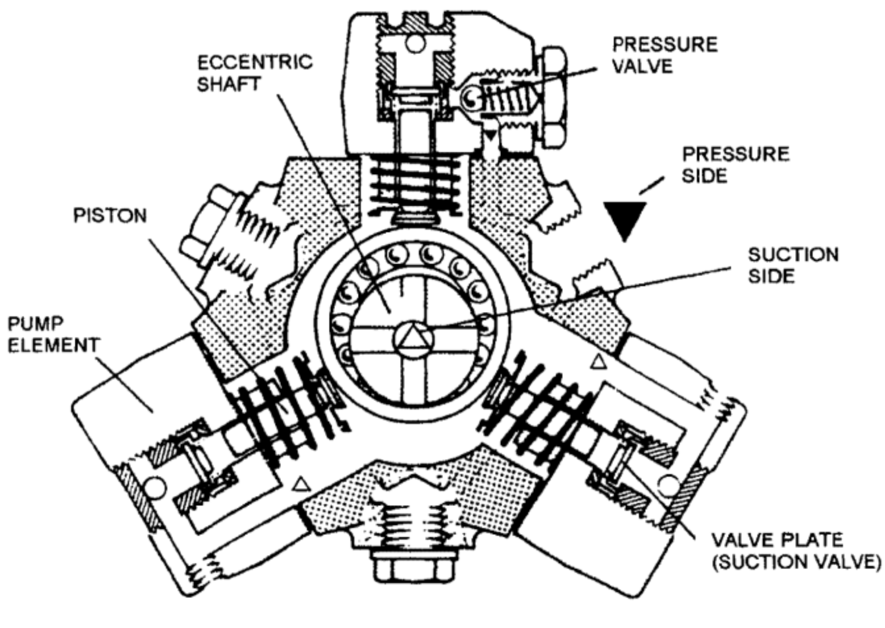

Figure 2.8.2.12.6-4 – Radial piston pump

Pumps should be checked for all the same routine inspection items listed for valves and cylinders. Misalignment, heat, contamination, pressure, and leaks are all potential problems. The single most damaging fault in a pump is cavitation. Cavitation can occur in any fluid when pump suction causes an area of low pressure that allows the hydraulic fluid to boil. Fluids boil at increasingly lower temperatures as the pressure of the fluid drops and at higher temperatures as pressure of fluid increases. This relationship between pressure and boiling point temperature means that suction at the inlet or interior to the pump becomes more likely to cause cavitation if the fluid is warmer and/or the pressure drop due to suction is higher. Bubbles will form and collapse in the area of cavitation, causing very high localized pressure spikes which can pit metal and erode other material very rapidly. Cavitation makes a distinctive noise, but pump noise can be caused by other factors. A pump troubleshooting chart is presented in Table 2.8.2.12.6-1.

Current AASHTO specifications (Reference 6) prefer that gear or piston type pumps be used in systems where operating pressure exceeds 2,000 psi (14 MPa).

Table 2.8.2.12.6-1 – Pump troubleshooting chart

POTENTIAL CAUSES OF PUMP NOISE	LOOK FOR THE FOLLOWING TO CONFIRM	ITEMS WHICH MAY REQUIRE CORRECTIVE ACTION
Cavitation	Pitting inside lines or pump. High fluid temperature or low inlet pressures.	Low oil level, dirty strainer or suction filter, clogged or cramped inlet line, inlet lines too small. Oil cold and very viscous at inlet or too warm.
Aeration	Air bubbles in reservoir, air sucking leaks on inlet side of pump or inlets, oil level too low and allowing air into the inlet.	Leaking seals or pipe fittings.
Worn Pump	Dirt in oil, wrong oil type or system pressure overload, poor pump performance.	Replace pump, replace filter, flush oil reservoir and lines.

2.8.2.12.7 Hydraulic Motors or Rotary Actuators

In some newer systems, hydraulic motors or rotary actuators are used to provide rotational motion. Swing bridges and bascules may be driven by hydraulic direct drive motors. A hydraulic motor is essentially a hydraulic pump used in reverse. Instead of rotary motion pressurizing fluid, pressurized fluid creates rotary motion. Figure 2.8.2.12.7-1 shows a typical hydraulic motor.

Hydraulic motors should be checked during routine inspections as for pumps, except that cavitation is unlikely to occur. All the other inspection guidelines for pumps apply.

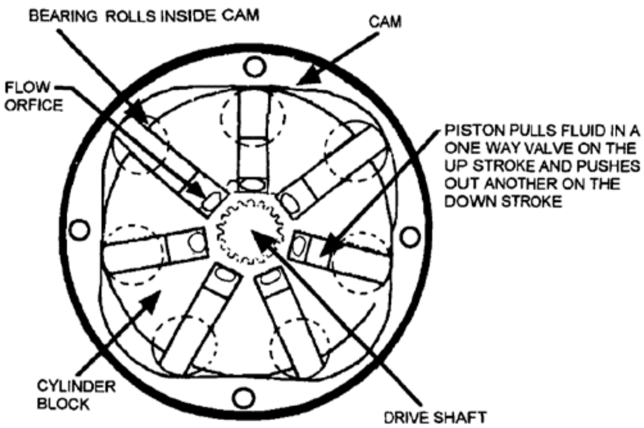

Figure 2.8.2.12.7-1 – Radial piston type hydraulic motor

2.8.2.12.8 Filters

Filters should generally be of the bypass type, where system failure due to a clogged filter is unacceptable, and should be checked to see if they are flowing properly. Filters that are flowing through the bypass should be reported via deficiency report for corrective action and inspectors should investigate all other filters and check for reservoir contamination and/or other causes of the clogged filter. Figures 2.8.2.12.8-1 through 2.8.2.12.8-3 show some of the filters used in hydraulic systems.

The single most likely cause of hydraulic system failure is damage that results from system contamination. Properly designed, installed, and monitored filters are a vital preventive measure intended to remove damaging contaminants from the hydraulic fluid before they damage vital components like pumps, valves, or cylinders. Fluid sampling during routine and in-depth inspections and subsequent testing is a way to verify that filters are performing their vital function properly. See Chapter 2.10.

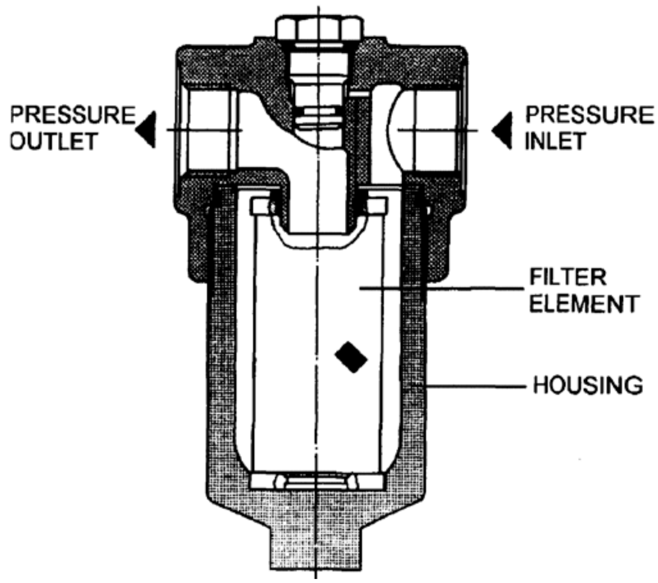

Figure 2.8.2.12.8-1 – Pressure line filter

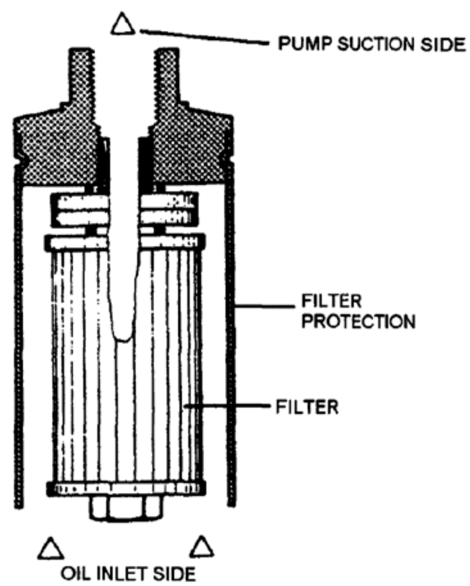

Figure 2.8.2.12.8-2 – Suction line filter

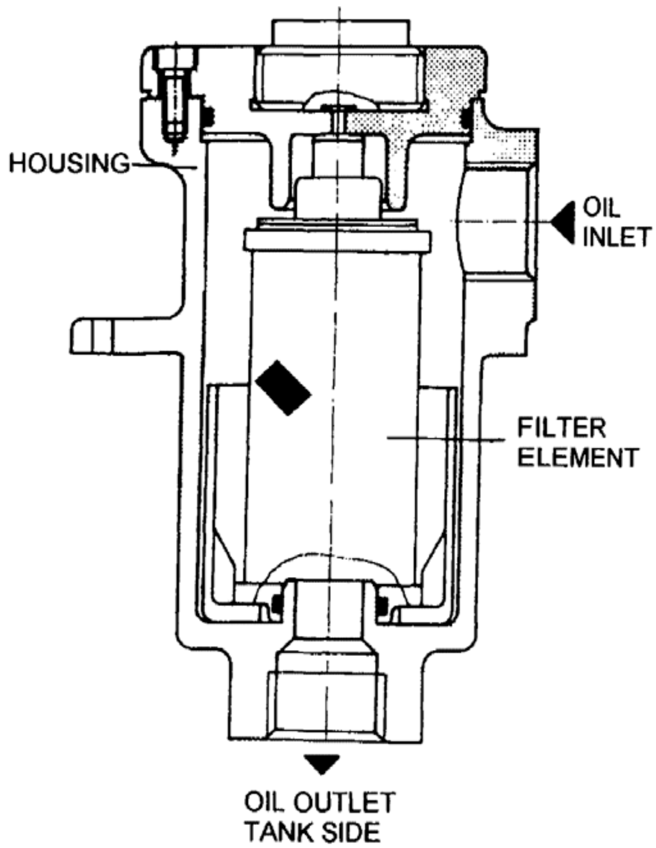

Figure 2.8.2.12.8-3 – Return line filter

2.8.2.12.9 Rigid Hydraulic Piping and Tubing

Rigid hydraulic piping should be checked for conformance in size and type to as-built plans and for proper cushion mounting. Elbows and changes in pipe direction should be checked for signs of excessive motion or support damage and inspectors should observe piping during system operation to look for excessive pipe movements that may cause pipe fatigue due to bending stresses at elbows. Pipe fittings should preferably be either welded or flange to flange type and should be checked for leakage. Tapered thread pipe fittings are at present considered generally unacceptable in pressure lines and other pipe fittings may be leak prone and should be closely monitored for leaks. Any leakage is unacceptable and should be reported via deficiency report for corrective action by maintenance.

Tubing is more flexible than piping, but is not particularly resistant to fatigue. Tubing should be monitored during operation to check for flexing and any areas that flex should be checked for cracking or signs of fatigue. Flare fittings and most other types of tube fittings may be leak prone, and should be closely monitored for leaks.

Inspectors should also inspect the protective coatings on the exterior of pipes and tubing during routine inspections and note any coating damage or exterior corrosion.

2.8.2.12.10 Hydraulic Hose

Hydraulic hose is typically used to connect to moving cylinder or hydraulic motor parts. It may also be used to connect rigid piping to the fixed end of motors and cylinders to avoid stresses in this area due to movement as pressure changes and for vibration damping.

Flexible hoses should be installed with no twisting of the hose, and in accordance with manufacturer's recommended bend radius in a smooth curve that does not move excessively when pressurized. Excessive hose movement can cause the hose and/or the fittings to fatigue, causing leaks or breaks. A common leakage point is at the hose ends, especially swivels.

Inspectors should check for abrasion damage, cracking of the neoprene (or other elastomer) sheath, and leakage during routine inspections. They should also observe the alignment of the hose and how the hose behaves during system operation. Hose clamps that incorporate elastomeric inserts to protect the hose are preferred. Inspectors should check the condition of these inserts during routine inspections and should look carefully for abrasion damage to the hose on clamps that do not incorporate such inserts.

2.8.2.12.11 Reservoirs

Hydraulic reservoirs provide a storage vessel for the fluid needed to be pumped to and from the cylinders or motors during opening and closing of the bridge. Reservoirs should be fitted with a pressure cap or with a filter/breather unit (Figure 2.8.2.12.11-1) and should have some means to check fluid level and fluid temperature without opening the cap.

During routine inspection, inspectors should check fluid level and check for proper breather operation without opening the tank. Current AASHTO specifications (Reference 6) prefer the use of bladder type reservoirs in dusty environments, which may complicate inspection.

It is recommended maintenance practice to record the amount, type, and date of addition of any replenishment fluid added to the reservoir to permit tracing leakage. Regularly scheduled fluid changes should also be noted stating date, type, and amount of fluid drained and added. This can be done on a tag or in a book attached to the reservoir at the reservoir fill cap. Reservoirs provide some heat dissipation, but some systems may also require heat dissipation radiators or special cooling circuits that are activated by a temperature control on/off limit switch.

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In general, it is not advisable to open the reservoir too frequently to avoid inadvertent contamination of the fluid by introduction of debris. For this reason, it is recommended not to open the tank during routine inspections.

During in-depth inspections, inspectors should open the tank to inspect for internal corrosion, dirt, and fluid condition.

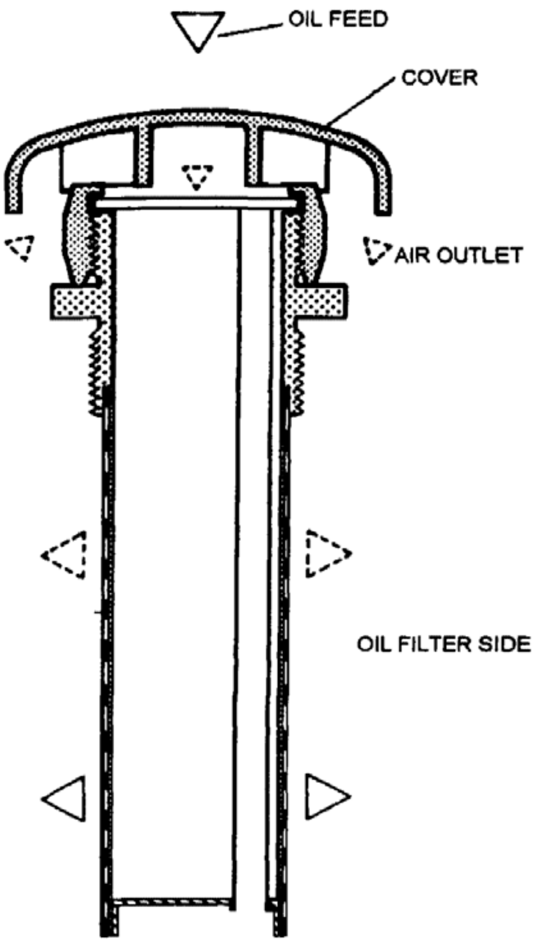

Figure 2.8.2.12.11-1 – Filter/breather unit

Inspectors should carefully clean around the cap and take other actions as necessary to avoid entry of dirt or any other contaminants into the reservoir. Condensation can cause water accumulation in the reservoir on breather type reservoirs that should be drained periodically and should also be checked for water during routine inspections. On occasion, bubbles or water emulsions can indicate a severe problem that should be reported via deficiency report for correction by maintainers.

2.8.2.12.12 Hydraulic Fluid

Hydraulic fluid is a very important check during any inspection. Traditionally, hydraulic fluid has been a lightweight or low viscosity oil (similar to an SAE 10 weight), that is generally petroleum based (such as mineral oil, transmission fluid, or an SAE 10 weight lubricating oil) in most older systems, because these fluids are compatible with most seal materials and provide lubrication for pump, cylinder, motor, and valve moving parts. Any incompressible fluid can be used, however, as long as it is compatible with seals and has appropriate characteristics of self lubrication, resistance to freezing, corrosion, and viscosity and other physical characteristics as required by component manufacturers. There has been a trend toward using water/oil emulsions with anti-freeze in the water, vegetable oils, or other biodegradable hydraulic fluids in recent years due to pressure from environmental concerns to avoid petrochemical spills if a fitting or line breaks.

The problem for inspectors with this trend is that some of the numerous types of hydraulic fluids are not compatible with each other or with all types of components. Under no circumstances should different types of fluids be combined in one system.

Inspectors should determine what type of fluid the system was designed to use during inventory inspections and verify what type is present during each routine inspection and if any other types have ever been used since the last inspection. If there have been any changes in fluid type from the original design, inspectors should note this condition for evaluation via deficiency report and should be alert to caking, clotting, or formation of internal coatings in tanks or other components and should exercise additional care in checking for heating, sticky valves, and other problems.

It is recommended that filler caps be marked with a plaque or tag that clearly specifies the type of hydraulic fluid to be used.

Samples of fluid should be collected from the reservoir base and other areas during each routine inspection and inspected for the presence of particulates and other harmful substances. It is recommended that owners also consider routine testing of fluid samples to obtain chemical analysis and a particulate count. Testing allows predicting trends and may also provide early detection of a serious system defect such as pump cavitation, cylinder misalignment, or formation of harmful acid in the fluid. See Chapter 2.10.11 for discussion of fluid sampling and testing. Fluid degrades over time due to heat, oxidation, and other factors that vary with the application. Regularly scheduled fluid and filter changes are vital for reliable long-term system performance. Inspectors should inquire about the fluid replacement schedule and verify that it is being followed.

2.8.2.12.13 Hydraulic Systems Interlocking Sensors and Controls

Many movable bridges utilize electrical control panels; therefore, standard electromechanical limit switches are often used for interlocking of hydraulic components. (See Chapter 2.8.3 for electrical inspection procedures). Two usual sensors used for hydraulic system control are pressure switches and temperature switches that are used to control temperatures and pressure and to actuate pumps, heaters, or cooling measures as may be designed. Figure 2.8.2.12.13-1 shows a standard bourdon tube type pressure switch schematic.

Valve type control stations are less complex than electrohydraulic controls and should be inspected as stated in Section 2.8.2.12.4 for valves.

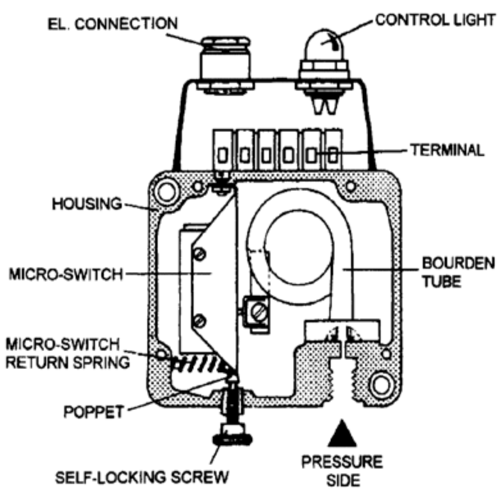

Figure 2.8.2.12.13-1 – Bourdon tube type pressure switch

For any type of control system, hydraulic components should be inspected for leakage, electrical components should be checked for cleanliness and other checks as described in Chapter 2.8.3, and the entire system should be performance tested during routine inspections.

2.8.2.12.14 Hydraulic Machinery Coding Recommendations

Due to the proprietary nature of design data for hydraulic components, it is difficult to precisely quantify the criteria for numeric condition evaluation coding on individual hydraulic components unless external evidence is present to assist in making a determination.

General recommendations: If the system and components are well connected, protected, secured, safely operating, and functioning as intended, a coding of "good" (recently installed, no defects), fair (minor deterioration or wear), or "poor" (functional, but with obvious deterioration or wear) should be assigned as appropriate to each component and system.

Components or systems that exhibit leakage of hydraulic fluid should generally be coded "poor" or "severe" based upon whether the inspector believes action is required in the near future or immediately. If the inspector believes that corrective action can be deferred for a short period of time, the component should be coded "poor" with clarifying documentation. Any hydraulic component observed to be leaking fluid to the waterway should be coded "severe." Components that exhibit no signs of problems or external evidence of defects or leaks should be coded based on engineering judgment or Table 2.9.1-1.

Accumulators that are believed to have damaged bladders or that exhibit signs of insufficient gas cushion should be coded "poor" or "severe," depending on the urgency of needed corrective work.

Valves that do not operate reliably and give signs of sticking open or closed should be coded "poor." If such symptoms and heavy leakage are present, the valve should be coded "severe." Solenoid valves that smell of hot insulation or with signs of melting or burning insulation should be coded "severe."

Hydraulic cylinders that are overheating should be coded "poor." Cylinders that are leaking and overheating or are in systems with evidence of contamination should be coded "severe." Misalignment, loose fittings, or excessive fitting pin clearances should be rated "poor" unless the inspector believes failure is imminent, in which case a coding of "severe" is appropriate.

Pumps that are cavitating should be coded "severe." Pumps that are failing to provide necessary system pressure without running constantly should be coded "severe" unless the problem is traced to incorrect setting of pressure switches or insufficient gas cushion in the accumulators.

Motors or actuators that fail to drive the span or leaf under heavy loads (e.g., high winds) when other parameters such as system pressure and interlocking appear to be functioning properly should be deemed to be worn and should coded "poor" or "severe."

Filters that are clogged on systems showing signs of heavy particulate contamination should be coded "severe" because such a filter is very close to failing and is allowing particulates to pass through the filter. Filters with a history of frequent replacement may be inadequate to their installed use and should be reevaluated by a qualified fluid power engineer.

Hoses with damaged elastomer should be coded "poor." Hoses with excessive movement at fittings and signs of fitting or hose leakage or other distress such as broken internal reinforcement fabric or tears in the fabric should be coded "severe."

Piping and tubing that is leaking should be coded "poor." If it is cracked, or observed to be moving significantly at a change in line direction or a fitting with cracks in the paint, or displays other signs of an imminent break should be coded "severe."

Pump suction inlet pipes, tubing, or hoses that are kinked, too small, or give evidence of nicking air leaks should be coded "severe."

Hydraulic fluid that has overheated or shows signs of particulate or chemical contaminants should be coded "severe."

2.8.3—ELECTRICAL INSPECTION PROCEDURES

Various systems may be employed to operate movable bridges including manual, hydraulic, internal combustion engine drive, and electric motor drive systems. This chapter concentrates on components of electrically driven bridges.

Reference 6 currently recommends that the electric power supply for new movable bridges consist of a primary source from the local utility and a secondary or emergency source provided by an alternate method such as an engine driven emergency generator or auxiliary power feed from another electric power source. Some existing movable bridges do have an available secondary power source.

Control systems associated with electrically operated bridges typically consist of motor control equipment and either electric relay or electronic control logic, often with numerous interlocking and safety devices to verify that defined sequences of operation of the movable structure are followed and cannot be defeated in normal bridge operation. The inspector should familiarize himself with the typical bridge operating sequence outlined in Section 2.8.3.13.2, Bridge Operating Sequence, prior to performing any inspections.

Personnel and public safety issues associated with movable bridges are addressed in Chapter 2.5. Additional descriptions of concerns regarding these issues are addressed in detail as part of this chapter. Potential hazards to maintenance and operating personnel are described.

Periodic inspections of the electrical systems associated with movable bridges are required to verify that the systems are operating safely, reliably, and within their design parameters. These periodic inspections are divided into two categories:

- **Routine inspection**, which should not include major disassembly for inspections, performed by either the Engineering Evaluation or Predicted Life methods described in Chapter 2.9. The methods presented in the text of this Section and Section 2.8.2 apply primarily to routine inspections by the Engineering Evaluation method. Routine

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Electrical components include motors, traffic control devices, power supply equipment, electrical devices, etc.

Currently, although an alternate power source is not required on existing movable bridges, this provision of the code for new design is preferred on some existing movable bridges. (See Chapter 4.2.)

inspections by the Predicted Life method will generally consist of performance testing as described herein, visual inspection, and component age based on condition ratings. Routine inspections using either method should include a check of span balance by the ammeter method (see Chapter 2.10) for bascules and lift spans and a check of swing span main drive loads by the same method.

- **In-depth inspections** are preferred to be done by the Engineering Evaluation method on movable bridges with a history of significant defects during previous routine inspections. If an owner elects to use the Predicted Life method for the in-depth inspection of a particular structure, components rated "poor" or "severe" in previous inspections should be inspected by the Engineering Evaluation method and the inspection of those "poor" rated components should include any methods listed in this chapter for in-depth inspection.

Methods defined in Chapter 2.9 should be applied to the inspection to rate the condition of the electrical components and assess the overall condition of the electrical systems associated with the bridge.

2.8.3.1—Electrical Systems for Movable Bridges

Three basic types of electrically operated movable bridges are in common use today: bascule, swing, and vertical-lift. Each has generally similar electrical power and control systems. Specific unique characteristics are discussed herein.

2.8.3.1.1 Bascule Bridges

Bascule bridges are divided into two sub types: trunnion and rolling lift. The electrical system associated with both types of bascule bridges is similar, but the location of the machinery, including the drive operators and brakes, distinguishes one from the other. Trunnion type bascule bridges have a stationary trunnion with machinery mounted on a stationary platform or machinery room located below the bridge. Rolling lift type bascule bridges are arranged to roll back the superstructure on a track as the toe end of the leaf rises. The machinery platform is usually mounted on the superstructure and rotates with the bridge. Therefore, the fundamental difference between the two is that all power connections and electrical equipment are usually stationary in the case of the trunnion type, whereas the electrical drive and braking system rotates with the moving structure in the case of the rolling lift type. Therefore, all electrical connections to these drives are via flexible cables from the control equipment mounted on the fixed structure.

2.8.3.1.2 Swing Bridges

A swing bridge in operation usually turns approximately 90° in the horizontal plane from its fully closed to fully open position. All machinery and electrical power and control equipment resides on the moving structure and electric utility feeds and traffic control cabling are routed from the bridge abutment via submarine cables. The connection to the movable superstructure is made either by flexible cables or by collector rings.

2.8.3.1.3 Vertical-lift Bridges

There are two distinct types of vertical-lift bridges in common use: span drive and tower drive. A span drive is arranged with machinery and electrical power and control equipment mounted on the movable span and electric utility feeds and traffic control cabling routed to the movable structure via flexible cables. A tower drive bridge is arranged with machinery, drive motors, and brakes located in the end towers and the control equipment located in a control house either mounted on the moving structure or at one of the towers. Power and control cabling routed between the towers are either run on a structure connecting the two towers at high level or under the navigable channel between the towers with the use of submarine cables. When the control equipment is located on the moving structure, flexible cables are used to connect the tower mounted equipment, utility feeds, and traffic control equipment to the movable structure.

2.8.3.1.4 Other Movable Bridge Types

There are other uncommon, obsolete, or novel types of movable bridges, notably including floating pontoon bridges—both retractile and swing. Special electrical systems for use on floating pontoon bridges include leak detection systems and cathodic protection systems.

2.8.3.1.5 Basic Electrical Equipment

Certain basic electrical equipment is common to most electronically operated movable bridges. The following electrical equipment will be discussed herein:

- Motors
- Electric cables
- Power distribution equipment
- Traffic control devices
- Navigation control devices

Electrical controls and interlocking are covered in Chapter 2.8.3.13.

2.8.3.2—Inspection Scope

In order to reduce the difficulties and hazards caused by unscheduled service interruptions, it is essential the electrical equipment be kept in “good”, serviceable condition. Inspection of the electrical system is primarily carried out to assess the operation of the systems and the condition of the components. The inspections also provide an evaluation of the equipment's ability to operate safely and reliably and an assessment of the expected continued useful life of the electrical system.

Inspections vary in intensity from bridge to bridge based on the age of the equipment, its operating characteristics, and its exposure to the prevailing environment. A further criterion for the intensity and frequency of the inspections is the essentialness of operation of the bridge and the importance placed on its reliable service.

2.8.3.2.1 Routine Inspections

Routine inspections are intended to detect obvious deficiencies or safety violations and system failures. The frequency of inspection is dependent on the needs of the owner and of the bridge. At a minimum, a routine inspection by the engineering evaluation method should include the following:

- A visual inspection of all electrical components of the bridge. This is intended to determine, in broad brush terms, the status of the equipment and installation, including: identifying corrosion, deterioration, integrity of enclosures and completeness of the electrical installations. It also provides the inspector with the basis and understanding of the operating systems, location of equipment, and the presence of required safety devices.
- Basic electrical testing of system components including the measurement of motor load currents, system voltage under both load and no load conditions, and motor control center bus systems.
- Evaluation of the status of those items recommended from previous inspections for corrective action. It will also include, in the event that corrective action of these items has not taken place, a determination of the criticalness of these items and recommendations for immediate action or an appropriate implementation of operating restrictions.

Following completion of the inspection, a report should be developed for record purposes to document the current status of the bridge and to prioritize any corrective action needed. The data base for the electrical systems associated with the bridge, in terms of equipment, operating data and status of system insulation resistance, can be updated accordingly. The report should also include conclusions as to the status of the bridge's electrical

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The contents of Chapters 2.2 and 2.3 of this Manual and the NBIS (Reference 1) provide further guidance on frequency and definitions of the various types of inspections systems in terms of age, safety, reliability, maintenance, and operating procedures.

2.8.3.2.2 In-depth Inspections

These inspections are intended to fully quantify the status of the bridge's electrical system and its prevailing operating characteristics, define its standard of safety for bridge personnel and the public, assess its reliability, anticipate subsystem remaining useful life, and estimate the cost of any required repairs and rehabilitation necessary to maintain the bridge in a safe and reliable operating condition. In-depth inspections are normally carried out in lieu of every third routine inspection by the engineering evaluation method and include interviews with both operators and maintainers regarding the operations and maintenance procedures for the bridge. The specific inspections vary from bridge to bridge, but at a minimum should consist of the following:

- A comprehensive visual inspection of the bridge and vehicular and marine traffic approaches to the bridge. The intent is to define, in specific terms, the physical condition of all electrical equipment and installation associated with the bridge. This definition will include the degree of corrosion and integrity of equipment enclosures, wireways, conduits, and submarine cables exposed to the prevailing environment, as well as completeness of the electrical system to operate safely and reliably.
- Testing of the complete electrical systems associated with the bridge and evaluation and analysis of the test results to determine the conditions and operating parameters of the system. The specific tests conducted are dependent on the types of electrical equipment and form of installation, but generally consist of:
    - Insulation resistance testing of all motors, controllers, switchgear cables, and submarine cables, as described in Chapter 2.10.9. The condition of electrical insulation is a “good” indication of the service life that can be expected from aging equipment. Whenever an insulation resistance test is made, all pertinent data should be recorded, including the time of day, the date, the test voltage, temperature, and humidity. Temperature and humidity influence test results. Since insulation resistance changes with age and operating environment, no specific resistance can be given for an absolute minimum value. The method adopted to evaluate insulation is to record the test results and plot this data on a curve from inspection to inspection. Normally, the plotting of the test results produces a gradually changing line. When this line or curve deviates substantially from

normal trend, the insulation is failing.

- Starting and load current tests are carried out to determine the loading of motors and the adequacy of the ratings of the system components. These tests are also recorded from inspection to inspection to give an indication of operating parameters with age. An example would be an increase in starting and load current of the drive motors from the previous inspection. This could be due to aging of the mechanical system, a partial failure of the winding of the motor, motor brush failure, or wound-rotor resistor failure.
- Current injection tests are conducted to simulate fault currents and prove the effectiveness of the system's electrical protective devices. These tests are carried out with a low voltage current source, by either injecting current directly through circuit breakers, thermal overload relays, or by injecting the secondary circuits of CT drive protective relays and thermal overload relays. The purpose of the current injection is to prove that the devices have maintained their original characteristics and are properly coordinated to prevent nuisance tripping of the system.

2.8.3.2.3 Inspector Safety

The primary role of the movable bridge electrical inspector is to observe and record deficiencies. The inspector should never attempt to make repairs or adjustments to equipment. This is the responsibility of trained, experienced electrical maintainers. Inspectors bear primary responsibility for their own safety. The inspector should review and understand the safety guidelines outlined in Chapter 2.5. By observance of these guidelines, the risk of accidental shock while inspecting electrical equipment will be considerably reduced.

Although both personnel and public safety issues associated with movable bridges are covered in Chapter 2.5, special precautions required when dealing with electrically operated systems are further addressed in this section.

Prior to and during inspection of the electrical system, particular attention should be given to avoiding personnel or non-insulated metal tool contact with energized live electrical equipment. The inspector should verify that the power is off to electrical equipment being inspected whenever possible.

For public safety it is essential that vehicular and moving traffic control equipment function reliably and safely at all times. Inspectors and maintainers should pay particular attention to the controls and interlocking associated with this equipment. The equipment should be exercised regularly and the effective operation of all safety devices proven by attempting to defeat those particular devices.

Inspectors and maintainers should always isolate and lock out equipment and check for the presence of voltage prior to removing equipment covers and enclosures for inspection and maintenance. Do not work on live parts. Make sure rotating machinery is deenergized and locked out prior to inspection or maintenance.

2.8.3.3—Motors

The three most common types of electric motors found on movable bridges are AC (alternating current) squirrel cage induction motors, AC wound-rotor induction motors, and DC (direct current) motors. Occasionally, synchronous motors may be encountered on older bridges. Traffic gates, resistance gates, span locks, and rear locks most often are driven by AC squirrel cage induction motors. Figure 2.8.3.3-1 shows a span lock motor for a mechanically operated lock. Main span drive motors are most often AC wound-rotor or DC motors. However, newer span drive motor designs may utilize vector variable frequency drives (VFDs) and inverter rated AC squirrel cage induction motors as an alternative to the traditional forms of span drive motor speed control.

Figure 2.8.3.3-1 – A span lock motor

C2.8.3.3

The span drive motors are usually arranged as variable speed units by interfacing with either a combination of drum controllers (or contactors) and resistors, silicon controlled rectifiers, primary or secondary voltage control, or by using variable frequency speed control with AC induction motors. The latter is becoming more common for new movable bridge designs.

2.8.3.3.1 AC Squirrel Cage Induction Motors

The squirrel cage induction motor is in common use throughout general industry. It is popular because it is simple, reliable, and is generally less expensive than other motor types of the same horsepower.

The term "squirrel cage" is derived from the motor rotor (rotating element) construction, which resembles a squirrel

C2.8.3.3.1

Squirrel cage induction motors were previously single speed devices; speed remains almost constant from no load to full load in the absence of outside frequency control. However, with the development of the solid-state adjustable frequency motor cage (see Figure 2.8.3.3.1-1). The rotor employs solid bar copper or aluminum conductors that are soldered at each end to a shorting ring. The shorting ring actually short circuits the individual conductors of the rotor.

All induction motors have a stator (stationary) winding, called the primary, connected to the electrical power source. The rotor, also called the secondary, of a squirrel cage induction motor has no electrical connections. The magnetic field produced by the primary rotates the rotor due to the progression of AC current through the winding. The voltage induced in the secondary (rotor) is accompanied by a magnetic field. Because the rotor is free to rotate, motion is produced by the interaction of the magnetic fluxes.

Figure 2.8.3.3.1-1 – Squirrel cage induction motor

controller, the squirrel cage motor can presently be used to provide variable speed and torque control over a wide range of load conditions.

2.8.3.3.1.1 Inspection

Routine inspection should be performed with the motor running. The inspector should check the following performance criteria:

- Listen to the motor; check to determine if the bearings emit a squealing or grinding sound.
- Feel the motor casing for excessive vibration.
- Feel the motor in the bearing locations. If it is unusually hot to the touch, bearing trouble is indicated.
- Check to make sure all components are tight and all bolts are in place.
- Check bearing seals for signs of lubricant leakage.

C2.8.3.3.1.1

The squirrel cage motor is the easiest to inspect. Because of the frame construction, only the external components can be inspected. In-depth inspection of the motor should include insulation resistance testing using a megger as outlined in Chapter 2.10.9.

2.8.3.3.2 AC Wound-rotor Induction Motors

Wound-rotor motors (shown in Figure 2.8.3.3.2-1) operate on the same principle as the squirrel cage motor, current induced from the stator windings produces magnetic fields in the rotor. However, there is a significant difference between the two types. A wound-rotor motor, as the name implies, has several coils mounted on the rotor, instead of the conducting bars found on the squirrel-cage type.

The windings are connected to collector rings, or "slip rings," mounted on the shaft. Brushes contact the slip rings, connecting them to external resistors in the motor controller. Figure 2.8.3.3.2-2 shows a view of collector rings and Figure 2.8.3.3.2-3 shows the rotor assembly.

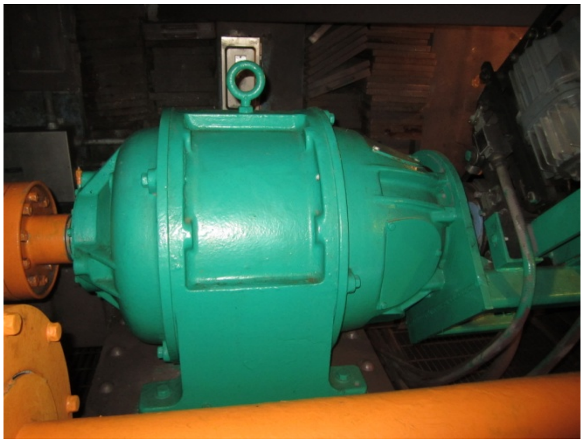

Figure 2.8.3.3.2-1 – A wound-rotor motor

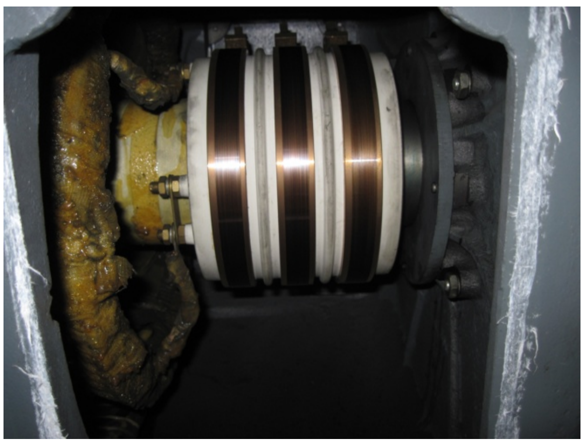

Figure 2.8.3.3.2-2 – Slip rings

Figure 2.8.3.3.2-3 – Wound-rotor motor assembly

When the rotor windings are shorted out, the motor operates much like a squirrel cage motor. However, by using the controller to insert a number of steps of secondary resistance across the windings, the speed and torque of the motor can be varied. This type of motor requires internal inspection to determine the condition of the rings during an in-depth inspection.

2.8.3.3.2.1 Inspection

The external inspection described in Section 2.8.3.3.1.1 for the squirrel cage induction motor should also be performed during the routine inspection of AC wound-rotor induction motors.

For the in-depth inspection, remove the inspection covers on the end of the motor frame to provide access to the inside of the motor. The brush assembly and slip rings are located behind these cover plates. The following outlines additional internal examination suggested during an in-depth inspection.

- Check the slip rings for signs of surface pitting, grooves, and cracks.
- Check the insulation around the rings. It should be in good condition with no contamination, carbon build up, or arcing damage.
- Check the carbon brushes for length, freedom in the brush-holders, surface fit, and conduction.
- Check for oil and grease contamination of the winding. Buildup should be removed by maintainers using an approved solvent.
- Check that the air passages between the windings are not plugged, preventing air circulation.

C2.8.3.3.2.1

Chapter 2.10 describes brush inspection procedures that should be performed as part of an in-depth inspection.

The insulation resistance test and bearing inspection, outlined in Chapter 2.10, should be applied during an in-depth inspection. With the motor running, brush conduction should be checked and vibration levels observed. Bearing temperatures should be checked for high operating temperatures with an infrared non-contact thermometer.

- Check the insulation for signs of overheating, cracking, or short circuit possibilities.

The following other performance tests should be done during routine inspections:

- Observe the secondary controller during motor operation. The contactors should not chatter or bounce on their contacts. No sustained arcing should occur during any part of the control operation. Make certain the controller sequence is correct and that all components function properly. A schematic diagram of the controller will be required to perform this check.
- Visually check the controller components for wire and cable conditions. Cable connections should be tight. Look for broken conductors and signs of terminal cracking. Partially broken connectors can accelerate an insulation failure due to overheating.

Figure 2.8.3.3.2.1-1 shows the wound-rotor motor external resistors. The in-depth inspector should check for white discoloration (see arrow in Figure 2.8.3.3.2.1-2), which indicates possible trouble.

This white area could be a sign of severe overheating or an atmospheric corrosion of the metals. Overheating can be caused by broken resistor grids or poor contact between adjacent resistor grid plates. This condition should be corrected; Figure 2.8.3.3.2.1-2 shows broken grids. Discoloration around the break point will be apparent.

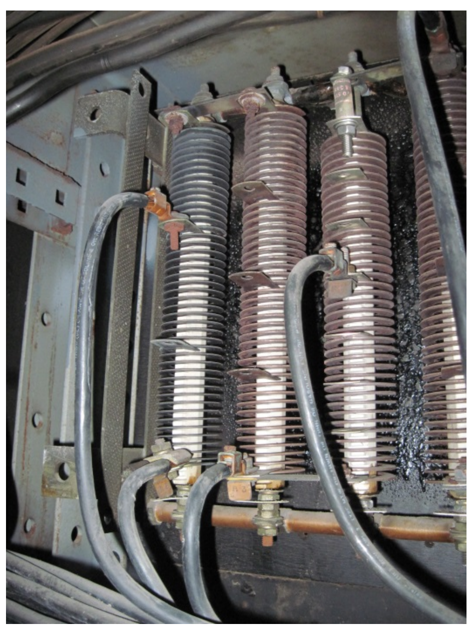

Figure 2.8.3.3.2.1-1 – Wound-rotor motor external grid type resistors

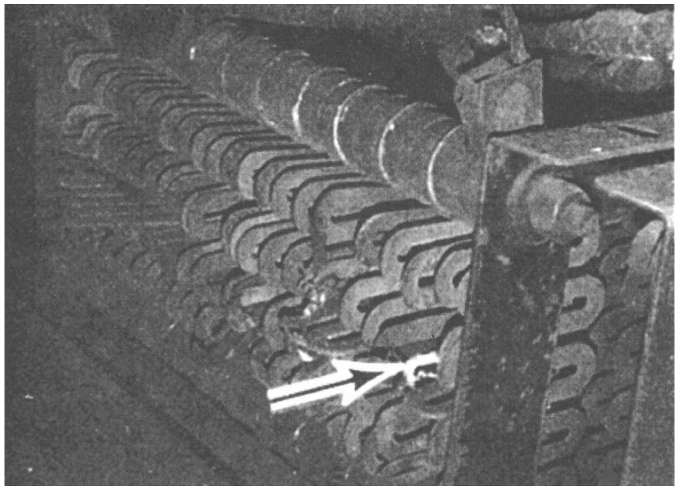

Figure 2.8.3.3.2.1-2 – Wound-rotor motor external resistors with broken grids

2.8.3.3.3 DC Motors

A shunt wound direct current (DC) motor is one in which the field windings and armature may be connected in parallel across a constant voltage supply. The speed of a DC motor is proportional to its armature voltage and the torque is proportional to its armature current.

Direct current motors provide a continuously variable speed range and have excellent speed control capability. Torque (load) variations do not affect the DC motor as much as the wound-rotor or the squirrel-cage motor. This permits better speed control of the DC motor than the wound-rotor motor. Figure 2.8.3.3.3-1 shows the construction of a DC motor.

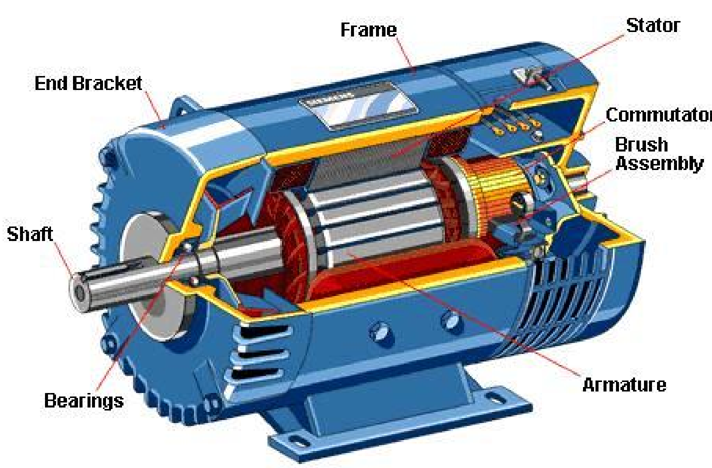

Figure 2.8.3.3.3-1 – Direct current motor

The armature (rotating member) is constructed with insulated copper formed coils positioned in slots in the laminated rotor

C2.8.3.3.3

In adjustable speed applications, the field is connected across a constant voltage supply and the armature is connected across an independent adjustable voltage supply.

body. The ends of these wire wound coils are connected to copper segments called commutator bars. The commutator bars are assembled on, and insulated from, the motor shaft and each other. To conduct current through the coils, the DC motor has one or more sets of carbon brushes that complete the electrical circuit from the power supply through the commutator and coils, and back to the supply. Each brush (one positive and one negative) makes contact with a coil in the armature through a commutator bar. DC voltage applied to the brushes produces a current flow in the armature coil, that in turn produces a magnetic field in the motor rotor. As the rotor turns, the next coil connected to the armature advances and makes contact with the brushes on the commutator and a new magnetic field is created. This change from one bar to the next on the commutator is referred to as “commutation.”

2.8.3.3.3.1 Inspection

External inspection methods described in Section 2.8.3.3.1.1 are also applicable to the routine inspection of direct current motors.

During in-depth inspections, remove the cover plates on the end opposite the output shaft of the motor. The commutator and brush assembly are located immediately under the plates. The following outlines the internal in-depth inspection procedure:

- Check the commutator surface for smoothness. The commutator bars should be evenly glazed and free of grooves.
- Examine the slots between the bars for “bridging,” i.e., copper spill-over from bar to bar.
- Check the mica insulation material between the bars. If the copper is worn below the mica, the brushes will not commutate properly and “brush chatter" will become noticeable.
- Check all brush holders for equal clearance from the commutator surface; ⅛ in. (3.2 mm) is average but the equipment manual should be checked for specified clearances.

C2.8.3.3.3.1

Grooves are caused by copper, abrasive particles, or foreign matter embedded in the brushes cutting into the soft copper as the commutator rotates.

If bridging is allowed to develop, short circuiting or “flashing” of the commutator will result.

The brushes should not project beyond the edge of the commutator, and brushes on multiple brush-arm machines should be staggered and aligned so they do not ride in exactly the same position on the commutator. Some overlapping should occur to provide more even commutator wear. See the manufacturer's recommended procedures for proper brush installation, settings, and spring pressure. In the absence of manufacturer’s data, an approximate spring pressure of 2½ lbs (11 N) could be used.

2.8.3.3.4 Synchronous Motors

A synchronous motor is similar to an AC induction motor, except that the rotor consists of a series of direct current field poles. These field poles are normally wired in series with their polarities alternating from north to south magnetic fields. The two connections to the DC field are wired to a pair of “slip rings” (collector rings) that are mounted on the shaft. DC voltage is applied through the brush assemblies on the collector rings from the controller.

The synchronous motor should be started just like an induction motor. Three-phase power is applied to the stator and the rotor connections are shorted through a small amount of external resistance. After the motor approaches rated speed, a DC voltage is applied to the field coils. The DC current in the rotor coils produces magnetic fields that interact with the stator produced magnetic fields. The stator coils alternate in magnetic polarity with the AC supply frequency each time the current reverses. The rotor poles should follow this alternating magnetic pole of the stator because like poles repel each other and unlike poles attract; i.e., the rotor coil (separated by the air gap from the stator coil) will be a magnetic north for one half cycle of the supply frequency and then change to magnetic south for the second half cycle. This means that the rotor coils will move past the stator coil at a rate of two poles per cycle, first a south, then a north magnetic pole. At running speed, the rotor is said to be synchronized (magnetically) with the stator frequency. This is the reason the name "synchronous" is given to this motor. If the rotor does not rotate at "synchronous speed," it is "not magnetically coupled" with the stator poles and slip will occur until the rotor poles synchronize with unlike poles on the stator.

The "slipping of poles" occurs only at start-up or from a high overloading of the motor (usually above 160 percent), and occasionally from mechanical binding or friction. Normally, the synchronous motor does not slip during running operations and the speed remains constant regardless of motor load change.

2.8.3.3.4.1 Inspection

The inspection of the stator is the same as for a squirrel-cage stator. The rotor should be checked somewhat differently. During in-depth inspections, the following procedure should be used:

- Check the two slip rings and brush assembly as though it were a wound-rotor motor.
- Inspect the rotor windings for insulation failure.

C2.8.3.3.4.1

The damper winding is a weak point of the synchronous motor and particular attention should be focused on this area during in-depth inspections to verify that the insulation has not been overheated.

2.8.3.4—Motor Controls and Motor Control Centers

Main switchgear and motor control equipment is provided to power the bridge's electrical equipment. Older designs may consist of enclosed control equipment (Figure 2.8.3.4-1) mounted on a slate or synthetic compound board. Modern systems consist of enclosed main switchgear and motor control centers of modular metal construction (Figure 2.8.3.4-2).

C2.8.3.4

The inspector should be sure to remove power feeding the starter before inspecting the starter cubicle. Do not operate starters or disconnect switches with contact arc covers removed.

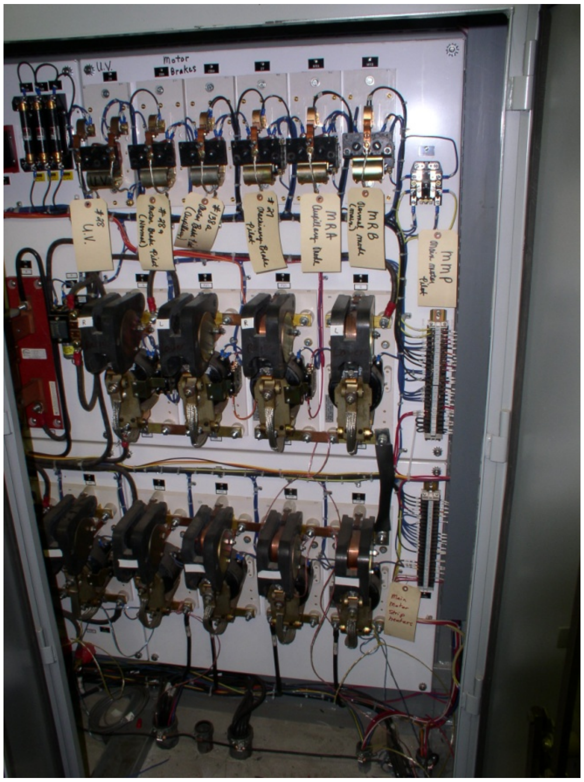

Figure 2.8.3.4-1 – Enclosed control equipment

Figure 2.8.3.4-2 – Motor control center

Motor controls are electromechanical or solid-state devices used to control electric motors. Motor controls can be divided into two categories: starters and controllers. A starter is used to start, stop, and often reverse the direction of motor rotation, but not to control speed and the rate of acceleration and deceleration. A controller performs the functions of a starter and also controls speed, acceleration, and deceleration. If circuit breakers, fuses, disconnect switches, and overload relays are furnished with the starter unit, the starter is called a “combination starter.” On modern movable bridges, motor controls are grouped together in cabinets or enclosures. These cabinets or enclosures, along with the motor controls and associated control equipment, such as disconnect switches and circuit breakers, are called motor control centers. Motor control centers can be of standard manufacture or custom made for the particular application. Motor control centers have compartmentalized sections for motor starters, motor controllers (variable speed), incoming power, circuit breakers, and other equipment.

Motor starters used to control AC motors are divided into two broad categories: full-voltage starters, also called across-the-line starters, and reduced voltage starters. A full-voltage or across-the-line starter is one that connects its controlled motor directly to full value of motor circuit voltage. Starters used in bridge control applications are typically magnetic type. In the magnetic starter, the contactor is operated by the contactor electromagnetic coil that is remotely controlled by a push-button or selector switch located at the control console. The full voltage magnetic type starter is typically used to control movable bridge traffic gates and resistance gates and span and tail locks.

A reduced voltage starter, as the name implies, initially connects the motor to a value of the voltage less than that of the supply circuit and then increases the voltage gradually until the motor receives full circuit voltage. Reduced voltage starters are used to serve large motors, typically span drive motors.

During routine inspection, the inspector should look inside each compartment for signs of rust and corrosion, dust, debris, and broken parts that may have fallen from equipment housed within the compartment. Wiring should be visually checked for deteriorating insulation and terminal connections should be tight. All wires should be properly tagged in accordance with the as-built drawings. The exterior of the motor control center should be checked for rust and corrosion. Motor starters should be inspected for loose wires, missing or loose hardware, burned coil or wire insulation, worn and pitted contacts, and the presence of dust and debris. The inspector should also listen to motor starters during operation and note any unusual noises. In-depth inspection should consist of infrared monitoring of all cable connections and insulation resistance testing of all cabling connected to the line and load sides of all motor control center starters and circuits.

2.8.3.5—Brakes

Since brakes are composed of a linkage of moving parts and a friction member, normal wear is expected. Proper inspection and quality of maintenance directly contribute to the proper operation and life of the brake.

Braking systems usually consist of separate devices designed to perform two distinct braking functions: To decelerate and stop the moving span, and to hold the moving span in the fully closed position or the fully open position.

C2.8.3.5

Brake shoe lining wear necessitates most frequent inspection, as it directly affects the brake adjustment. All bearings and pins should be kept lubricated with general purpose grease. All nuts and locking devices should be periodically inspected to verify that the brake is in proper operating condition.

Brakes used to decelerate and stop the moving span are known as motor brakes and are normally connected directly to the drive motor shaft. They are arranged to operate in concert with the drive motors. The brakes used to hold the moving span are known as machinery or emergency span brakes and are connected within the machinery system, usually as close to the final machinery output shaft as possible. The machinery brakes are usually set after the motor brakes are applied and the moving span is stationary.

2.8.3.5.1 Thruster Brakes

The thruster brake is a motor operated hydraulic brake. The brake motor runs a pump that produces hydraulic pressure in the brake cylinder to release the brake shoes. Figure 2.8.3.5.1-1 shows a hydraulic thruster brake.

Brake torque is a function of the spring tension forcing the shoes onto the drum. By increasing the spring force, more brake torque is applied. However, the brake release mechanism should overcome this spring force to release the brake and correct adjustment is required at all times. The other adjustments compensate for shoe wear and alignment in the drum.

A time delay feature in setting is usually supplied on thrusters and can be adjusted to provide a time of application of up to five seconds. This is usually by means of a controllable flow hydraulic orifice and allows the brakes to be applied gradually, lessening the stresses on the mechanical bridge components. Changing the setting time does not affect the releasing time. The time delay setting can generally be adjusted with a screwdriver. On thrusters having the adjustment screw and the nut on the outside of the tank cover, arrows indicate the direction of rotation for the desired time.

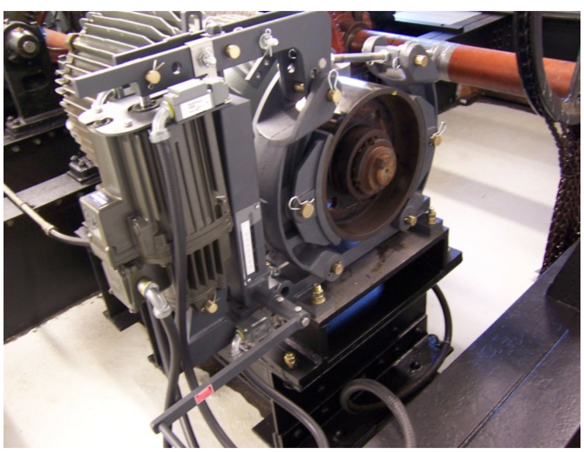

Figure 2.8.3.5.1-1 – Hydraulically operated thruster brake

C2.8.3.5.1

Most new motor and machine brakes are usually of the thruster operated shoe type, where the shoe applies the braking torque to the drive shaft when the thruster drive motor is deenergized. The thruster consists of an actuator, which obtains straight line motion by means of oil pressure generated under a piston by a motor driven impeller.

It is an important feature with motor and span brakes that power is used to release the brake rather than to apply the brake. If power fails, the brake will set and prevent uncontrolled span motion.

2.8.3.5.2 Dual Magnet Clapper and Solenoid Brakes

On this design, electrically operated dual magnets operate the brake assembly that releases the brake shoes. The two magnets, called clappers, are shown in Figure 2.8.3.5.2-1. One magnet is wound to produce a north magnetic pole at its face and the other is wound to produce a south magnetic pole face. When energized, the coils attract each other and press against the end of the brake rod on top of the frame; this compresses the spring and releases the brake.

Figure 2.8.3.5.2-2 shows a solenoid brake. The electrically operated solenoid coil magnetically draws the iron core into the solenoid. The iron core is attached to the operating arm assembly that releases the spring tension applied to the shoes.

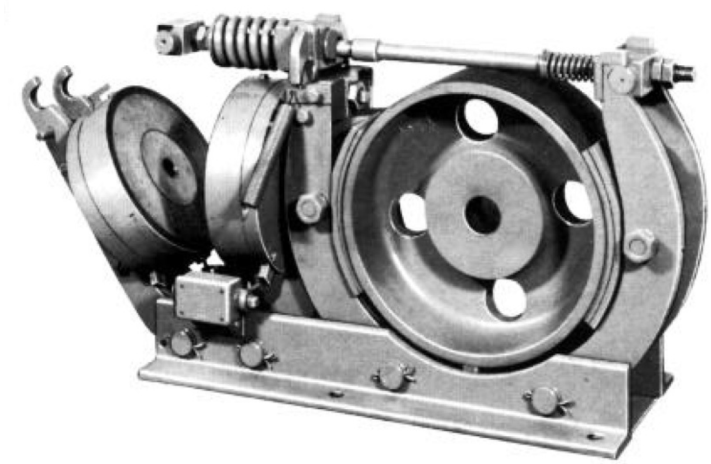

Figure 2.8.3.5.2-1 – Dual magnet clapper type brake

Figure 2.8.3.5.2-2 – Solenoid type brake

C2.8.3.5.2

Magnetic clapper and solenoid brakes are "instant on" types which can impose heavy braking torques on drive machinery. Systems with this type of brake or with thruster brakes that are set to engage instantly should be thoroughly investigated for signs of shaft or gear distress that sometimes may result from higher braking forces applied quickly to older systems. This is particularly true if the brake is a replacement component that was not part of the original design.

2.8.3.5.3 Disc Brakes

Disc brake lining is of the module type. The linings are the rotating portions of the brake and pressure is applied to both faces by a smooth finished cast iron pressure plate.

A lining wear indicator, which is an extension of the solenoid lever, gives an indication of lining wear. On standard brakes, the indicator is visible from the outside of the case. On watertight disc brakes, an inspection plate covers the indicator. When the indicator reaches the point marked "adjust," the wear adjustment nut should be adjusted to bring the indicator back to the "off" position. When the limit of the adjustment nut is reached and the indicator shows "adjust," relining of the brake is necessary.

C2.8.3.5.3

There are several different types of disc brakes in use on movable bridges. One type is a disc rotor combination where the discs contact the rotating rotor to apply the braking torque. Another type is the enclosed multiple plate disc brake. Inspection procedure for the different types of disc brakes should be based on the manufacturers literature/or the particular type of brake.

2.8.3.5.4 Brake Inspection

In-depth inspection of brakes should include visual inspection and performance testing. All electrical interlocking should be checked. Brake shoe clearance should be checked and the spring compression setting should be verified.

The electrical circuits and lead wires to solenoids should be inspected for signs of deteriorating insulation. Also check for signs of overheating and loose connections. Thruster motors can be overloaded and become overheated because of an improper torque spring adjustment. Check that the thruster motor air passages are clear and that the hydraulic piston is leak free.

2.8.3.6—Electric Cables

The various types of cables used on a movable bridge include:

Power cables: The power cable may have three or four insulated copper or aluminum wires that connect directly to a motor, generator, or transformer. The applied voltage is usually 240 or 480 volts, but can be 2,400 to 4,160 or higher. The load currents are usually above five amps.

Control cables: The control cable contains insulated copper or aluminum conductors of low power capacity. They provide low voltage for the various control functions and bridge sensor devices. The wires in the control cables can be single conductor or stranded wire. Control cables can contain many color coded wires with a durable outer covering to protect and keep them together.

Submarine Cables: Submarine cables are used to carry power and control signals from one pier to another pier on a double-leaf bascule or to the central pier in the case of a swing bridge. The cables are designed and constructed for direct burial on the channel bottom.

C2.8.3.6

Control cables should be properly identified by a tagging system that is referenced to an as-built wiring diagram. The inspector should note if existing cables cannot be properly identified during routine inspection.

The inspector should check system control voltage prior to inspection.

2.8.3.6.1 Cable Insulation Inspection

There are many types and classes of wire and cable available. In any type of cable, insulation failure results mainly from overloading, physical damage, or deterioration with age. Dirt, moisture, oil, corrosive atmosphere, over voltage, or over current can cause unexpected insulation failure.

Worn insulation can result in short circuits between the equipment and ground or between two or more cables. The inspector should carefully check the entire cable installation visually during a routine inspection. The following areas of concern should be noted on the inspection report:

- Wearing of insulation from rubbing or abrasion.
- Repeated bending of wires.
- Deterioration of insulation from age or atmospheric conditions. (See Figure 2.8.3.6.1-1.)
- Overheating (insulation discoloration).
- Cable insulation showing signs of “sweating.” This condition indicates cable insulation deterioration.

Figure 2.8.3.6.1-1 – Deterioration of electrical cables

Flexible cables are frequently used to interconnect the power supply and controls that are located on the substructure elements with other electrical equipment (such as the drive motors) mounted on the moving span. Each opening and closing of the span causes the cables to bend and flex. Improper installation can result in a cable breakdown. The following routine inspection procedures should be performed:

- Check to make sure that the cables are supported at both ends of the loop. A loop is provided so that the movement of one end, during raising and lowering of the span, does not cause the cable to bend too sharply or twist while moving.
- Check to see if cable supports are provided. If not, cables may drag along the floor. This can cause a short circuit.
- Check for severe (short radius) bending. This can cause the

C2.8.3.6.1

Control and power cables cannot tolerate continuous movement against another surface. Rubbing of cable insulation against any other surface results in the loss of small amounts of insulation. It does not matter whether the rubbing is against a solid surface or another wire. Eventually, the insulation will break down and a short circuit will develop.

Since a movable bridge has a number of wires and cables that are hung to provide control and power, these wires and cables should be supported at each end so that they do not bend excessively. A careful inspection should be made for cracking or wearing of the insulation at support points and at locations where the cables are bent. Tight radius bends can damage cable insulation.

Cable insulation can deteriorate from atmospheric conditions. Moisture is usually present in the air and frequently contains contaminants such as salt from sea water. The effects of these contaminants reduce the expected life of the cables.

On swing spans, the submarine cables typically pass through the center casting at the center of span rotation. This area is usually difficult to access, but is also a likely spot for insulation and wire mechanical damage and deterioration resulting from repeated flexing during span rotation. It should be checked during routine inspection.

When system voltages exceed 600 volts, consideration should be given to hiring a specialist cable testing company to test the cables.

wires to break at these points.

- Check for cracking or wearing of the insulation at stress locations.

In-depth inspections should determine how much insulation has been lost. Meggering of cables can be utilized to give an accurate cable insulation quality. Check for cracks that continue through the insulation to the conductor. These provide a short circuit path. If found, this condition should be corrected, especially if pieces of insulation are cracking away completely from the conductor. Insulation resistance testing with a megger and spot checking of wire resistance, circuit amperage and other vital system parameters should be performed during in-depth inspections.

Insulation overheating: The heating of insulation above a temperature for which it was designed will cause discoloration and may lead to failure. If overheating continues long enough, drying and cracking of the insulation results. The conductor metal will be severely discolored at this point. A thorough inspection of the cable insulation can reveal potential trouble spots before the wire is severely damaged and corrective action can be taken.

Localized overheating: Wires and cables carrying electrical current operate at a higher temperature than the ambient or surrounding temperature. Avoid contact between cables that are carrying heavy current since this creates an area where heat cannot be dissipated readily. This lack of heat dissipation can result in localized overheating of the insulation and soften insulation between the cables. The cable insulation will develop an indentation and have reduced insulation value at this point.

If localized overheating is suspected, carefully separate the cables and check for signs of overheating of the insulation. Cables will sometimes stick together due to fusing of the insulation or contamination. Other types of insulation will dry up and crumble when overheated, rather than bond together. In either case, loss of insulation will result in short circuit failures.

Insulation contamination: Dirt and moisture cause a buildup of contamination, which reduces the heat transfer from a cable to the atmosphere and results in higher operating temperatures. The ambient effect of this temperature rise is an acceleration of normal insulation deterioration.

Grease and oil are very detrimental to insulation life because of their adherence to surfaces. The normal dirt in the air mixes with oil and grease and builds up very rapidly. Contamination from oil on any equipment presents a problem, not only for insulation, but also as a major fire hazard.

2.8.3.6.2 Terminal Connections of Wires and Cables

Terminal points provide increased stress on wires and insulation terminal connections frequently support some of the weight of the wires. Vibration and normal flexing of the cables should not break or crack these connections if they are properly designed and installed; however, loose connections frequently overheat and can cause insulation failures. Connections can become loose over time by repeated resistance heating and subsequent cooling of the connector metal parts, which can sometimes cause temporary thermal stresses that tend to loosen threaded fasteners. Inspection of connections for tightness and signs of insulation deterioration can prevent failures and unexpected equipment shutdowns.

Wherever components are connected together, the surface contact area of wire terminals and equipment terminals are subject to corrosion and resistance buildup. Even newly made connections have a "junction resistance" and their contact surfaces develop some heat while conducting current across the junction. If the corrosion is excessive, overheating of the insulation and conductors results. Failure of the insulation will eventually lead to electrical failures.

C2.8.3.6.2

Infrared heat temperature sensors provide a safe non-contact means of identifying loose wiring connections. Cable terminations should be "hot spot" tested by infrared testing equipment during an in-depth inspection.

2.8.3.6.2.1 Inspection

Routine inspections should include de-energizing circuits and spot checking threaded fasteners for tightness. In-depth inspections should include checking all threaded terminal connections for tightness and electrical resistance testing across the fastener to check for corrosion buildup.

Routine cable inspection should include the following:

- Check the wire terminations for tightness.
- Check cable insulation condition. An overheated connection will appear blue in color.
- Check control wire or power cable that passes through a wall or apparatus housing and check the condition of the insulation.
- Check for flat or worn spots and cuts in the insulation from support brackets or motor frames.

2.8.3.7—Power Source

Electrical power supplies commonly found on existing movable bridges consist of a service provided by the local utility and possibly a redundant supply line or backup standby generator. The local utility electric service can take a number of forms.

Primary service consists of a medium or high voltage connection from the utility, which is transformed down to the appropriate utilization voltage for the bridge (208/120 volts, 480/277 volts, etc.). The high voltage switchgear and

C2.8.3.7

Power company transformers, normally mounted on top of the pole, step down the voltage to a level compatible with the bridge equipment. Electric power then enters the bridge house at a weather head type service or via conduit. The power then connects to the main motor control center and/or switchgear.

transformation equipment is usually located in a vaulted area, secured by the utility, or on a power pole located at the bridge site. See Figure 2.8.3.7-1.

Overhead or underground secondary service is usually provided at the utilization voltage, with service from the utility system to the bridge structure and termination in the utility metering cabinet. The utility metering cabinet is normally found in the same room as the bridge main switchgear and motor control equipment.

The utilization voltage for movable bridges usually consists of a three-phase, 60 Hz service.

Figure 2.8.3.7-1 – Pole mounted transformers

The electric service is typically one of the following:

Normal Voltage	Phase	Wires
120/240	1	3
120/208	1	3
208/120	3	4
240	3	3
480/277	3	4
480	3	3
600	3	3

2.8.3.7.1 Inspection (Incoming Power)

The following procedure should be used during routine inspection:

- Check for signs of rust, corrosion, oil leakage, or any condition at the power company transformer that may lead to failure of the incoming power.
- Check the line jacks. If any of the line jacks, which are fused elements, are hanging down, a blown fuse is indicated. A blown fuse will cause the bridge to operate on what is called a “single-phase” condition that can destroy equipment.
- Check for signs of loose hardware, supports, and conduits.
- Use of a voltmeter to monitor voltage fluctuations.

2.8.3.7.2 Electric Generator

Where provided, a backup standby generator maintains continued electric service for the movable bridge in the event of utility service failure. Usually, the standby system consists of an internal combustion engine driven synchronous generator with either an automatic or manual transfer system, to transfer from utility service to standby service in the event of utility failure. See Figure 2.8.3.7.2-1. The size of the standby generator is based on the starting requirements for the bridge drive motors and can be as much as twice the capacity of the utility service. Both AC and DC type generators are used on movable bridges.

Figure 2.8.3.7.2-1 – An automated generator

2.8.3.7.2.1 Inspection

AC generators are similar in construction to AC motors and similar inspection procedures should be followed.

Brushless exciter generators should be checked similarly to a squirrel cage motor. Caution should be observed to prevent damage to the diodes in the generator caused by testing equipment, and the manufacturer's equipment manual should be consulted before performing any testing.

DC generator inspection is similar to that of a DC motor. In addition, a self excited DC generator should be checked to verify that the generator comes up to voltage within five to ten seconds after the generator has reached rated speed.

Regulated DC generator supplies should be checked for stability (generator output) only when the generator load is stable. If the generator is unloaded the voltage should not be oscillating above or below the control voltage value. Similarly, when the generator has a constant load, the regulator should stabilize the output voltage after the first two or three transients caused by load change. If the voltage regulator tends to "hunt," the regulator may require calibration and a tune-up to improve its operation.

The engines on emergency generator sets should be started on a biweekly basis. This is necessary to push oil to the top of the engine and maintain proper lubrication. Also, the generator should be utilized to open the bridge once a month and during the routine inspection. The starting circuitry should be operated and checked at the same time. Vibration levels should not exceed the manufacturer's specification, and can be checked during testing of the generator. The generator room should be inspected to determine if adequate air flow is available for engine cooling and combustion. Engine exhausts should be properly ducted or piped outside of the generator room. If the generator is incapable of producing the necessary drive power to open the bridge, it should be listed as critical.

2.8.3.7.3 Transformers

The transformer is a relatively simple device that has made the economical transmission of electrical power over long distances practical. Its function is to transform, or change, AC power from one voltage and frequency to another voltage at the same frequency. There are many types of transformers. Two types will be discussed herein: dry transformers and liquid-filled transformers.

C2.8.3.7.3

Transformers are used to reduce generated voltages to levels that the customer can use for his equipment. The primary voltage usually requires another transformer to reduce the voltage used on the customer level. The size of transformers depends upon, among other things, the load requirements of the customer.

In addition to the large transformers used on incoming service power, there are also numerous other applications for transformers within the bridge circuitry. Transformers are used to change power voltages to control voltages and to step down power to low voltage indicator lights and other devices within the bridge circuitry. The inspection methods for these devices will vary from manufacturer to manufacturer and should be developed based upon the latest available manufacturer's literature on the particular type of unit. The general concerns as discussed herein for larger transformers will in general also apply.

2.8.3.7.3.1 Dry Transformers

The dry type, air-cooled transformer is constructed by winding coils around a laminated iron core. The coils are separated and have air spaces to enable air to circulate around the copper and between the iron core and windings. One advantage of the air cooled transformer is the accessibility of the windings for maintenance. The tap connections, used for changing voltage, are normally at the sides. The transformer can be inspected by removal of the cabinet panels. Figure 2.8.3.7.3.1-1 shows a view of the air-cooled transformer. The high voltage tap connections are not shown. They are located on the rear of the transformer.

Two advantages of this type construction are less weight and ease of tap changing.

Figure 2.8.3.7.3.1-1 – Air-cooled transformer

2.8.3.7.3.1.1 Inspection

The inspector should perform the following checks during a routine inspection:

C2.8.3.7.3.1.1

Sometimes the 60 Hz of the AC transformer winding creates mechanical vibration. Extreme vibration can cause

- Check that supports are not bent and that bare conductors are not exposed to adjacent metal.
- Check the frame for signs of rust or metal cracking, especially around welds.
- Inspect the transformer primary disconnect switches (if furnished) for damage, loose materials, or contamination.
- Inspect installation location for any unfavorable environmental conditions.
- Visually check the equipment ground and record the number and size of ground bus and straps.

The inspector should perform the following checks during an in-depth inspection:

- Check the tightness of terminals at the high and low voltage connection points. The terminals should not show signs of breaking or overheating.
- Check insulation for signs of cracking, overheating, or breakdown indications. Make certain dirt has not accumulated to plug the air passages around the coils.
- Check insulators. They should be clean and intact without signs of cracking or chipping.
- Check high voltage switches (if furnished) for operation and adjustment. Check the insulation quality of switch phase-to-phase and phase-to-ground with megohmmeter.
- Check insulation of all control circuits to ground with a suitable megohmmeter.
- Check key interlocks (if present).

frame cracking and contribute to an electrical failure of the limit. In-depth inspection should be designed to detect any such undesirable cracking conditions.

2.8.3.7.3.2 Liquid-filled Transformers

Better cooling capability is obtained by using liquid around the transformer core and coils because liquids conduct heat better than air. Liquid-filled transformers built today use two types of insulating fluids: mineral and synthetic oils. Figure 2.8.3.7.3.2-1 shows a liquid-filled transformer.

Mineral type insulating oil is degradable and can be handled in the normal manner. It is combustible and presents an explosion and fire hazard.

Synthetic insulating oils, called askarels (PCBs), are noncombustible, but toxic when absorbed through the skin. Special handling is therefore required, and stringent restrictions for use and disposal have been established. Askarels do not present an explosion or fire hazard and have a higher insulation value than mineral oil.

C2.8.3.7.3.2

Askarel (a generic name for PCBs) was widely used as a dielectric fluid for transformers manufactured from 1930 to 1976. In the 1970s, concerns about possible toxicity and environmental impact of PCBs came to the fore. Regulation of the use of these transformers began in 1978 with the EPA's Marking and Disposal Rule.

In 1982, The Electrical Use Rule introduced the concept of periodic leak inspections. Detailed records, as a minimum, are now required for any installation utilizing a PCB filled transformer.

Figure 2.8.3.7.3.2-1 – A liquid-filled transformer

Many liquid-filled transformers require cooling radiators to dissipate the heat generated internally. Usually mounted on the sides of the tanks, the radiators conduct heat from the liquid to the atmosphere. The radiators may be fan cooled to assist in conducting heat from the radiator surfaces. Sometimes oil circulating pumps are used to improve the thermal capability of the transformer.

2.8.3.7.3.2.1 Inspection

There are additional items to check on the liquid type transformer in addition to those items listed for inspection under dry transformers. The following additional areas should be checked during a routine inspection:

- Check for proper oil level inside the tank. Many transformers have dial type indicators for liquid level and temperature. The oil level of the transformer at the operating temperature can be determined from these gauges. The temperature indicator usually has a safe temperature point marking e.g., 70°F (21°C). If the oil level is correct, then the dial indicator should point to that mark.
- Check the tank and floor area for signs of oil leakage. Oil leakage indicates a potentially dangerous condition because the oil level is dropping inside the tank.

The following should be checked during in-depth inspections:

- Transformers without level indicators should be checked by removal of inspection covers on top of the transformers during in-depth inspections. This work should be done by personnel who have received safety training concerning proper methods to protect themselves against PCBs in the insulating oil.
- Check the insulating bushings for signs of cracking or chipping. Dirt build up should be noted.

C2.8.3.7.3.2.1

Caution: Unless absolutely sure that the transformer oil is not PCB contaminated, the inspector should not touch any of the oil if a leak is found. The inspector should call for immediate corrective action and file a deficiency report that should indicate the leak and request immediate investigation by an expert in liquid filled transformer evaluation.

- Check the radiators to make sure air passages are clear. If fans are used, they should be free from vibration and properly directed toward the radiators.
- Check the sudden pressure relay to be sure that it has not operated. This relay operates when a sudden pressure develops inside the transformer due to a fault condition. Normally it is wired into an alarm system to provide warning and shutdown functions. A small indicator located on the top of the relay will show operation.
- Check high voltage connections terminating inside a connection box to verify that the insulation on the pot head, cables and support is in "good" condition. Normally, the high voltage cable has a shielding wire. Be sure that these are properly connected to the grounding point.

2.8.3.8—CIRCUIT BREAKERS

Circuit breakers are used both as protective devices and for switching electrical power. One of the main requirements of a circuit breaker is that it should be capable of carrying rated current continuously. If a short circuit or overload occurs, the circuit breaker must open the circuits.

The general classifications of circuit breakers are:

- Low or high voltage air circuit breakers (ACB).
- Molded case circuit breakers.
- Oil circuit breakers.

C2.8.3.8

To isolate or open a circuit when no current is flowing is one thing, and to interrupt the flow of current and maintain the interruption is another. A simple knife switch may be quite adequate under no load conditions, but not for power interruption. Not too many years ago, breakers were merely manually operated switches with a tripping device and no electrical control. Some later designs were equipped with shunt tripping coils similar to those described in the air circuit breakers, while others used an undervoltage relay to operate the trip mechanism. An undervoltage relay trips the breaker when voltage dips below a safe level or if there is a power failure.

2.8.3.8.1 Air Circuit Breakers

This type of breaker operates in air to extinguish the arc when a circuit is opened.

An air circuit breaker is generally used where the voltage is above 250 volts to ground. Figure 2.8.3.8.1-1 shows a three pole air circuit breaker. This breaker is of the open construction type and is normally part of a switchgear system. The main components are shown in Figure 2.8.3.8.1-1 and include the arc chutes pole contacts, trip and overload mechanisms. The overloads in this breaker are thermal/magnetic types and can be adjusted for a number of selected trip values.

C2.8.3.8.1

In low voltage applications (120 volts to 277 volts to ground), typically molded case circuit breakers are used.

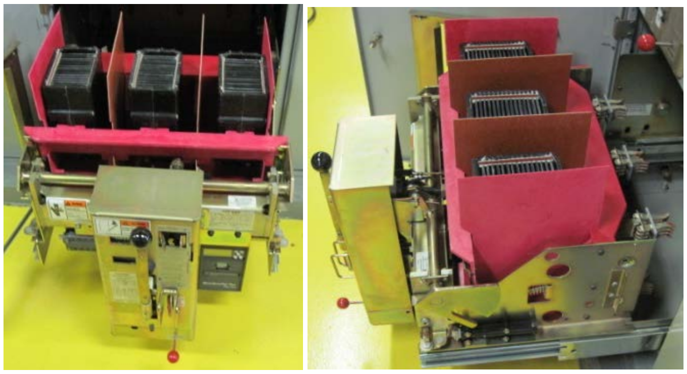

Figure 2.8.3.8.1-1 – Air circuit breaker

Some circuit breakers use spring charged operating mechanisms. These devices have manual or electric motor charging devices to compress the spring(s). When the breaker is closed the “stored” energy snaps the breaker contacts closed, maintaining a contact pressure. When the breaker is opened, stored energy must open the contacts in a precise, fast operation to minimize contact wear due to electrical arcing.

In Figure 2.8.3.8.1-1, the air circuit breaker operating handle is used to close and trip the breaker. Some types of ACBs close with the handle mechanism, but trip with a push-button on the panel. Electrically operated shunt tripping coils can also be used to trip the breaker. These shunt trip coil units are mounted on the breaker frame, with the coil plunger operating the breaker tripping bar. The overload protection units shown in Figure 2.8.3.8.1-1 monitor the load current continuously for time over current conditions. The trip unit (one for each pole) will actuate the trip bar to open the breaker when an overload condition is detected.

Additional equipment can be mounted on the breaker, such as auxiliary contacts for the breaker indication. These contact blocks are mechanically coupled to the operating mechanism by link arms and close and open with the breaker main contacts. Other equipment might include electronic protection circuits with multiple monitoring functions. A check of equipment drawings will indicate the items supplied and the circuitry involved.

2.8.3.8.2 Molded Case Circuit Breakers

Another commonly used breaker is called a molded case circuit breaker. It is built with a complete enclosure of molded plastic. Its contacts operate in air with arc chutes around them to extinguish electrical arcing during contact opening. The breaker cases are factory sealed so that they cannot be tampered with. Figure 2.8.3.8.2-1 shows a molded case breaker used for motor circuit protection. The trip element in this type breaker can be changed to give a range from 7 to 4,000 amperes. Current exceeding the set values causes the circuit breaker to trip.

On any adjustable breaker, the trip setting is normally calibrated at the time of installation to suit load requirements. The setting should be kept on record and checked by the inspector during inspection.

Figure 2.8.3.8.2-1 – Molded case circuit breaker

2.8.3.8.3 Oil Circuit Breakers

Oil filled circuit breakers are sometimes applied where large motors must be started and stopped. Oil provides increased insulation for high current interruption. Normally, this type of breaker will not be used on bridges, but older power circuit breakers were all oil immersed units.

2.8.3.8.4 Inspection

The following outlines the routine inspection checks that should be performed for all breaker types:

- Check connection points to verify that overheating has not occurred. Cable connections should be tight.
- Check for stressing of the breaker terminals caused by unsupported cables.
- Check the trip settings on the front to make sure the proper trip settings are in use.

Air circuit breakers: The following tests should be performed during an in-depth inspection:

C2.8.3.8.4

The inspector should not attempt to restore the contact surface with a file or other abrasive device. Record the contact condition only. The proper testing of circuit breakers requires trained personnel with portable equipment. Except for small breaker testing (under 100 amps) special test equipment is required. Breaker testing will not be included in this discussion.

- Check the arc chutes for loose or missing hardware, foreign material, and the condition of ceramic insulation and arc interrupters. On most air circuit breakers, the arc chute can be removed for inspection.
- Check contact surfaces for arc damage, pitting, and erosion. It should have at least 90 percent contact. Good contact operation requires a slight amount of "contact wipe" or overtravel after contact is made.
- Check to see that the contacts are clean and positively seated. Adjustable spring compression is normally provided.
- With the breaker in the test position and deenergized, check contact alignment and verify that they make simultaneous contact when closing.
- Check overload trip settings to make sure they have not been moved from their calibrated setting. Only authorized personnel should be permitted to change trip unit settings.
- Check the terminal connections where the line and load cables are connected to the breaker. Loose connections are a major cause of breaker failure. Loose connections produce heat resulting in insulation failure or breaker malfunction.

Molded case breakers: The molded case breaker requires little inspection because the case is sealed.

Liquid-filled circuit breakers: Routine inspections are similar to those described for molded case circuit breakers. When liquid filled circuit breakers are used, an in-depth inspection should include testing a sample of the insulating oil. This should be performed by a specialized testing company. A complete check of the breaker's oil immersed parts should be made at every in-depth inspection if the switching operation is very light, more often under frequent load interrupting conditions. If oil level indication is provided on the breaker, check the oil level every month or less depending upon operating conditions. Oil should be tested according to the test methods outlined in Chapter 2.10.

Some limited testing of breaker insulation to ground can be performed by using the megger test. Refer to Chapter 2.10.9 for a description of this test. **Caution:** Other equipment connected by cables to the breaker may have testing limitations; check the equipment before making any tests.

2.8.3.9—TRAFFIC CONTROL

Traffic control electrical systems operate traffic signals, traffic gates, advance warning signs with flashing lights and message boards, and resistance or energy absorbing barriers located on bridge approaches open to the waterway crossing.

2.8.3.9.1 Warning Lights and Signals

The use of "drawbridge ahead" warning signs is required on all movable bridges to give advance warning to motorists, except in urban conditions where such signing would not be practicable (MUTCD, Reference 65). When physical conditions prevent a

C2.8.3.9.1

Any malfunctioning or missing warning lights, signals, or navigation lights should be reported immediately and recommended for immediate repair.

driver from having a continuous view of at least one signal indication, for approximately 10 seconds while travelling at 85 percent of the posted approach speed before reaching the stop line, an auxiliary yellow flashing light is required by the MUTCD on the warning sign. The inspector should check for proper installation of these warning signs and for proper operation of the flashing light if required. Any sign or warning light found to be missing or inoperative should be reported in a deficiency report.

2.8.3.9.2 Traffic Signals

Traffic signals should be checked for proper electrical connections, tightness of the bolts, corrosion of any metal parts, broken lines, and non-functioning lights. Any traffic lights found to be inoperative should be reported immediately.

2.8.3.9.3 Traffic and Resistance Gates

A typical gate arm motor is shown in Figure 2.8.3.9.3-1.

The following should be checked during a routine inspection of traffic and resistance gates:

- Check for traffic gates' smoothness of operation, tightness of the gate arm to the housing, and for proper lubrication of the gearing.
- Spot check electrical connections for tightness and signs of corrosion at the terminals.
- Check wiring for frayed, cracked, or deteriorated insulation.
- Check the gate housing for corroded or deteriorated metal parts.
- Check the service panels to verify that they fit tightly and the frames and gaskets are in good condition.
- Check the limit switch for proper operation.
- Check that all warning lights are operating properly and their associated wiring is in good condition. An installation using solid conductor wires is not acceptable on the electrical cable leading to warning lights on the moving gates. A stranded wire multi-conductor cable should be used and protected against chafing at the point where it enters the gate housing.

C2.8.3.9.3

The electrical inspection procedure for resistance gates is similar to that of traffic gates. Some types of traffic and resistance gates may utilize special mechanical linkages and/or hydraulic systems to actuate motion of some or all components. The inspection methods for such gates should be developed based upon the procedures described in Chapter 2.8.2.

Figure 2.8.3.9.3-1 – A typical gate arm motor

2.8.3.10—NAVIGATIONAL LIGHTS

Navigational lights should be checked to confirm that they are present and operating properly in conformance with the bridge permit. Check to see that all globes are clean. Check the condition of the gaskets on the light covers. Check for corrosion on metal frame and support brackets. Any lights that may be inoperative or missing should be noted in a deficiency report.

C2.8.3.l0

Any malfunctioning or missing warning lights, signals, or navigation lights should be reported immediately and recommended for immediate repair.

2.8.3.11—LIGHTNING PROTECTION SYSTEM

The fundamental principle in the protection of life and property against lightning is to provide a means by which a lightning discharge can enter or leave the earth without resulting in damage or loss. A low-impedance path must be offered which the discharge current will follow in preference to alternative high-impedance paths offered by the bridge materials such as metal or concrete. When lightning follows the higher-impedance paths, damage may be caused by the heat and mechanical forces generated by the passage of the discharge. Most metals, being good electrical conductors, are virtually unaffected by either heat or the mechanical forces if they are of sufficient size to carry the current that can be expected. During a routine inspection, the inspector should verify that:

- The metal path is continuous from the ground terminal to the air terminal.
- The conductors are either copper or aluminum, are free of the effects of rust or corrosion, and are attached to the structure at intervals not exceeding three feet.
- All connections are tight.

2.8.3.12—ELECTRICAL COMPONENT CODING GUIDELINES

Due to the proprietary nature and sealed "black box" appearance of electrical components, it is extremely difficult to quantify criteria for numeric condition evaluation coding without extensive testing by a qualified electrical engineer. There are, however, some general guidelines as follows:

General recommendations: If the system and components are well connected and grounded, protected, secured, safely operating, and functioning as intended, a coding of "excellent" (recently installed, no defects), "good" (minor deterioration or wear), or "fair" (functional, but with obvious deterioration or wear) should be assigned as appropriate to each component and system.

Electrical components that are observed to be smoking, hot, or otherwise exhibiting signs of resistance heating should be coded "severe." Sparking, melted or burned insulation, or black residue left by arcing or shorting of components should be cause to rate components "severe." Components that create a potential shock hazard to the public or workers should be rated "severe." Components with no external signs of distress should be coded based upon testing, engineering judgment, and/or Table 2.9.1-2. If an individual inspector cannot determine whether a component is "poor" or "severe," he should code it "poor" and request additional investigation with an explanation of the reason and type of investigation needed.

Motors that are excessively hot to the touch or that smoke or emit smells of burning insulation should be rated "poor" or "severe" depending on the inspector's assessment of the likelihood of motor failure. Motors and associated motor controls, breakers, and relays should be performance tested during in-depth inspections.

Brakes with damaged or excessively worn brake pads should be coded "poor" or "severe." Brakes and other machinery not designed for cyclical loading, but subjected to cyclical loading due to span motion under live load, should be coded "fair," "poor," or "severe" based upon the inspector's assessment of the likelihood of fatigue fracture of a nonredundant component. Motor and span machinery brakes should be internally inspected and performance tested during in-depth inspections.

Electric cables and connections that are not properly protected by enclosures or conduit; that show signs of

C2.8.3.12

Motor resistors that have gotten a lot of dust or other debris on them can get hot during motor operation.

If sparking or arcing is observed in any electrical equipment, every effort should be made to deenergize the circuit to prevent further damage.

corrosion, damaged insulation, or other conditions that add electrical resistance to circuits; or that create risk of an electrical short circuit or shock hazard should be coded “fair,” “poor,” or “severe” based upon the inspector's judgment of the probability of component or circuit failure.

Transformers that leak fluid or show signs of overheating should be coded “poor” or “severe” depending on the inspector's assessment of the likelihood of transformer failure, and whether the fluid is likely to contain PCBs. If a transformer is known to contain PCBs and is leaking, it should be coded “severe.”

Backup generators that are powered by gas (propane, etc.) or gasoline motors should be installed in adequately ventilated areas so that combustible gases do not accumulate and create a risk of explosion. Backup generators that fail performance tests and are incapable of producing the necessary drive power should be coded “poor” or “severe.”

Breakers that are excessively hot, emit a smell of burned insulation during operation, or that have a history of nuisance trips, should be coded “severe.”

Contactors with missing arc chutes that arc across to the adjacent contactor or other components, or show carbon tracks due to arcing should be coded “poor” or “severe” based upon the inspector's assessment of the likelihood of component failure.

Lock mechanisms that are inoperative should be coded “severe” with an explanation. Those that exhibit signs of overheating or other distress should be coded “poor” or “severe” depending on the inspector's assessment of the likelihood component of failure.

2.8.3.13—CONTROLS AND INTERLOCKING

2.8.3.13.1 General

Bridge control systems play a vital role in the operation of every movable bridge. This chapter addresses inspector preparation and outlines basic inspection criteria for discrete control system components, the control console system components and main drive motor controls.

The information presented in this chapter is intended for the inspector without a formal electrical engineering or electrical maintenance background. The inspector should be able to identify general deficiencies and unsafe conditions brought about by poor maintenance. The inspector should note any areas within the general bridge control system that require a more detailed inspection by a specialist with a background in control system design and maintenance.

2.8.3.13.2 Bridge Operating Sequence

The inspector, through evaluation of as-built documentation and discussions with bridge operators, should understand the bridge control system being inspected. The inspector should familiarize himself with the typical bridge operating sequence prior to proceeding with the detailed control system inspection. A typical sequence is below:

Opening Sequence:
- Turn traffic lights from green to red
- Lower traffic, then resistance gates
- Withdraw span locks/wedges
- Release brakes
- Open span
- Set brakes

Closing Sequence:
- Release brakes
- Close span
- Set brakes
- Set span locks/wedges
- Raise resistance, then traffic gates
- Turn traffic lights to green

C2.8.3.13.2

The goal in control system inspection is to perform sufficient control tests to permit the inspector to verify that necessary controls and interlocking are present, functional, and capable of being operated by a reasonable and prudent individual in a manner that is consistent with the safety of the structure, the public, and workers.

The fact that a particular component or system is present in the control panel does not prove that it is functional. Performance testing of controls and interlocking by qualified engineers including verification of the system's behavior in response to unusual control inputs or other possible errors is the most reliable method to determine that system function is reliable.

2.8.3.13.3 Discrete Control System Component Inspection

Field-mounted discrete system components provide vital information to the bridge control system regarding the status of the bridge. Limit switches, selsyns, resolvers, encoders and tachometer feedback generators are the main components inspectors should focus on during their inspection. Inspectors should be familiar with these devices and their function in the control system being inspected.

2.8.3.13.3.1 Limit Switches

A limit switch (see Figure 2.8.3.13.3.1-1) is a device that converts mechanical motion into an electrical control current by the closing or opening of a set of contacts at definite settings of the switch. The limit switch contact closures provided as a result of the mechanical movement are used to control the movement of the bridge or to make a change in its operating sequence. A limit switch provides feedback to the control system and can be called a sensor.

C2.8.3.13.3.1

The limit switch is the most important control device utilized in modern or traditional automated bridge control systems. Each bridge component that would cause a safety hazard or operational component damage if operated out of sequence generally utilizes some type of limit switch to report the position or status of the device during operation.

The primary disavantage for using a lever type limit switch is the limited travel of the

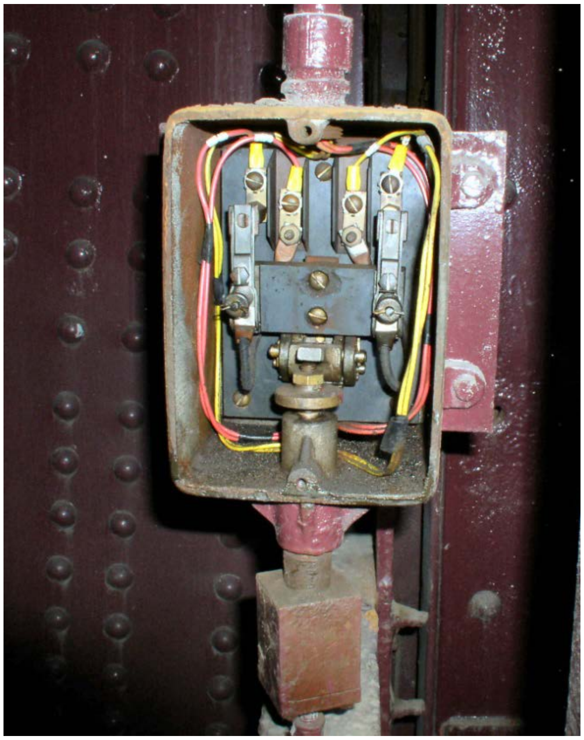

Figure 2.8.3.13.3.1-1 – Dual contact limit switch

The four most common limit switches found on movable bridges are the plunger, lever, rotating cam, and proximity types. Discussion in this Manual is limited to these types of limit switches.

Plunger type limit switches, as shown in Figure 2.8.3.13.3.1-2, are normally used to indicate when the movable span is fully closed or fully open. The switch housing is attached to either the movable or fixed part of the bridge and the plunger is depressed upon contact by a strike plate mounted to the span. As the plunger is pushed linearly into the housing, a spring is compressed, and the plunger rod forces two contacts to come together or pull apart. An electrical connection is made and/or broken as the case may be. There are various means for adjustment.

During routine inspections, check the following:

- Carefully examine the operation of the switches to make sure they are operating normally (the plunger is depressed or released at the appropriate time in the bridge operating sequence).
- Confirm the limit switch is functionally active in the control circuit.
- Carefully and safely push the rod and see if the bridge does not stop prematurely during the operation.
- Check wiring to and from each limit switch for looseness or deterioration.

During an in-depth inspection, check the following:

limit switch operating arm. Forcing the lever arm past the end of travel point will destroy the limit switch. This is the most common cause of failure for this type of switch.

- Open the cover and check for water inside the housing. If water is present, check seal around the plunger for wear or damage.

Figure 2.8.3.13.3.1-2 – Plunger type limit switch

Lever type limit switches, as shown in Figure 2.8.3.13.3.1-3, are often attached to shoe brake operating linkages to indicate when the brake is set and released, in the operating system to indicate when the movable span is fully closed or fully open, and on the span locks and wedges to indicate their position. A roller is usually provided at the end of the limit switch lever arm. A moving object contacts the roller and causes the lever arm to rotate through a limited arc of travel, usually less than 90°. Lever arm movement causes cams to rotate within the housing and open and/or close contacts. The inspection of lever type limit switches is similar to plunger switch inspection. In addition to the previous steps, check the following during routine inspections:

- Check lever arm rollers to make sure they are free to rotate and make sure the limit switch housing is properly aligned with the contacting object.
- Check for excessive looseness of the lever arm assembly. Wiring should be checked for looseness or deterioration.

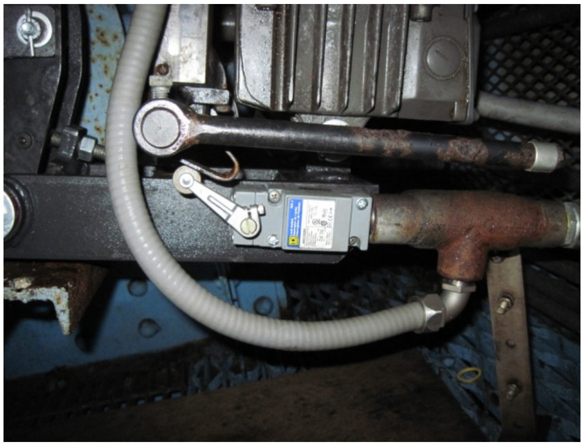

Figure 2.8.3.13.3.1-3 – Lever type limit switch

Rotating cam limit switches, Figure 2.8.3.13.3.l-4, are connected to the span drive machinery and typically are used to indicate critical points of span travel, such as the "nearly closed" and "nearly opened" positions. The limit switch shaft, which is coupled to the span drive machinery through reduction gearing, usually is designed to rotate less than 340°. Cams mounted on the shaft, within the housing, rotate with the shaft and open or close spring loaded contacts. Check the following during routine inspections:

- Check for any signs of looseness or deterioration of the wiring.
- Check the enclosure gasket for moisture seal.
- Check for moisture or signs of corrosion inside the switch enclosure.

Check the following during in-depth inspections:

- Check each of the contact surfaces, both the movable and stationary contacts, for any signs of wear or corrosion. Sometimes oxidation will take place, creating a poor contact that results in an intermittent circuit.
- Check all bearings for lubrication and play.

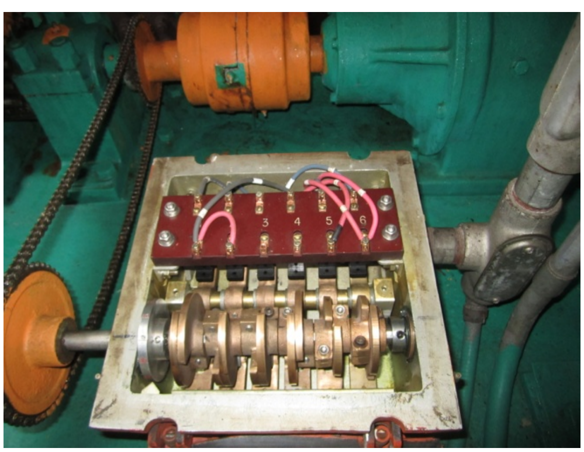

Figure 2.8.3.13.3.1-4 – Rotary cam type limit switch

Proximity type limit switches, as seen in Figure 2.8.3.13.3.1-5, are often attached to the bridge structure to indicate the movable span position, such as fully closed or fully open. Proximity switches, often magnetic, open or close an electric circuit when they make contact with or come within a certain distance of ferrous metal. Proximity switches do not have exposed moving parts. Check the following during routine inspections:

- Confirm the limit switch is functionally active in the control circuit.
- Check each of the contact surfaces, both the movable and stationary contacts, for any signs of wear or corrosion if accessible. Sometimes oxidation will take place, creating a poor contact that results in an intermittent circuit.
- Check for any signs of looseness or deterioration of the wiring.
- Check that surfaces are free of metal filings, grease, and other debris.

Figure 2.8.3.13.3.1-5 – A proximity limit switch

2.8.3.13.3.2 Selsyn Transmitters

Selsyn transmitters are rotary position sensors designed to convert mechanical input rotation to an electrical signal proportional to the input shaft position. The sensor may be equipped with a potentiometer and a two-wire transmitter that converts potentiometer movement to 4-20 mA signal.

Selsyn transmitters require no interior inspection. If the position indicators on the control console are functional then the selsyn transmitters, located in the machinery room, are functional. The selsyns should be inspected externally to detect signs of deterioration or misalignment. The inspector should check the selsyn for proper alignment with the span drive machinery. Check the condition of the flexible coupling that connects the selsyn drive shaft to the span drive machinery. The bolts that attach the selsyn to its support should be checked for tightness and corrosion. The selsyn housing should also be checked for corrosion. Check wiring for looseness and deterioration.

2.8.3.13.3.3 Resolvers and Optical Encoders

Resolvers and optical encoders, as shown in Figure 2.8.3.13.3.3-1, are rotary positional transducers, similar to selsyn transmitters, but are designed to interface with modern solid-state controls such as programmable controllers and digital panel meters. They provide greater positional accuracy than selsyn transmitters and for that reason are generally used in modern, automated bridge controls using programmable controllers requiring accurate position information for control algorithms.

Resolvers are rotary transformers having one rotor (rotating) winding and two stator (stationary) windings. The stator windings are located 90° apart. Output voltage indicates direction of rotation and the magnitude is a function of shaft displacement in degrees. Resolver output must be converted to a digital signal for proper interfacing with programmable controllers or other digital equipment.

Optical encoders consist of a rotating disc (rotor) with precisely located transparent sections. A stationary disc (stator) contains LEDs (light emitting diodes) arranged so their light shines through the transparent sections of the rotor. Photo transistors sense the LED light during rotor rotation and produce an output whose magnitude is a function of shaft displacement in degrees. Like the resolver, the output must be converted to a digital signal.

The inspection procedure for resolvers and encoders is similar to that of selsyn transmitters.

Figure 2.8.3.13.3.3-1 – Resolver type transducer

2.8.3.13.4 Control Console

The bridge is operated from a control console that contains the switches for the span operating motors, seating switches, bypass switches, instruments, position indicators or meters, indicating lights, and other control devices and apparatus necessary or pertinent to the proper operation and control of the span and its auxiliaries. Figure 2.8.3.13.3.4-1 shows a typical traditional control panel and Figure 2.8.3.13.3.4-2 shows a modern control panel. The bridge tender is responsible for operating the movable bridge. The push-buttons and switches on the control console are activated in the proper sequence to initiate and control span operation. The sequence is either performed manually by the operator or automatically by the control system. Sequence control and interlocking are accomplished through logic provided by relay panels and/or programmable controllers interfaced with or contained within the control console.

The inspector should note the location of the control console. The control console should be positioned in the operator's house so as to provide the operator a clear view in all directions. The console should be a cabinet-type console with a horizontal front section about 36 in. (914 mm) above the floor and an inclined rear instrument panel set at such a slope that all control devices are within easy reach of the operator. Specific dimension requirements have been intentionally omitted, following the example set in AASHTO's *LRFD Movable Highway Bridge Design Specifications,* to allow owners more leeway in choosing a control console design that best suits their particular needs.

Based upon current code requirements (Reference 6), there should be installed on the control console indicator lights of suitable colors that show to the operator the various positions of the bridge, especially the fully closed, fully open, nearly closed, and nearly open positions. Additionally, lights indicating the closed and open positions of the traffic gates, bridge locks, and end lifting devices should also be present. The inspector should note in the report section if these are not provided. Indicating lights may also be provided to show when each span brake is released, and the status of other functions as required to alert the operator to emergency conditions. These items should be noted by the inspector.

The inspector should also note that if push button automatic sequence open/close controls are provided, then the control console should also be provided with additional controls for manual operation.

Figure 2.8.3.13.3.4-1 – Traditional control panel

Figure 2.8.3.13.3.4-2 – Modern control panel

The seating switches, if foot-operated, should be inspected to ensure they are operational.

All outgoing control connections from the console should be brought to suitably marked terminal strips supported on straps securely attached to the console frame. The terminal boards should be so located that they do not interfere with access to the inside of the console through the doors. All wires should be brought from the terminal boards to their respective terminals in a neat and orderly arrangement, properly bunched and tied. The inspector should note the presence or lack of the numbered wiring and the condition and/or neatness of the internal wiring.

The console interior should be suitably lighted and the lights controlled from a switch on the console. Each piece of equipment and each indicating light on the control console should be properly identified.

2.8.3.13.4.1 Metering Equipment

Operator panels are equipped with indicating meters to monitor the electric power circuits. Because current and voltage values are important to good operation, indicating instruments are provided for the operator's use. Only current (load) and voltage meters are required for the operator's use. The routine inspection procedure should include the following:

- Check for loose connections.
- Check for corrosion of metal parts.
- Check for cracks or broken cases in the cover glass.
- Check for collection of dirt or grease.

2.8.3.13.4.2 External Inspection of Control Console

The inspector should check overall console condition, looking for rust, corrosion, peeling paint, and the presence of objects on the console that interfere with bridge operation. Check all switches for proper operation and make sure bypass switches are properly locked or sealed to prevent inadvertent operation. The inspector should look for burned out pilot light lamps and missing or broken lamp lenses. Check all voltmeters, ammeters, and position indicators for proper operation as the span is operating. The inspector should record the voltmeter and ammeter readings during both opening and closing operations.

2.8.3.13.4.3 Internal Inspection of Control Console

The internal inspection of the control console consists of the following subsections.

2.8.3.13.4.3.1 Component Inspection

The inspector will note that no two bridge control systems are identical. For discrete or relay logic based control systems, check the following during routine inspections:

- **Internal temperatures of the enclosure:** The temperature should be between 32°F (0°C) and 104°F (40°C) for all control consoles.
- **Cleanliness of the enclosure:** The control console should be clean and dry internally.
- **Neatness of internal wiring:** The control wiring inside the console should be neatly arranged and run at 90 degree angles throughout the enclosure. Wiring should not run from field devices direct to relay or PLC inputs. Terminal blocks should be provided to terminate all field wiring.
- **Internal wiring** should be tagged and numbered.
- **Plug in relays** should be checked. Relays should be firmly in their sockets or secured firmly to the backplane of the control console enclosure.

- **Modifications, add-ons, and extraneous equipment:** The only components inside the control console should be directly involved in the control circuitry. Compressors for the air horn or other extraneous systems should not be located within the console. Inspectors should spot check the control console wiring diagrams against the existing wiring during in-depth inspections and inventory inspections to detect modifications from design documents.

2.8.3.13.4.4 Bridge Control Interlocking

The following describes the basic interlocks that should be provided for in every bridge control system. By following the system tests outlined, the inspector should be able to assess the suitability of the control interlocking system. All tests should be performed with the bridge operating. The tests outlined are an attempt to determine lack of adequate bridge control interlocking. There is potential trouble for pedestrian, vehicular, and marine traffic during any bridge opening/closing sequence. Steps should be taken to provide for the safety of the general public prior to initiating bridge testing.

C2.8.3.13.4.4

For manually operated bridges, the inspector should confirm that a written sequence of operation exists within the bridge operator's house. The inspector should witness an opening/closing sequence and note adherence to and correctness of the written guidelines.

2.8.3.13.4.4.1 Bridge Control Interlocking Tests

With the bridge in the closed position, the test sequencing during routine inspections is as follows:

- Prior to sounding warning lights and horn, attempt to lower the traffic gates. Traffic gates should not lower. Record results.
- With traffic gate up, insert gate arm hand crank (note if gate arm hand crank limit switch is present). Attempt to lower gate. Gate should not lower. Record results. Repeat test for all traffic gates.
- With traffic gates up, attempt to lower resistance gate, if provided. Resistance gate should not be able to be lowered until its corresponding traffic gate is lowered. Record results.
- With resistance gate (if provided) or traffic gate raised, attempt to disengage the locks, centering devices, wedges, or jacks. Record results.
- With each resistance gate arm up, insert resistance arm hand crank (note if hand crank limit switch is present). Attempt to lower resistance gate. Resistance gate should not lower. Record results.
- With locks, centering devices, etc. engaged, attempt to raise the bridge span. Record results.

Confer with the operator and bridge inspection supervisor prior to performing the following tests. Once again, caution is emphasized.

C2.8.3.13.4.4.1

Caution should be used during these tests. Vehicular and pedestrian traffic must be stopped during testing.

Test sequences are generic. The inspector is responsible for adjusting this sequence to fit the bridge being inspected.

During the bridge opening sequence, the inspector should note if span speed is controlled automatically or manually by the operator.

- Confirm that if any hand crank device is inserted for the locks, centering devices, etc. that the corresponding motors are disabled. Record results.
- Confirm that the main drive motors cannot be started prior to all brakes being released. The inspector should manually set a brake and attempt to open the span. The main drive motor starters should not engage. Record results.
- Test limit switches at full open. Record results.

2.8.3.13.5 Programmable Logic Controllers (PLCs)

A programmable logic controller (PLC), shown in Figure 2.8.3.13.5-1, is a general purpose industrial microprocessor based control system. The National Electrical Manufacturers Association (NEMA) defines a PLC as “a digital electronic device that uses a programmable memory to store instructions for implementing specific functions such as logic, sequencing, timing, counting, and arithmetic to control machines and processes.” A PLC is designed to interface with industrial equipment and carry out a preprogrammed control scheme. The PLC checks the status of input devices such as push buttons, selector switches, limit switches, and pressure switches, and responds to these signals by activating the appropriate output devices such as motor starters, solenoids, and indicators, as called for by the program.

C2.8.3.13.5

It is recommended the inspector checks the PLC log or printout for faults or errors during previous bridge operation to alert them to possible problem areas.

Figure 2.8.3.13.5-1 – A programmable logic controller (PLC)

PLCs are being used in ever increasing numbers by general industry to replace “hard-wired” (fixed operation) relay logic systems. The advantages offered by PLCs over hard-wired relay systems include greater reliability, less downtime due to built-in diagnostics, modular construction, and economical expansion. Many new bridges are equipped with PLCs and some older bridges are being retrofitted with them. The inspector should familiarize himself with this type of control component.

As a general guide, the inspector should check the following items during a routine inspection of the PLC. The inspector should refer to the manufacturer's manuals for specific maintenance information.

- Check the status of diagnostic indicator lights located on the CPU and I/O modules. Diagnostic lights will indicate equipment malfunction if present.
- PLCs are often installed in enclosures. The enclosures are equipped with air filters to provide clean air circulation over the PLC components. Make sure all air filters are clean.
- Check the accumulation of dirt and dust on PLC components. Components need to be clean for proper heat dissipation.
- Check wiring connections to all components for tightness. Check condition of wiring.
- Batteries, which provide backup power for program memory, should be inspected. Batteries usually have visual or audible alarms that become activated when battery power becomes low.
- Unnecessary articles should be kept away from the PLC equipment inside the enclosure. Drawings and manuals placed on or adjacent to equipment can obstruct air flow and create hot spots that can cause system malfunction. Paper materials can also burn if they become too hot.

Older movable bridge controls were designed prior to the advent of PLCs. The older bridges that were designed for semiautomatic operation often use relay logic systems and drum controllers to provide interlocking and control sequencing. In addition, some designs continue to prefer relay logic to PLCs.

2.8.3.13.6 Drum and Relay Logic Controllers

2.8.3.13.6.1 Drum Controllers

Drum controllers are used for starting and reversing small AC and DC motors that can be started across the line without using accelerating resistors. They can be supplied as two pole or three pole switches also with or without limit switch connections. The drums are furnished with rotary operating handles. The drum contacts are usually hard drawn copper and are renewable. The contact fingers are mounted on finger boards. They are formed hard drawn copper with flexible shunts and are easily replaced. Contact pressure is maintained by means of special coiled compression springs.

Figure 2.8.3.13.6.1-1 shows a circuit diagram for a simple relay logic control system with sequential control of motor secondary resistance and interlocking with the span locks and other components. Relay logic is often designed using drum

C2.8.3.13.6.1

If partial disassembly is required, the bridge owner may, at their option, move this part of the inspection to in-depth inspections.

switches, as shown in Figures 2.8.3.13.6.1-2 through 2.8.3.13.6.1-4. Manual rotation of the drum switch control by the bridge operator engages the various control circuits in order, but incorrect operation is disabled because limit switches must be in the required position in order for circuits to be completed. Older systems may have manual operation of circuits at the drum switch. Newer designs use the drum switch to actuate magnetic contactor relays that complete the various circuits. Drum switches should be checked as follows:

- Inspect the condition of the contactors and cams or contact segments. Also inspect the wiring and wiring contacts.
- Wiring should be clean, insulation should be in good condition, and wires should be labeled and routed clear of any moving parts.
- Contacts should be clean and tight. Inspector should de-energize the system and check a representative sample of contacts for tightness.
- Operate the span as described for other types of control systems and verify that the operation is as designed.

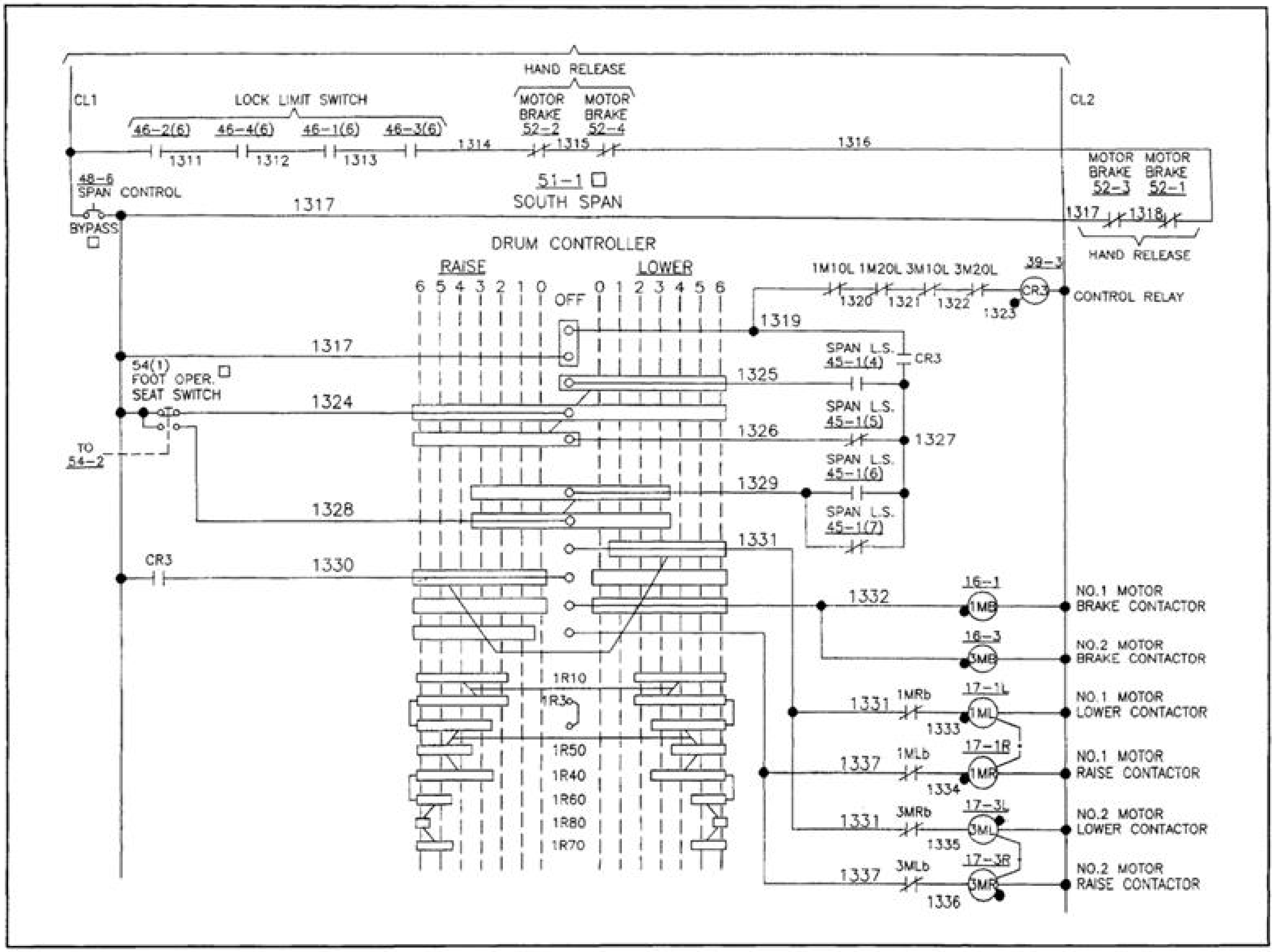

Figure 2.8.3.13.6.1-1 – Circuit diagram for a relay logic control system

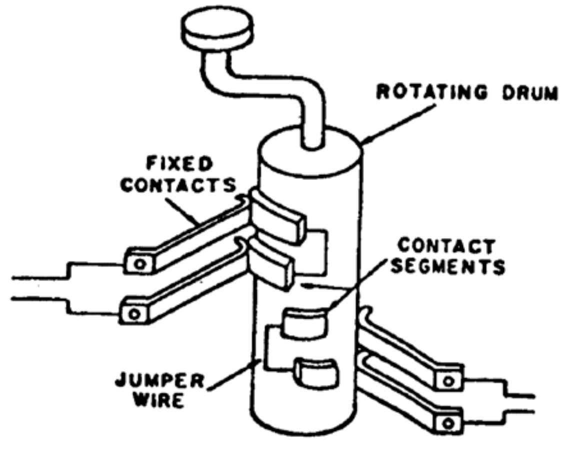

Figure 2.8.3.13.6.1-2 – Segment type drum switch

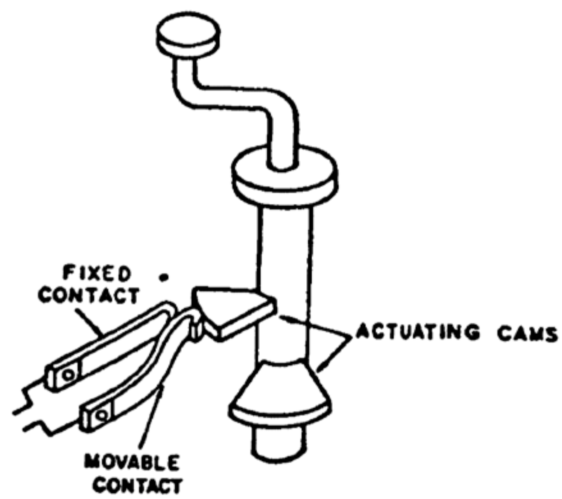

Figure 2.8.3.13.6.1-3 – Cam type drum switch

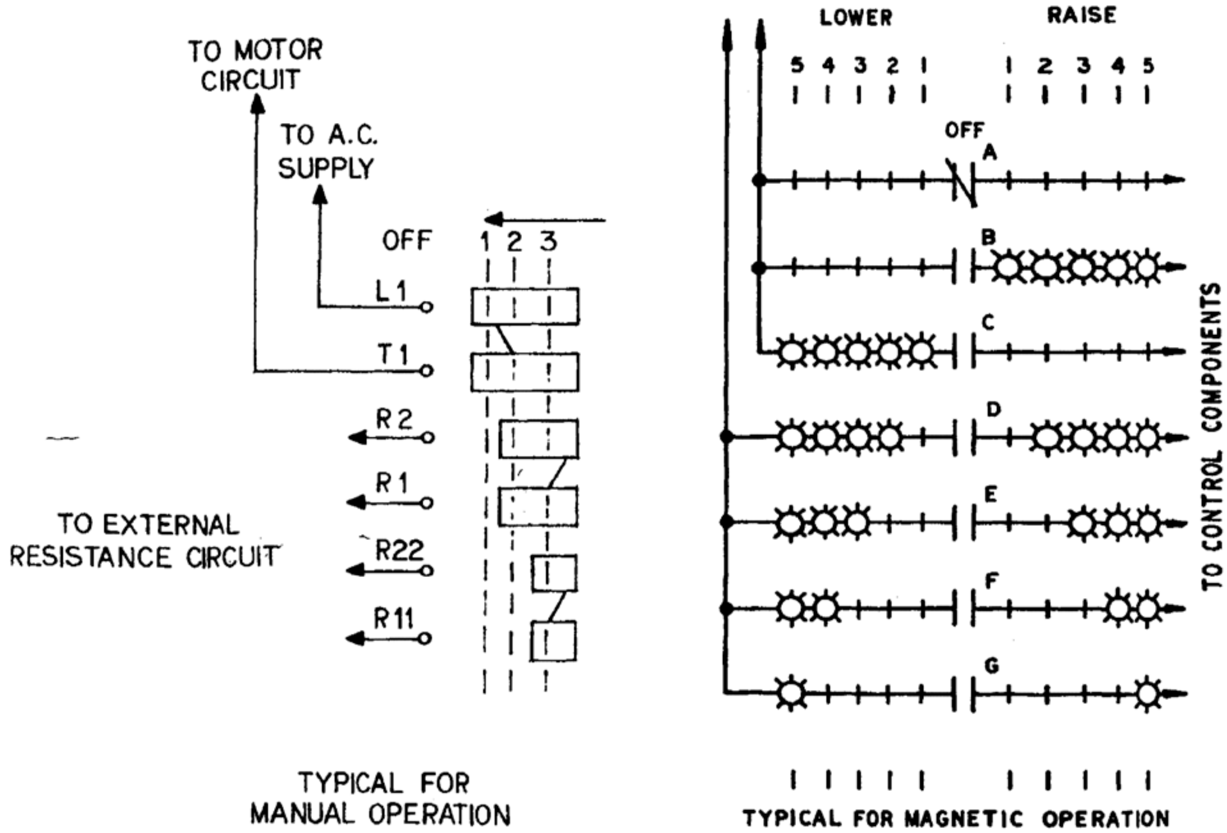

Figure 2.8.3.13.6.1-4 – Manual and magnetic drum switch control scheme

2.8.3.13.6.2 Relay Logic Controllers

Relays are devices that are generally operated by a variation in the conditions in one electric circuit that serve to make or break one or more connections in another electric circuit. A series of relays can thus be used to perform several related tasks sequentially in a logical order. For example, on a movable bridge, when the first function of lowering the traffic gates is completed, a limit switch will trip a relay that would energize the next circuit to perform the next sequential function and so on. A system that uses relays to perform a portion of the semiautomatic or automatic sequential tasks in controlling the operation of any machinery is called a relay logic system.

There are a number of types of relays used in relay logic systems. In general, the relay contactors should be checked for burning or contamination. Timers, coils, and other mechanisms should be verified to be functioning properly as per the original design parameters. Specific inspection procedures should be developed based upon manufacturer's literature for the particular type of relay. Inspectors should consider the following while performing routine inspections:

- The typical motor usually draws five to ten times the normal current at start-up. High starting current is normal and the motors are built to handle these loads for a brief period of time. As the motor accelerates, this current decreases to the normal running values. Mechanical binding of the drive will cause the starting current to remain high. For example, when the motor stalls against the mechanical stop, the operating current immediately goes up. This indicates that the limit switch is not set correctly or is not operating and the motor overloads will have to protect the motor against burnout. It is a different case for some bridge drive motors when stalled drive motor seating is the recommended method of seating bascule and vertical-lift bridges, or swing bridges that close against a stop bumper. In these cases, the stalled drive motor is required to be in a reduced torque mode for 2 to 3 seconds while setting the brakes. Extended stalled motor conditions can indicate a failed limit switch, failed time delay relay, or other electrical or electronic interlock failure.
- If the overload relay contacts are visible, the inspector should observe the relays to determine if they operate during motor operation. Overload relays usually operate when there is some problem. Repeated reset operations can result in a motor failure.

Performance inspection of relay logic:

- Observe the motor; starting the motor will produce a sequence of distinct sounds. When coming up to speed, the motor may vibrate noticeably. If there is mechanical binding in the equipment, or if the equipment runs into a mechanical stop, the motor will show an immediate current increase and will “hum” or vibrate.
- Occasionally, trouble situations are bypassed by use of an electric jumper. This means of temporary repair to allow operation should not be continued for very long. The application of the jumper can eliminate the overload protection or even the interlocking incorporated in the circuit. Check for wire jumpers in the control circuits. If found, inspectors should file a deficiency report and rate the controls as “poor.” As a motor ages, it starts to deteriorate. Torque output may decrease and the running load will increase. This can result in intermittent overload operation. Visual inspection will not usually show the motor deterioration but the motor controller may show trouble starting by occasional nuisance tripping. If a jumper is applied around the overload contact, the nuisance tripping will be eliminated. The motor overload protection will also be eliminated. The probable result will be a failure in the motor or the cabling to the motor.

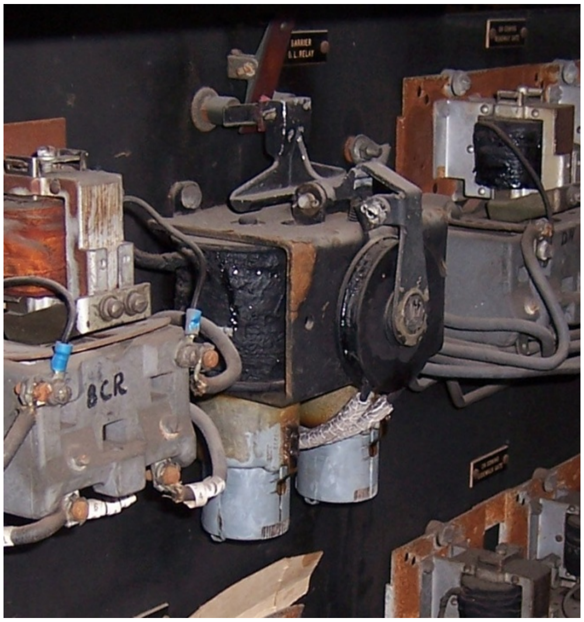

Figure 2.8.3.13.6.2-1 – Dash pot overload relay

- Overload relays on early design contactors were built with "dash pots." Figure 2.8.3.13.6.2-1 shows this type of overload relay used on wound-rotor span motors. Note that the cups on the bottom are calibrated for load settings. These calibrations are normally specified and set during the initial start-up of the equipment. In the illustration, only two dash pots are shown. The older controls used two overloads for protection of a three phase motor.

During an in-depth inspection, check the following:

- Remove the cups carefully from the dash pots and check for the proper dash pot oil level in the cups. There is usually a line indicator to show the proper oil level inside the cup.
- Check the oil in the cup for sediment. The oil should be renewed at least every two or three years and the cups thoroughly cleaned each time. Only approved dash pot oil should be used. Operate the plunger with the cup in place. There should be no metal to metal interference and the plunger should move freely to the trip position.
- Visually check the arc chutes on the contactors. Excessive erosion of the inside surfaces is the result of heavy current interruption. Arc chutes that are readily accessible should be removed for inspection. Check for missing baffles and for uniform separation of plates. The areas in the path of the arc will deteriorate during interruption. When very little material is left at the supports, or if parts are missing, cracked, or badly burned, the arc chute needs to be replaced. The arc chutes should be coded "poor."

2.8.3.13.7 Motor Speed Controller

There are a number of types of motor control systems commonly used on movable bridges to control span driving motors. The following sections discuss the most common types.

2.8.3.13.7.1 AC Wound-rotor Manual Control

Manual speed control utilizing the AC wound-rotor motor is the oldest method for controlling span speed. A master switch or drum controller mounted on the control console is controlled by position switches. The changing switch position varies the secondary resistance seen by the wound-rotor motor.

Although often regarded as a speed control system, the AC wound-rotor manual control does not truly control speed. The secondary resistance varies the torque producing capability of the motor and in so doing, depending on the magnitude of span loads, causes the motor to speed up or slow down in response to span loads. The system will provide moderately reduced speed operating with loads of 50 percent of full load motor torque or greater. It will also provide maximum starting torque with minimum starting current. However, it will not provide for reduced speed operation with light loads, unless some means of mechanical braking is provided. In addition, it will not provide the desired low speed, usually 10 percent to 20 percent of full load speed, when the movable span is approaching the fully open or fully closed positions.

AC wound-rotor motor manual controllers require more maintenance than the other (solid-state) controllers and for this reason need to be carefully inspected.

The inspector should observe the drum (or master switch) controller during motor operation. Stationary contacts are mounted on the side of the drum frame. A movable cam rotates with the drum and activates the movable contacts. No sustained contact arcing should occur during any part of the control operation.

Make certain the controller sequence is correct and that all components function properly. If a schematic of the controller is available, this can be used to properly inspect this sequence. If the schematic of the controller is not available, the inspector should observe the drive motor amps as the bridge is stepped through the sequence, and watch for fairly consistent jumps in amperes with every new step, this will help the inspector determine if the operation of the stepped resistance system is correct.

Visually check the controller components for wire and cable conditions. Cable connections must be tight. Look for broken conductors and signs of terminal cracking. Partially broken connectors can accelerate an insulation failure due to overheating.

C2.8.3.13.7.1

Nearly all older bridge control systems utilize this type of bridge control system or a slight variation thereof.

Resistor grid banks should be inspected. A white area could be a sign of severe overheating or an atmospheric corrosion of the metals. Overheating can be caused by broken resistor grids or poor contact between adjacent resistor grid plates.

2.8.3.13.7.2 Variable Speed Controllers

Motor controls that provide true speed and acceleration control are becoming more common on movable bridges, both on new structures and as retrofits to old ones. The AC wound-rotor motor thyristor control, AC adjustable frequency (inverter) control, and the digital DC drive are such systems. These variable speed drives, as they are called by general industry, are solid-state and can be easily interfaced with programmable controllers or relay operated systems. In addition, they can provide electronic dynamic braking capabilities to reduce the dependence on mechanical motor brakes and can provide regenerative braking for true four-quadrant control when operating against overhauling loads.

During routine inspections, the controllers should be inspected by the same methods listed for control consoles and PLCs.

2.8.3.13.7.3 AC Adjustable Voltage Controller

The AC wound-rotor motor thyristor controller was the first solid-state variable speed drive to be used on movable bridges. Thyristors are also known as silicon controlled rectifiers (SCRs). In this type of controller, the thyristors are controlled by either a master switch located on the control console or discrete bridge position input. The thyristors vary the amount of voltage to the AC wound-rotor motor primary from zero to full line voltage, which controls the shape of the RPM/torque curve of the particular motor and thereby controls the torque the motor applies at a given motor speed. The ability to change the shape of the RPM/torque curve provides the capability to alter speed at a given motor load.

The adjustable voltage controller uses SCRs connected opposite of each other to control the average voltage applied to the motor. This is called “phase angle control.” The average voltage supplied to the motor is adjusted by controlling the phase angle signal gating of the SCRs. The motor speed is controlled by varying the motor primary voltage. The direction of motor rotation is controlled by selecting the appropriate SCRs. During a “span open,” the motor will be “driving” the load. In this case, the motor is doing the work. Typically, the bridge spans are balanced, requiring the motor to be overcome only frictional, inertial, and wind loads. Under this scenario, the voltage controller will gradually increase the applied voltage until the preset speed is maintained and the bridge opening completed.

During a “span close,” the voltage controller will accelerate and control an overhauling load by operating the motor in a counter torque mode. The controller is actually producing a controlled raising torque to control the descending span.

During a “span seating,” the motor must supply a controlled limited stall torque. Voltage controllers allow one to simply reduce the current limit operation at minimum speed, thereby reducing the stall torque requirements by controlling stall currents.

2.8.3.13.7.4 AC Adjustable Frequency Controllers

The VFD, shown in Figure 2.8.3.13.7.4-1, varies the speed of the induction motor by varying the frequency applied to the motor. To produce rated torque, the relationship between voltage and frequency must be maintained at a constant ratio. Therefore, the VFD's output voltage varies directly with output frequency. During a “span open” operation, the adjustable voltage controller and VFD work similarly. The VFD gradually increases the applied voltage and frequency to the motor in response to a ramped speed signal. The VFD current limit operation will also occur when additional acceleration, wind, or other unknown loading is present.

During a “span lower,” the VFD accelerates and controls an overhauling load in motor regeneration, but cannot pass this energy back to the power system. Braking resistors are required to dissipate the energy.

During a “span seating,” the motor must supply a controlled limited stall torque. For a VFD, lower torque limit should be utilized at seating for stalled seating. Wound-rotor motors could be used with switched secondary impedance to control stall torque. However, the adjustable voltage controller is more suited for operation with wound-rotor motors.

C2.8.3.13.7.4

AC adjustable frequency controllers are used to control the speed of AC squirrel cage motors. The squirrel cage motor has long been the workhorse of general industry but until fairly recently there has been no economical and reliable way to provide true speed control using these motors.

Figure 2.8.3.13.7.4-1 – A motor control center with integral VFD controller

2.8.3.13.7.5 AC Flux Vector Controller

The flux vector controller (FVC) utilizes the same basic power devices as the VFD. However, instead of controlling the voltage and frequency magnitude, which yields very poor performance at low speeds or under dynamic conditions, the FVC regulates the flux and torque producing components of current. The FVC operates with rotor position feedback from an encoder that is connected to the motor shaft. This position information is then used to control the flux and load current. These components are added to develop the controlled stator current that produces the optimum speed torque control of the load.

The "span open" and "span close" operations are similar to the VFD. However, during "span seating," precise torque control is easily achieved. The FVC provides continuous full rated torque from base speed down to and including zero speed.

2.8.3.13.7.6 DC Static Drive Controllers

DC drives are currently being used by many highway departments. The inspector should be aware of this type of drive. The static (solid-state) DC drive rendered the DC motor-generator set and the mercury-arc rectifier obsolete. For many

C2.8.3.13.7.5

The AC flux vector adjustable frequency controller has grown in popularity and is used predominately over VFD wound-rotor drives and DC drives in movable bridge applications.

years, either a DC motor-generator set or a mercury-arc rectifier was needed to supply DC power in applications where the advantages of the DC motor were needed. Both these methods of furnishing DC power were inefficient and maintenance prone. The DC drive was a breakthrough and quickly became popular in general industry. The DC drive combines the rectifier power supply and all required speed controls in a single package (see Figure 2.8.3.13.7.6-1).

Figure 2.8.3.13.7.6-1 – DC drive controller

2.8.3.13.8 Surge Protection

Until the use of solid-state devices, most AC-powered equipment found on movable bridges was too insensitive to be upset by “dirty” or surging power. However, electrical power surges, and the damage they can cause, are commonplace today. Many movable bridge control consoles are comprised of solid-state devices and are vulnerable to surges.

These solid-state devices depend on consistent, good-quality power. A single powerful surge can literally melt, weld, pit, or burn its way through solid-state circuits and components.

Solid-state device failure is often the result of surges and the cause is typically not detected by the repairing technician. In addition to crippling the bridge control system, any stored data

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It is a misconception to think of surge damage as being caused by a single, catastrophic event such as a lightning strike. While lightning is one of the most powerful and destructive surges, it is not always the cause of most of the surge damage.

Powerful, random surges result from the switching of an inductive load such as a main drive motor starter, arc welder, furnace ignition, compressor, etc. These momentary surge sources range from 250 to over 3,000 volts.

is lost and input or output information is meaningless. It is imperative that a bridge designed to be served from a grounded electrical system be maintained so that it remains adequately grounded. If the grounding system is allowed to deteriorate, the surge suppression system will not function properly and an electric shock hazard may exist.

If a particular bridge has reported electronic device failures since the previous inspection and if the bridge is not provided with an electrical surge suppression system, then the inspector should note this condition as a deficiency.

Older electrical designs utilize ungrounded systems due their ability to maintain service to the faulted electrical system. These systems were prevalent in locations where down time costs outweighed other significant factors. However, any fault should be located immediately upon occurrence and the necessary action taken to safely reenergize the electrical system. It is recommended that ungrounded systems be noted on the inspection deficiency reports and the system subsequently replaced with a grounded system during any upcoming bridge rehabilitation.

2.8.3.13.8.1 Inspection

The inspector should thoroughly survey the bridge and its power supply. An examination of electrical layout, circuit plans and inventory of electric loads (present and future) connected to all circuits can provide the information to form a recommended plan of inspection. The following items should be thoroughly checked during routine inspections of grounded electrical systems:

- Verify that all electrical and system grounds are bonded together. Confirm the neutral is bonded properly to ground at the service. Verify that there is no bonding of the AC neutral and ground at electrical sub panels. Record the finding.
- Verify that the bridge span and other metallic structures are bonded to ground. Make sure all steel reinforcement and framing of the structure is bonded to your common ground. Record the finding.
- Verify whether or not the main electrical service panel is equipped with a surge protector on the load side of the main breaker. All sub panels should be so inspected. Verify if surge suppression is present on incoming electric service panel and record the finding.
- Inspect the control console. Verify if surge suppressors are installed on the input power line and record the finding.

Figure 2.8.3.13.8.1-1 illustrates an incoming surge suppressor and Figure 2.8.3.13.8.1-2 shows a typical control console surge suppressor.

The following items should be thoroughly checked during in-depth inspections of grounded electrical systems:

- If possible, verify the resistivity of the ground system. The resistance of the ground system should be 10 Ohms or less. If this measurement cannot be performed, it should be so indicated on the report form.

For ungrounded systems, the inspector should verify that ground fault indicating lights are provided and functional. Also, the inspector should verify whether or not surge protection is provided for the ungrounded electrical systems at the main and sub panel locations.

Figure 2.8.3.13.8.1-1 – Incoming power surge suppressor

Figure 2.8.3.13.8.1-2 – PLC power surge suppressor

2.8.3.13.9 Controls and Interlocking Coding Guidelines

Due to the proprietary nature and sealed "black box" appearance of control and interlocking components, it is extremely difficult to quantify criteria for numeric condition evaluation coding without extensive testing by a qualified electrical engineer. There are, however, some general guidelines as follows:

General Recommendations:

- **Excellent:** the system and components are well connected and grounded, protected, secured, safely operating, and functioning as intended (recently installed, no defects).
- **Good:** minor deterioration or wear.
- **Fair:** functional, but with obvious deterioration or wear.
- **Poor or Critical:** Components are observed to be smoking, hot, or otherwise exhibiting signs of resistance coding depends on the inspector's assessment of the likelihood of an electrical failure or fire.
- **Critical:** Sparking, melted or burned insulation, or black residue left by arcing or shorting of components. Components that create a potential shock hazard to the public or workers.

Components with no external signs of distress should be coded based upon testing, engineering judgment and/or Table 2.9.1-2. If an individual inspector cannot determine whether a component is "poor" or "severe," he should code it "poor" and request additional investigation with an explanation of the reason and type of investigation needed.

Control, interlocking, and sensor devices (e.g., limit switches) should be performance tested during in-depth inspections. Controls, interlock of sensor devices that fail to actuate span motion and proper sequential control of the various functional control systems should be investigated fully and coded "poor" or "severe" based upon the results of the investigation. Limit switches that are functionally inactive should be coded critical and should cause immediate filing of a deficiency report. Limit switches that are not functioning smoothly, or that show evidence of significant corrosion or wear of operating parts or other defects that could interfere with reliability should be coded "poor" and should also cause filing of a deficiency report.

Control consoles with inoperative indicators and/or gauges should be coded "poor" with a deficiency report. Interlocking systems, which permit unsafe modes of operation, which might endanger (based on performance tests) the functional systems of the bridge, workers and the public should be coded "critical," and a deficiency report should be filed immediately. If reliable written operating procedures are in place to prevent such unsafe

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Inspectors should be knowledgeable as to whether the control system is designed to be grounded or ungrounded. Ungrounded systems that are properly designed and are safely functioning may exist without the presence of grounding.

Systems which do not have surge protection or which do not meet the criteria given in Section 2.8.3.13.8 should be not be rated "poor" if they were designed under a standard that did not require surge suppression, but it should be noted in the report.

modes, then such conditions may be rated “poor.”

The overall rating of the bridge controls and interlocking should be based on the results of performance tests. A system that performs adequately but that contains individual vital components that are ”poor” or “severe” should generally not receive a rating exceeding that of the worst vital component, since the reliable operation of the entire system is compromised by the questionable component.

Controllers should be rated based on performance tests, but the presence of wires or contacts that are loose and/or deteriorated should also cause a lower condition rating of the controller.

Wires or contacts that show signs of overheating should be rated “poor” or “critical,” as discussed in Chapter 2.8.

Surge protection that is inactive or systems which do not have surge protection or which do not meet the criteria given in Section 2.8.3.13.8 should be rated “poor” or “severe” based upon the likelihood of a lightning strike or power surge at the particular site.

CHAPTER 2.9 – PREDICTED COMPONENTS LIFE

2.9.1—PREDICTED COMPONENT LIFE FOR HYDRAULIC AND ELECTRICAL COMPONENTS

For hydraulic and electrical components, it is at times difficult to make objective condition evaluations based upon visual inspection. Hydraulic and electrical components are frequently sealed units which require considerable engineering expertise and time consuming functional testing to evaluate their condition. For these types of components, there are two methods which may be used to inspect and make decisions for numeric condition evaluation coding:

Engineering evaluation: The responsible owner agency may design an appropriate inspection and testing program for the hydraulic or electrical system internal components of each individual movable bridge. This program should be carried out by experienced fluid power or electrical engineers or licensed hydraulic system mechanics or electricians who meet the qualifications of Section 2.4 for lead inspectors.

Predicted life: Agencies may opt to use a predicted life system of numeric condition evaluation, where each hydraulic and/or electrical component is assigned a predicted useful life. The condition evaluation code of each component starts at "excellent" when the component is new and reduces progressively as the component ages. The inspection team can assign a condition code based on the percentage of predicted life expended at the time of inspection.

The major requirements of this system are as follows:

- **Component life** may be obtained by one of two methods. Values may be selected from Table 2.9.1-1 and Table 2.9.1-2 which list conservative predicted life values for various classes of hydraulic and electrical components on movable bridges.
- **Component labels** are required on all hydraulic and/or electrical equipment evaluated by the predicted life method. Component labels should be permanently attached weather-proof, heat resistant metal or plastic, engraved, stamped, or indelibly printed, and laminated tags or plaques which provide the following minimum information: tag number, bridge number, component name, date of manufacture, date of installation, and date of last engineering evaluation type inspection.
- **Numeric condition evaluation coding** can be based upon simple component age computation from the tag data and date of inspection. Components should be deemed to have the following condition ratings based upon age:

Excellent: less than 15 percent of predicted life expended.

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Table 2.9.1-2 is based upon Reference 89c, Table 2, modified somewhat based upon responses from experienced movable bridge industry representatives during peer review of the draft manual. The second method is to perform a component life evaluation (based upon the methods contained in References 89c, 147, and 149) for individual components and substitute the values determined by this study for the Table 2.9.1-1 and 2.9.1-2 values.

No data was available in Reference 89c for motor starters or contactors, and the predicted life of these components is based on the data for switchgear busses. Electrical components generally have very long lives based on their electrical performance. Mechanical life of moving parts is typically the controlling factor. For components exposed to weather, corrosion is a factor. In the aggressive environment typical at many movable bridges, it is possible for components to fail due to corrosion without any electrical activity at all. The reason that low usage components have shorter lives is that corrosion has time to form on parts which are not used frequently, and the presence of corrosion will accelerate mechanical wear. Structures which open less than 400 times a year may be expected to have less than one opening per day during portions of the year and therefore have more opportunity for corrosion to form.

Similar logic applies to hydraulic components. The data presented for hydraulic components is based upon data gathered from industry sources and may be modified by owners if they maintain records of component performance data on their bridges.

Good: 15 percent to 35 percent of predicted life expended.
Fair: 35 percent to 65 percent of predicted life expended.
Poor: 65 to 85 percent of predicted life expended.
Severe: more than 85 percent of predicted life expended.

Hydraulic and/or electrical components that are rated "severe" by either of the above two methods are by definition prone to failure in the near future. Owner agencies should consider the following corrective actions:

- Replace or rebuild the "severe" rated component(s).
- Order the replacement part and monitor the condition of the existing component until replacement is accomplished.
- Perform an engineering evaluation that includes sufficient performance testing of the component(s) to allow revising the predicted component life. The revised predicted life of a component by this method should not exceed a 50 percent increase in the predicted life shown in the table.

For some existing bridges, there may be some difficulty in determining the age of in-service components. Components should be assumed to be of bridge original installation unless other documents are available showing the component to be a replacement part. Components for which no age data can be obtained should generally be assumed to be not less than 45 years of age, since the majority of existing movable bridges nationwide were built prior to 1970. Individual owners who have data concerning the age of their inventory may develop specific guidelines which are based on the average age of their bridges. Note that asbestos is a risk for components fabricated prior to 1985.

Table 2.9.1-1 – Predicted Hydraulic Component Life

COMPONENT TYPE	PREDICTED LIFE FOR STATED CONDITIONS (IN YEARS)					
	LOW USAGE Fewer than 400 openings per year		**AVERAGE USAGE** 400 to 4,000 openings per year		**HIGH USAGE** More than 4,000 openings per year	
	W/O Fluid Testing	**With Fluid Testing per Chapter 2.10.11**	**W/O Fluid Testing**	**With Fluid Testing per Chapter 2.10.11**	**W/O Fluid Testing**	**With Fluid Testing per Chapter 2.10.11**
Accumulators and Reservoirs	28	42	36	55	24	36
Pumps and Motors or Rotary Actuators[1]	24	36	30	45	20	30
Cylinders[1]	16	24	20	30	12	18
Operating Valves and Hydraulic System Sensors other than Electromechanical Limit Switches[1]	20	30	25	38	16	24
Welded Pipe or Flanged Pipe with O-rings[2]	36	55	36	55	24	36
Tubing (except Flare Fittings)[2]	15	22	15	22	10	15
Flexible Hoses [1,2]	5	7	5	7	3	5

[1] If systems have history of contamination or overheating, a 50 percent reduction in the tabulated values should be assumed for components subject to accelerated wear of seals, O-rings, and other soft parts which can be easily damaged by grit or varnish accumulation.
[2] Pipe, tubing, and flexible hoses do not experience an increase in deterioration due to infrequent use.

Table 2.9.1-2 – Predicted Electrical Component Life

COMPONENT TYPE	PREDICTED LIFE FOR STATED CONDITIONS (IN YEARS)					
	LOW USAGE Fewer than 400 openings per year		**AVERAGE USAGE** 400 to 4,000 openings per year		**HIGH USAGE** More than 4,000 openings per year	
	Open to Environment	**Closed Room or Sealed Unit**	**Open to Environment**	**Closed Room or Sealed Unit**	**Open to Environment**	**Closed Room or Sealed Unit**
Motors, Generators, and Circuit Breakers[3]	30	60	35	70	25	50
Brushes in DC Brush-type Motors/Generators	8	16	10	20	6	12
Limit Switches	3	5	4	6	3	5
Motor Starters and Contactors	24	48	30	60	20	40
Open Wiring[3]	18	36	20	40	16	32
Wiring in Conduit[3]	20	40	30	60	25	50
Wiring Terminals	16	32	20	40	14	28

[3] Motors, generators, wiring, and other components which depend on insulation integrity for reliability will be adversely affected by overheating. Such components should be rated “poor” or “severe” if they have a history of overheating, regardless of remaining life, due to the potential for failure and/or electrical fire.

CHAPTER 2.10 – TESTING AND ADVANCED INSPECTION METHODS

2.10.1—GENERAL

Various testing techniques can supplement visual inspection methods and provide the movable bridge inspector with a quantitative assessment of various structural, mechanical, hydraulic, or electrical components.

Reference 8 contains discussion on the use of numerous test methods for structural investigations of bridges. The intent of this chapter is to discuss specific uses for selected tests, which require additional care when performed on movable bridges, and to discuss other tests, which apply to the mechanical, hydraulic, and electrical systems on movable bridges.

The following items should be considered when scheduling tests for movable bridges:

- Contamination from oil or other chemicals typically present on movable bridges is likely to affect results of some tests such as magnetic particle or concrete chemical tests.
- Concrete for counterweights often contains heavy metallic aggregates, which may interfere with magnetic, electrical resistance, and radiography tests.
- Selection of location for removal of concrete cores, steel coupons, and timber samples for material testing should consider machinery loads, temporary loads which may be imposed by maintenance or rehabilitation activities, and movable bridge operating loads.

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The AASHTO *Manual for Bridge Evaluation* (Reference 8) contains an extensive discussion of the use of various nondestructive test methods for concrete, steel, and timber. These methods are applicable to movable bridges. It is assumed that persons involved in inspection of movable bridges have access to Reference 8 and therefore the tests discussed therein are not repeated in this section. For convenience, a list of the test methods discussed in Reference 8 is presented in Table C2.10.1-1.

In addition to the nondestructive testing methods, Reference 8 also contains a list of standard material sampling methods and tests. For convenience, the tables provided in Reference 8 are reproduced in this section (Tables C2.10.1-2 through C2.10.1-6). The provisions of Section 5 in Reference 8 also apply to movable bridges.

2.10.2—ULTRASONIC INSPECTION OF SHAFTS AND GEARS

Ultrasonic testing of steel or iron machinery shafts or large spur gears can be performed longitudinally, radially, or at various angles to those directions to locate cracks, forging flaws, and other interior defects in the material that may result from fabrication, stress, or impact. Special attention should be focused at locations of abrupt changes of geometry (stress risers) which can initiate and propagate fatigue cracks.

Longitudinal testing of shafts should generally be done from both ends to provide detection of flaws in “shadow” areas outside the ultrasonic beam spread due to stepped shafts or other cross sectional variations.

Table C2.10.1-1 – List of test methods discussed in Reference 8

TEST MATERIAL	METHOD DESCRIPTION	COMMENTS
Conrete	Schmidt Hammer; Windsor Probe Mechanical Sonic Pulse Ultrasonic Magnetic (e.g., pachometer) Electrical Resistance (half cell) Nuclear (neutron absorption and scattering) Infrared Thermography Radar Gamma Radiography Endoscope	For new concrete only Best on bare concrete, no overlay Small defects not detectable Unreliable in heavy reinforcing Results not directly related to corrosion For moisture content Decks and members exposed to sunlight Primarily for decks Radiation hazard during test Drilled holes are necessary
Steel	X-ray Radiography Magnetic Particle Eddy Current Dye Penetrant Ultrasonic	Radiation hazard during test May leave permanent magnetism Only good for simple geometry Only good for surface defects Dependent on operator skills
Timber	Penetration (ice pick, drills, etc.) Electrical Resistance Electrical Capacitance Radio Frequency Power Loss Ultrasonic	Holes can cause later problems For moisture content near surface For moisture content near surface For moisture content near surface Small defects not detectable

Table C2.10.1-2 – Standard ASTM and AASHTO methods for material sampling (Table 5.3-1 in Reference 8)

DESIGNATION	TITLE
C42/T 24	Method of Obtaining and Testing Drilled Cores and Sawed Beams of Concrete
T 260	Sampling and Testing for Total Chloride Ion in Concrete Raw Materials
C823	Standard Practice for Examination and Sampling of Hardened Concrete in Constructions
A610	Sampling Ferroalloys for Size (Before or After Shipment)
A673	Sampling Procedures for Impact Testing of Structural Steel (Charpy Test)
A370	Standard Test Methods and Definitions for Mechanical Testing of Steel Products

Table C2.10.1-3 – Standard ASTM and AASHTO test methods for steel for the use in the laboratory (Table 4.4-2 in Reference 8)

DESIGNATION[1]	TITLE
A 370/T 244	Methods and Definitions for Mechanical Testing of Steel Products
E3	Methods of Preparation of Metallographic Specimens
E8/T 68	Methods of Tension Testing of Metallic Materials
E10/T 70	Test Method for Brinnel Hardness of Metallic Materials
E92	Test Methods for Vickers Hardness of Metallic Materials
E103	Method of Rapid Indentation Hardness Testing of Metallic Materials
E110	Test method for Indentation Hardness of Metallic Materials by Portable Hardness Testers
E112	Methods for Determining Average Grain Size
E340	Method for Microetching Metals and Alloys
E384	Test Method for Microindentation Hardness of Materials
E407	Practice for Microetching Metals and Alloys
E883	Guide for Relfected-light Photomicography

[1] ASTM test methods are designated A or E. AASHTO test methods are designated T.

Table C2.10.1-4 – Standard ASTM and AASHTO test methods for concrete for use in the laboratory (Table 4.4-1 in Reference 8)

DESIGNATION[1]	TITLE
C39/T 22	Test Method for Compressive Strength of Cylindrical Concrete Specimens
C1804/T 178	Test Method for Cement Content of Hardened Portland Cement Concrete
C174/T 148	Method of Measuring Length of Drilled Concrete Cores
C457	Practice for Microscopical Determination of Air-void Content and Parameters of the Air-void System in Hardened Concrete
C469	Test Method for Static Modulus of Elasticity and Poisson’s Ratio of Concrete in Compression
C496	Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens
C617/T 231	Method of Capping Cylindrical Concrete Specimen
C642	Test Method for Specific Gravity, Absorption, and Voids in Hardened Concrete
C666/T 161	Test Method for Resistance of Concrete to Rapid Freezing and Thawing
C856	Recommended Practice for Petrographic Examination of Hardened Concrete
T 259	Method of Test for Resistance of Concrete to Chloride Ion Penetration[2]
T 260	Method of Sampling and Testing for Total Chloride Ion in Concrete and Concrete Raw Materials
T 277	Interim Method of Test for Rapid Determination of the Chloride Permeability of Concrete

[1] ASTM test methods are designated A or E. AASHTO test methods are designated T.
[2] Corrosion threshold is about 1.3 to 2.0 pounds of chloride cubic yard

Table C2.10.1-5 – Standard ASTM and AASHTO test methods for timber for use in the laboratory (Table 4.4-3 in Reference 8)

DESIGNATION[1]	TITLE
D143	Method of Testing Small Clear Specimens of Timber
D198	Method for Static Tests of Timber in Structural Sizes
D1860	Test Method for Moisture and Creosote-type Preservation in Wood[1]
D4442	Test Methods for Moisture Content of Wood
D2017	Method for Accelerated Laboratory Test of Natural Decay Resistance of Woods
D2085	Test Method for Chloride for Calculating Pentachlorophenol in Solutions for Wood (Lime Ignition Method)
D2395	Test Methods for Specific Gravity of Wood and Wood-base Materials
D2915	Method for Evaluating Allowable Properties for Grades of Structural Lumber
D3345	Method for Laboratory Evaluation of Wood and Other Cellulosic Materials for Resistance to Termites

[1] Substantially the same as APWA-A6

Table C2.10.1-6 – Other applicable standards ASTM methods and Specifications

ASTM #	TITLE
E114	Practice for Ultrasonic Pulse-echo Straight Beam Contact
E1561	Practice for Analysis of Strain Gage Rosette Data
E1237	Guide for Installing Bonded Resistance Strain Gages
E837	Test Method of Determining Residual Stresses by the Hole-drilling Strain Gage Method
D5185	Test Method for Multielement Determination of Used and Unused Lubricating Oils and Base Oils by Inductively Coupled Plasma Atomic Emission Spectrometry (ICPAES)
D257	Test Method for DC Resistance or Conductance of Insulating Materials
D887	Practice for Sampling Water-formed Deposits
D971	Test Method for Interfacial Tension of Oil Against Water by the Ring Method

2.10.3—INTERNAL INSPECTION OF COMPONENTS

Several instruments which can investigate the internal condition of mechanical, electrical, and hydraulic components include:

- Flexible endoscopes (fiberscope) with articulating insertion tubes and rigid borescopes with rigid insertion tubes can provide visual images within motors, brakes, bearings, enclosed gearing or other difficult to access areas where internal inspection is required. Fiberscopes and borescopes can be coupled to a video camera and their images displayed on a monitor. The benefits of this display include group study and evaluation of images.
- The electronic stethoscope is a portable listening device for pinpointing machinery noise. Gear and pump noise, and operation of relays and solenoids are just a few of many noises that can be traced, amplified and assessed with this device.

2.10.4—APPLIED AND RESIDUAL STRESS MONITORING

Local strain measurements can be made for a quantitative evaluation of the stress state and loads on components, gears, and shafts. Various strain sensing methods are available for field applications including electrical or vibrating wire strain gauges, and brittle coatings.

Electrical resistance or vibrating wire type strain gauges can be used to determine the range and magnitude of applied stresses for the purpose of a load or fatigue evaluation. Brittle coating techniques can be used in selecting locations for strain gauges on components with unusual geometry by indicating regions of high surface strain.

Although shear strains are not measurable with ordinary strain gauges, gauges with specially designed shear pattern

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Temperature, humidity, and prolonged exposure to adverse conditions should be considered when selecting gauges, adhesives, and connectors for field applications.

configurations provide measurements that can be used to obtain shear strain data (Reference 129).

2.10.5—LEAF OR SPAN BALANCE

Leaf or span balance can change over time due to dirt, debris, deterioration, component wear, or alterations in structure. A poorly balanced bascule or lift span can put excessive loads on all machinery and electrical components. Balance of swing spans does not generally affect drive system loads, but other factors such as mechanical damage or a rim bearing track which is not horizontal can adversely impact the drive system. The same test methods given for checking span balance can be used at the owner's option to test swing spans for unusual load effects on the span drive. Testing should be performed to check span balance during all routine inspections. Strain gauges placed on the surface of the component measure the strain relaxation of the material as the hole is drilled near the gauges. This method may only be used if it is acceptable to create a hole in the test location. In many cases, making a hole is unacceptable due to the deleterious effects on the fatigue life or strength that such a hole will cause on the component.

The following subsections describe several methods of checking span balance. Span balance measurement is affected by external forces and loads such as strong wind, snow, rain, or icing. Hence, the tests should be conducted when these external forces are not present.

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Theories on the best balance condition vary among owners. In the absence of a stated preference, the inspector shall refer to the suggested balance conditions in the latest version of the AASHTO *LRFD Movable Highway Bridge Design Specifications*, Section 1.5, Balance and Counterweights.

2.10.5.1—Checking Static Balance

The initial check of bascule leaf or lift span balance can sometimes be performed by lifting the leaf (or operating the span), engaging the brakes, slowly releasing the brakes, and checking drift. The test should be done at the $^1/_3$ and $^2/_3$ open positions. The drift indicates qualitatively whether the bridge is span heavy or counterweight heavy. This method should be used only under no wind, water, snow, or ice loads, and should only be performed under close supervision by qualified mechanical or electrical inspectors or maintainers.

2.10.5.2—Checking Balance by Motor Power Measurement

Measuring the operating power (amperage) of the motor during opening and closing can provide a relative indication of span or leaf balance. This method is the easiest method to use and is preferred during routine inspections. The rule-of-thumb for adequate balance (toe-heavy) is when opening/closing motor current are within 10 percent of equal. However, this technique does not allow for a direct correlation between observed readings and the required amount and necessary

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A recording wattmeter measures power directly and may give a better indication of opening power vs. closing power. Power measurements take friction loads into account directly.

This technique should be used sparingly since it can be very inaccurate, especially with variable speed drives. It should never location of balance weights needed to restore leaf balance, and requires a trial and error approach. This technique should not be used if the motors are driven by VFD, SCR, or Vector drives since the readings will not be accurate unless specialized metering equipment is used.

If the operator's console has amperage gauges, it may be possible to determine motor amperage by turning off unnecessary electrical devices (heaters, air conditioners, incinerating toilets, etc.) and operating the span while watching the ammeter. During span operating, when the only item drawing power is the drive motor, the gauge reading will be the drive motor amperage. The problem is that for some systems it is difficult to be certain that no other component is drawing power. However, it may not matter if other items (such as motor brakes) are drawing current if they draw the same current opening and closing. Therefore, the basic concept of measuring motor amperage to determine span balance of a bascule or lift-span and to verify that a swing-span is rotating in a horizontal plane is that the motor effort (as represented by amperage or hydraulic pressure) should be similar during opening and closing. One quick and easy way to check span balance is to compare drive motor amperage at a steady running speed during opening and closing for several cycles. This can also be done with hydraulic pressure readings for hydraulic systems.

It is important to note that wind or the presence of sand, water, snow, or ice on the span or on the bascule leaf can affect span balance results and that when electric motors are motor/generators, they can generate current flow when being pushed by outside forces such as imbalance or wind, thereby skewing readings. For systems without ammeters installed, portable magnetic induction ammeters are available at low cost which can be employed for testing.

Electrical testing with inductive hand held ammeters requires opening electrical panels and should only be done by properly trained personnel and in conformance with all Federal, state, and local regulations and the National Electrical Safety Code (Reference 89b).

be used for final balance condition determination.

2.10.5.3—Strain Gauge Balancing

Strain gauge balancing is a technique that provides an accurate means of establishing the balance of a bascule span leaf or lift span. In this technique, strain gauges are attached to the main drive shaft to measure the torsion strain induced in the shaft during bridge opening and closing (see Figure 2.10.5.3-1). A relationship is established between unbalanced torque of the shaft and bridge opening position. Based on this information counterweight blocks can be subtracted or added as required to achieve an optimum relationship between the shaft torque and bridge opening position. Correct balance is achieved when a

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A monitoring and recording system, usually referred to as a data acquisition system (DAS), can be interfaced with shaft mounted strain gauges for purposes of continuously monitoring leaf balance. Such a system can be provided on new movable bridges or as a retrofit on older bridges. The strain gauges provide precise strain measurements at predetermined intervals to the DAS during both opening and closing slightly toe heavy leaf (or span heavy span) requires a small amount of positive torque to open and the CG is located as desired by the owner such that acceptable imbalance torque is maintained throughout operation. A detailed discussion of this technique is provided in Reference 53.

The typical test procedure for strain gauge testing is as follows:

- Special shear pattern strain gauges are used to read torsional shear in the main drive shafts for the pinion on a bascule or for the main winch drum drive shaft on a lift span.
- An inclinometer is used on a bascule to relate strain readings to span angle in real time. On a lift span, the span position is somewhat more problematic to read directly, but it is possible to do so by adding a voice track to the data record and having someone call out span position at intervals. It is also feasible to use a wire reel type position transducer if the wire is wrapped around one of the drive or trunnion shafts that do not turn excessively. The main tower sheave trunnion shaft or a main winch drum drive shaft may suffice if a wire reel position transducer is available that will allow sufficient movement. One method to reduce the length of wire used is to apply the wire to the shaft at halfway open. The wire then wraps around the circumference of the shaft one way from halfway open to closed. The position transducer then shows the distance a point on the shaft circumference travels in each direction of shaft rotation from halfway open and can be mathematically related to span position.
- Torque strain gauge readings are established by calibration and recorded for each gauge.
- The system is run through not less than two full cycles of span opening and closing and the data analyzed to compute whether the bridge is out of balance, and if so by how much.
- The amount of imbalance is used to calculate adjustments to the counterweights to bring the bridge into an acceptable state of balance.

operations. The strain measurements can then be visually displayed or produced in hard copy (printout) form for detailed analysis by the inspector or engineer. MSDOT requires at least four complete opening and closing cycles as part of the testing.

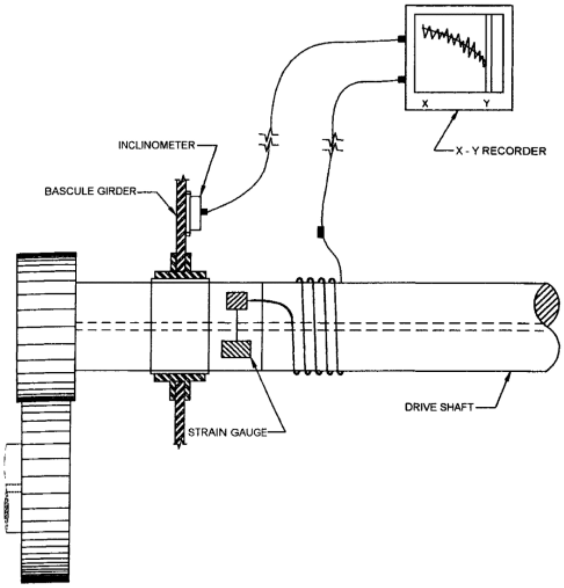

Figure 2.10.5.3-1 – Strain gauge of drive shaft torque

2.10.6—VIBRATION MEASUREMENT

The operating condition of rotating machinery that has been in service and performing satisfactorily for a reasonable period of time can suddenly change. Experienced bridge operators can usually detect the initial variation in performance by the sudden change in normal noise level or vibration. Periodic vibration measurement can provide a means of verifying the operating performance of rotating machinery and give advance warning of any changes in mechanical condition.

Vibration is readily distinguishable since it can be heard and felt, and its effects can be routinely measured by using a compact, battery powered vibration meter (Figure 2.10.6-1). Vibration measurements are obtained by holding the probe against the vibrating surface and observing the meter reading.

Figure 2.10.6-1 – Battery-powered vibration meter

C2.10.6

Standard motors are not designed for use where there is excessive vibration. Excessive vibration is undesirable because it imposes additional loads on the equipment or initiates fatigue cracks in machinery supports or fasteners. If the cause is not detected early and corrected, extensive damage can occur. Rough bearings can cause a machine to perform poorly and vibrate. Vibration adversely affects commutation on DC machines, destroys brushes on a wound-rotor motor and eventually loosens coils and hardware.

Changes in audible noise level or an increase in vibration can be caused by many factors. The most common is defective bearings. If the vibration level of the motor increases, test the housing close to the bearing. If hot to the touch, it would be advisable to remove the motor from service and inspect the bearing.

Vibration by definition is an oscillatory motion, and one of the factors needed to evaluate the extent of motion is the distance traveled, or the excursions occurring at each cycle. The amplitude of motion is usually expressed in mils "peak to peak." Example: a 0.001 in. (0.0254 mm) excursion in one direction is actually 0.002 in. (0.0508 mm) "peak to peak" amplitude. Therefore, in general usage the word "displacement" describes "peak to peak" motion.

Acceptable vibration limits for standard motors are taken from NEMA MGl-12.05, MGl-20.52 and MGI-23.51 as follows:

Speed RPM	Acceptable Displacement in. (mm)
3,000–4,000	0.001 (0.0254)
1,500–2,999	0.0015–0.002 (0.0381–0.0508)
1,000–1,499	0.002–0.0025 (0.0508–0.0635)
999 and below	0.0025–0.005 (0.0635–0.127)

2.10.7—LUBRICATING OIL ANALYSIS

Lubricating oil and/or grease analysis is used to determine the condition of lubrication used in mechanical equipment. Typical tests that can be conducted include:

- Viscosity
- Contamination
- Solids content
- Particle count
- Oxidation

Additional testing methods which can be performed on lubricating oil include:

Spectrographic analysis: Spectrographic analysis provides a chemical breakdown of the oil additives and contaminants contained in the oil. The various elements found can be classified as oil additives, contaminants, or wear metals.

Wear particle analysis: Wear particle analysis is similar to lubricating oil analysis but can provide direct evidence on the wearing condition of the mechanical component. By deriving information from the particle shape, size, composition, and quantity, various types of wear classifications can be obtained. The benefit of this analysis is achieved by taking periodic samples of the lubricating oil and comparing the amount of trace elements. This comparison can provide a relative indication of wear patterns in the mechanical components and help prevent machinery failure.

C2.10.7

In selecting a lubricating oil analysis method, the limitations of each test should be considered. Often more than one test method is used to supplement or confirm the results of the other.

Many manufacturers have developed synthetic oils, and most manufacturers provide free annual testing.

2.10.8—ELECTRICAL MEASUREMENT

Measurement of basic electrical parameters, such as voltage, current, resistance, and motor speed and temperature can be made using commonly available devices. Several measuring devices and their uses include:

Multimeters: Multimeters measure volts, amperes, or ohms using one instrument. Portable multimeters are available with either analog or digital readouts for DC or AC measurements.

Motion indicators (RPM testers): This test equipment is used to measure the rotational speed of a motor or other rotating device. Some incorporate a strobe light to synchronize with the speed of rotation of the device. When properly synchronized, the strobe light will give the impression that the rotating device has stopped moving. The inspector should resist the temptation to touch the rotating device when it appears to be motionless.

Clamp-on ammeter: A clamp-on ammeter measures currents by clamping around a current carrying conductor, when it is not practical for conventional instruments to be connected in series with the circuit (Figure 2.10.8.1).

Figure 2.10.8-1 – Clamp-on ammeter

Infrared thermometers: Infrared thermometers (Figure 2.10.8-2) provide noncontact temperature measurements to spot problems in electrical, hydraulic, and mechanical systems.

Figure 2.10.8-2 – Infrared thermometer

2.10.9—ELECTRICAL INSULATION RESISTANCE TESTING

Insulation testers impress a high voltage between a conductor and some return path, most commonly ground, and measure insulation resistance to ascertain the quality of the insulator. Insulation testers can generate a very high voltage and care in use should be exercised. A good cable or motor can be permanently damaged if too high a voltage is used to test an insulator. The insulation tester voltage level setting must be adjusted to be compatible with the voltage rating of the circuit or equipment to be tested. After each test is completed, make sure that the circuit tested is discharged to earth for a sufficient amount of time to confirm that no hazard exists to personnel or equipment.

The condition of electrical insulation can provide an indicator of the remaining service life that can be expected from aging electrical equipment. Insulation condition can be measured by two general methods: low voltage, low power testing or high voltage, high power testing.

Low voltage megger testing: A megger (see Figure 2.10.9-1) is a portable, low-voltage DC supply, calibrated to read insulation resistance in ohms or megohms (million ohms). The hand crank type has voltage outputs of 500 and 1000 volts DC, and a motor driven unit can generate 2500 volts DC. Newer hand crank models have continuity checking capability built into the megger, increasing its usefulness to maintenance and inspection personnel.

C2.10.9

Because insulation resistance changes with equipment, age, and operating environment, no specific resistance can be given for an absolute minimum value. The best way to evaluate insulation is to record the megger test results and plot this data on a curve over a long period of time.

Figure C2.10.9-1 shows two sides of an equipment insulation test record. One side is the data record, and the other side shows the data plotted on a log scale versus time. In this example. the owner of the 200 Hp (150 kW) wound-rotor motor has elected to test the insulation every two months, which is more frequent than would normally be done for movable bridge insulation. The data is useful to show the break-in period on a wound rotor motor and the effects of cleaning. The test instrument is a megger with 1000 volts output and the results have not been corrected for effects of atmospheric conditions. Some error is present because of this method, but these tests are made during periods of low humidity and at about the same temperatures. Note the point where an unusually low value of resistance was obtained in January 1995. This low reading

Figure 2.10.9-1 – Megger

indicated that dirt and or moisture was present on the motor insulation. The maintainers were alerted to a possible problem and the motor was cleaned thoroughly. Retesting after cleaning increased the insulation resistance to a level that appears normal on the chart. Note that the insulation resistance is well above the minimum acceptable level. If the variation in the resistance values had been disregarded, no specific trouble would be indicated until the resistance dropped to a very low level. At low insulation levels, failure is likely to occur because of flashover from contamination or a turn-to-turn failure. However, on some equipment the insulation resistance is normally low, even below the minimum resistance value obtained by the rule of thumb method described herein.

TESTING DATA RECORD

DATE	READING	TEMPERATURE AMBIENT DRY BULB	TEMPERATURE AMBIENT WET BULB	BASE TEMPERATURE NOTES	ADJUSTED INSULA. RES.
6-12-73	100 mΩ			INSTALLATION PERIOD	
8-73	–			CHECK OUT	
9-73	100 mΩ			START UP	
11-73	70				
1-74	50 ¼m				
3-74	49.8				
5-74	40				
7-74	35				
9-74	36.5				
11-74	30				
1-75	20/30			MOTOR WAS CLEANED	
3-75	28				
5-75	29				
7-75	11.0/			MOTOR NEEDS CLEANING	
9-75					
11-75					
1-76					
		DATA COLUMNS FOR DEW POINT AND RELATIVE HUMIDITY CORRECTION FACTOR			

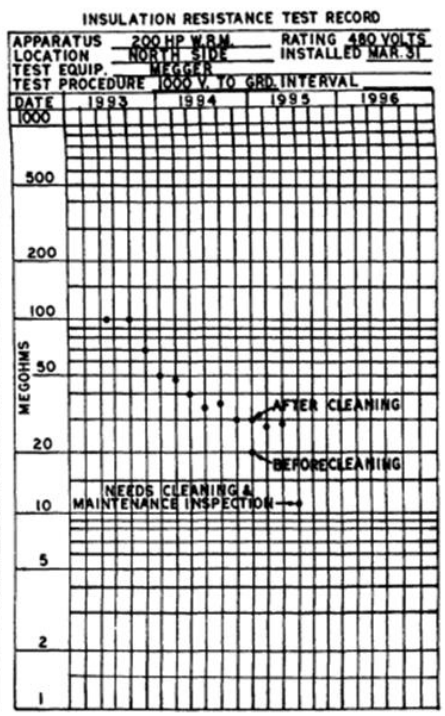

Figure C2.10.9-1 – Typical insulation test record

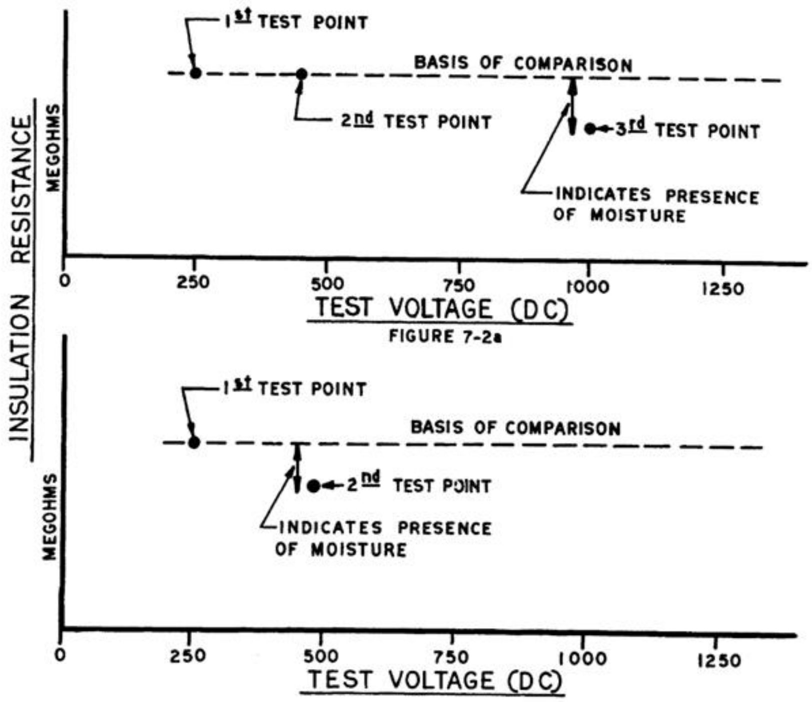

Figure C2.10.9-2 – Multi-voltage test for moisture presence in insulation

The DC megger provides an easy, quick method for checking the insulation resistance of low voltage equipment rated 1000 volts or less. By connecting the megger "line" terminal to the circuit conductor and the "earth" terminal to ground, the megger will read resistance of the insulation to ground. The megger is also used in a power circuit to check phase to phase insulation resistance. To do this, the "earth" terminal is connected to one of the phase conductors instead of ground. The reading is taken after the megger is cranked by hand, or turned by the motor, for at least 30 seconds. If a hand cranked megger is used, it must be turned continuously at an even speed. The DC charging current produces a low insulation reading as the insulation charges up (like a capacitor). As the charging current decreases, the megohm reading will increase at a slower and slower rate and finally level off. At this point, the charging current is near zero and the conduction current flowing through the insulation produces the resistance reading on the scale. When the meter has a steady reading, the resistance shown is the resistance of the insulation between the two megger terminals at the applied test voltage. It should be noted that changing the megger testing voltage can produce different resistance readings. Whenever a megger test is made, all pertinent data should be recorded, including the time of day, the date, test voltage, temperature, and humidity. Temperature and humidity influence megger test results.

All tests on a specific item of equipment should be at the same voltage and under comparable atmospheric conditions. By

Another method of testing insulation using the megger provides specific information about moisture in the insulation. By testing the equipment at three different voltages during the test, and plotting these three values, a straight horizontal line should result. If the line tends to curve downward, this indicates that excessive moisture is probably present. Even two test voltages can provide some indication that excessive moisture is present. The lower second test data will indicate moisture is present if it deviates substantially from the first test data point. Figure C2.10.9-2 shows these two conditions graphically. Note that the insulation resistance is shown only as megohms. The lack of specific values is not significant because of the wide range of insulation resistance values depending on the type of equipment and conditions. The minimum resistance rule of thumb is still valid, regardless of the shape of the curve. Equipment that is below these minimums should be reconditioned before being put back into service.

controlling the test, the results obtained will provide a better comparison of the actual condition of the insulation. Normally, the plotting of the individual test results produces a gradually changing line. When a new test result deviates substantially from the normal trend, the insulation is headed for trouble. Contamination or oil leakage into the equipment can create a coating on the insulation. Moisture will develop and penetrate the insulation, producing changes in the resistance. Contamination on the insulation can provide a creepage path between insulated and non-insulated conductors and ground, creating a dangerous situation.

Maintenance cleaning procedures usually minimize contamination, but if equipment is not maintained properly and insulation values change, the test data curve becomes a valuable way to identify sudden drops in resistance that signal the possible onset of a problem.

What minimum normal values of insulation resistance are acceptable? There is no specific answer to this question, but general practice accepts one megohm per thousand volts of operating voltage, with a minimum of one megohm. This rule of thumb is fairly uniform for megger testing.

High voltage DC testing: Equipment operating above 1,000 volts requires higher testing voltages to obtain meaningful results. Fairly compact high voltage DC testing equipment is available for these tests. Supplied from 120 volt alternating current sources, some units can provide a test voltage of 150,000 volts. However, lower rated units are more than adequate for testing the majority of equipment encountered today.

One nondestructive test being applied today is called a leakage voltage test. In this leakage test, a dielectric absorption test is made at a reduced voltage and followed immediately by an incremental overpotential test. The dielectric absorption test measures the leakage current flowing into the insulation (absorption) at specific time intervals for a period of ten minutes. This absorption test is applied at a constant voltage, usually about 40 percent of the highest test voltage to be applied. These currents (measured in milliamperes) are plotted versus time on log-log paper. The resulting curve is then compared to standard curves to determine the absorption ratio. This ratio is an indicator of insulation condition. Repeated tests over time provide indication of changes in insulation condition. The absorption test is normally followed immediately by step-voltage increases to the highest test voltage allowable. The amount of voltage increase to make at each step, and the time interval of each step, is determined from the absorption test data just obtained. The final test is called an overpotential test because the test voltage is normally higher than the operating voltage of the equipment. It is preferred that this maximum voltage be chosen by an electrical engineer, but it can be determined from the following formula:

$$V_t = (2V_o + 1000)(1.6)$$

where:

V_t = Test voltage
V_o = Rated operating voltage
1.6 = Conversion factor from AC to DC

A reduction in the test voltage normally used for "in service" equipment is also preferably selected by an electrical engineer, but it is usually 60–75 percent of the value obtained from the formula above. Any large deviation of individual data points from the line indicates insulation trouble.

High voltage AC testing: AC high voltage testing equipment is always larger than DC high voltage test equipment because of higher power requirements.

AC high voltage is used for a dielectric power factor test because the results obtained measure the power factor of the test voltage and current applied to the insulation. The chief advantage to this type of test is that coil insulation can be compared without dismantling equipment or destroying the coil insulation. With special techniques, transformer windings can be tested to indicate "turn-to-turn" insulation condition. This test is principally used on high voltage units.

2.10.10—TESTING TRANSFORMER INSULATING OIL

Dielectric strength is defined as the capability of an insulating oil to resist current flow through the liquid. Insulating liquids, mineral oils, and synthetic oils (askarels) provide adequate dielectric protection only if they are clean and dry. Moisture and contaminants can reduce their dielectric strength. Dielectric strength is determined by obtaining samples of the oil for laboratory testing.

The dielectric laboratory test only determines the present condition of the oil. Comparing test results over a prolonged period of time will establish the trend of oil deterioration, and a projection of the likelihood of probable failure can be made with reasonable accuracy.

To make a dielectric test, uncontaminated samples of the insulating oil must be taken from the tank. Use clean, dry bottles to collect samples.

Generally speaking, as the operating voltage increases on equipment using insulating liquids, the minimum dielectric breakdown voltage increases. For bridge applications where applied voltage supplies rarely exceed 4,160 volts, some minimum value can be established. For new mineral oils, a minimum breakdown voltage of 30 kV using the ASTM D897 method can be applied. For used mineral oil, a 22 kV minimum, breakdown limit is usually the lowest acceptable value before reconditioning is required.

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Caution: PCBs (askarels) are hazardous if they contact human skin. Only trained personnel wearing appropriate protective gloves, face shield, and protective clothing should be allowed to sample askarel based oil or oil of unknown composition. Spillage of askarel oils is a potential hazard and requires special cleanup and decontamination measures. Only personnel trained in such cleanup measures should be permitted to handle askarel sampling or transport.

Additional tests on insulating oils include chemical tests, gas tests, viscosity tests, and interfacial tests. These tests are more involved than the dielectric test and require a specialized testing laboratory. These tests can provide a thorough analysis of the insulating oil condition.

Synthetic oils (askarels) usually withstand higher dielectric breakdown voltages than mineral oils. However, the same limiting set for mineral oils above can be applied as a minimum standard for synthetic oils.

Acidity testing of insulation oils: Oxidation of the oil occurs naturally during operation and is accelerated by electrical arcing within the liquid. The arcing can be a normal occurrence from the operation of an oil circuit breaker, or it can be an exceptional occurrence from a fault condition causing a flashover in a transformer.

As oxidation occurs, sludge is produced and accumulates on the insulation. A reduction of heat transfer results and eventually insulation can fail due to overheating. Therefore, it is important to know if sludge build up is occurring and to what extent.

Because oxidation produces sludge and other residues, an acidity test can be made to detect these substances. By measuring the amount of neutralizer required to neutralize (or cancel out) the acid produced in the oil, an indicator is obtained that is directly proportional to the oxidation level of the oil. This neutralization number (acidity number) is the amount (in mg) of KOH (potassium hydroxide) required to neutralize one gram of oil. As a general rule, when the neutralization number reaches 0.6, the oil should be replaced. Usually when the number reads 0.3 or 0.4 at the most, the oil should be treated to remove the sludge and residues. Some engineers consider the 0.6 number to be too high, particularly on large power transformers. It is preferred to use periodic testing to determine if the acidity level is increasing at a rapid rate. Acceleration of the rate of increase in acidity usually occurs when the acidity level goes above 0.3. Large quantities of oil are usually reconditioned before being put back into service, but occasionally, new oil is cheaper and there is less inconvenience involved.

An acidity test is usually done as part of a complete chemical test on insulating oil. Other chemical tests performed are for color, specific gravity, and moisture content. They can provide information, by comparison, for changes in oil condition. Cautions and methodology of sampling are as stated for dielectric testing.

Interfacial testing of oil: Measurement of the interfacial tension of oil provides the capability of projecting the useful life of oil using relatively short duration testing procedures.

Interfacial tension is the bonding together of molecules, a characteristic that holds the liquid together. For example, water that beads up on a waxed surface is demonstrating the forces of interfacial tension in the water molecules.

Oxidation of oil reduces the interfacial tension of the oil molecules. An increase of the oxidation level over a period of time produces a decrease in the interfacial tension that can be calculated. The interfacial tension data obtained is plotted on a log scale against the linear plot of time and a straight line results from the data. When the lower limit of tension is known (usually set by an electrical engineer), the intersection of the straight line with the lower limit results in an accurately projected date when the oil will require some type of reconditioning.

The American Society for Testing and Materials (ASTM) has prepared a standard for the test: Standard Test Method for Interfacial Tension of Oil Against Water by the Ring Method (ASTM Designation D971). Samples are sent to a testing facility and a test report is prepared and returned. These reports should be kept on file for the specific equipment involved. Comparison of subsequent test results and projections can then be made to determine the remaining useful life of the oil.

2.10.11—HYDRAULIC SYSTEM TESTING

2.10.11.1—Hydraulic Oil Sampling

Regular sampling and testing of hydraulic fluid is a reliable method to monitor system performance and to provide timely detection of problems or contamination.

Samples of oil taken from the system should be analyzed in accordance with ISO 4406 – Hydraulic Fluid Power – Fluids – Methods for Coding Level of Contamination by Solid Particles. The degree and nature of contamination should be determined. A sample may be used to determine the specific gravity, viscosity, water content and neutralization number. A change in any of these from normal indicates dilution or contamination by water, coolant, lubricants, or other fluids. The neutralization number also indicates any increase in acidity of the fluid due to a breakdown of the oil. These contaminants, which are chemical in nature, cannot be removed by filtration. If tests show a high degree of such contamination, the oil must be changed.

Foreign particles in the oil can generally be removed by filtration. Filtration is a continuous process as long as the filters in the system are functioning properly. External filtration may be necessary to remove excess particle contamination from a system.

Particle count and particle identification can help in pinpointing trouble with filters, seals, motors, pumps, and particle contamination.

From the particle count, the class of contamination is determined. ASTM Class 0 through 4 oil is considered to be satisfactory for further use with future sampling at the regularly scheduled intervals. For Class 5 (or dirtier) oil, all filters should be checked and changed as necessary. Careful examination of each filter should be made to identify the type of contamination. External filtration is also recommended, especially if contamination is worse than Class 5. Anything that appears to contribute to the contamination should be corrected, and after a

C2.10.11.1

It is also recommended that samples of oil be taken and analyzed at maximum intervals as follows:

Step 1: Upon completion of system installation (or replacement of hydraulic oil):

- Take fluid samples while the system is in operation and has been running 15 minutes or more.
- Always take samples at the same place.
- Clean the area surrounding the sampling valve on the hydraulic system with a filtered solvent.

  NOTE: Rags should not be used for cleaning, because lint contaminates the oil. When wiping is necessary, only lint free wipers should be used. Keep the sampling bottles absolutely clean and free of any additional contaminants at all times.
- Open the sampling valve and flush a quart or two of fluid into a pail, fill the shipping bottle with fluid, remove the bottle, and then close the valve. (Discard the fluid in the pail; do not return it to the hydraulic system.)
- Place a 3-inch square of plastic wrap or similar material over the shipping bottle to seal the opening and screw the cap on tightly over this seal for shipping.

few days of operation another sample should be taken for analysis.

A particle count is practical for oil samples of Class 6 or cleaner. A gravimetric analysis test provides a useful measure of contamination for Class 6 and dirtier, but particles are not easily identified. Silt indices show an excess of particles below 5 mm and also varnish formation in the oil. For a high count of particles smaller than 5 mm, or a high silt index, external filtering with 2 mm or finer filters is recommended.

- Identify each sample with the date taken and machine serial number. Give the name and address of the person who is to receive the reports and the returned bottle.
- Place the bottle with the sample of fluid in the plastic bag and seal it. Prepare it for shipping by wrapping with corrugated paper and placing in a corrugated paper container and seal. (Do not pack in sawdust.)
- Label package "Hydraulic Oil Sample."

Step 2: Repeat the above procedure after the first three months of operation.

Step 3: Repeat the above procedure after one year of operation and every year thereafter. Should it be necessary to change the oil or some major component where the cleanliness of the oil may be affected, a sample analysis should be made.

2.10.11.2—Analysis of Filter Elements

After changing a hydraulic filter element, the old element should be cut open and inspected for debris. If excess debris is observed or if the filter clogged prematurely, the source of the contamination should be located. If the source is not apparent, the spent element should be sent to a testing lab for analysis.

2.10.11.3—Operating Pressures/Cycle Testing

Operating pressure and cycle testing should be performed during routine inspections or after any major maintenance activity. System pressures at critical locations should be observed and recorded through each phase of the system cycle (primary pressure near pump outlet, pressure at each actuator, return pressure to reservoir, oil and precharge pressure at accumulators, pilot pressures, etc.). Additionally, actuator speeds for each phase of the cycle should be documented. By comparing this data to specifications and past results, problems may be identified before they become serious.

2.10.11.4—Leakage Testing

Pressure testing for leakage should be performed after any major maintenance activity which could introduce leakage points. The portion of the circuit to be tested should be isolated from the other piping and components. A static pressure test should be performed to 150 percent of the maximum design operating pressure or to the pressure specified in the system testing specifications.

2.10.11.5—Case Drain Flow Analysis

Monitoring the case drain flows of rotary hydraulic equipment is a good method of evaluating component wear which occurs slowly over a long period of time. As a pump or hydraulic motor wears, efficiency decreases and thus internal leakage increases. For hydraulic devices with case drains, the case drain flow increases accordingly. Furthermore, a higher than usual case drain temperature may indicate problems. Case drain flows should be measured and recorded. Case drain oil temperatures and the corresponding bulk oil temperature in the reservoir should be documented. These values should be recorded and compared to design specifications and historical results.

2.10.11.6—Temperature Analysis

Excess heat is often an indication of a component problem. Therefore, periodic temperature analysis is of value in identifying potential failures. Skin temperatures of strategic working lines and components should be measured, recorded, and compared to specifications and historical values. Temperature strips, infrared remote read thermometers, or thermal crayons may be used for this purpose. This test should be performed during routine inspections or as required for troubleshooting.

2.10.12—DIAGNOSTIC MONITORING SYSTEMS

Diagnostic monitoring systems can be incorporated into a movable bridge to provide automatic data collection on critical operating parameters. The purpose of monitoring is to generate a real-time statistical database of the performance of the structure under actual operating conditions. This information is then compared to normal operating conditions to initiate preventive maintenance action if required, or to provide an assurance of a normal operating mode. The various operating parameters that can be automatically monitored on a movable bridge include:

- Traffic counts
- Operational hours
- Span position and span lock pressure
- Main girder, floor beam, and stringer stresses
- Torque/bridge balance
- Hydraulic system pressure
- Oil temperature

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Diagnostic monitoring systems described in this chapter fall under the general category of predictive maintenance or condition monitoring systems. These terms refer to a program of performance monitoring either continuously or at periodic intervals to assess the operational characteristics of a machine or system. This is achieved through the integration of a sensor network within the machine or system that measures critical operating parameters. The sensor network is then linked to a signal converter/display unit for collecting and processing the raw signals into a form suitable for display and interpretation. By comparing this data with normal operating characteristics,

- Gear box/motor vibration
- Open gear, rack, and pinion vibration
- Open gear corrosion
- Trunnion angle, shear, sound
- Live live shoe and span lock contact
- Drive motor current
- Channel depth
- Wind speed
- Strain
- Displacement

One of the critical objectives of the monitoring is to develop methods and approaches for monitoring of maintenance operations. With appropriate measurements, it is important to develop methods that can provide information for the engineers. The information extracted from the bridge should be easy to interpret by the bridge engineers, as well as robust, as demonstrated by field tests. As a result, a number of different data analysis methods have been developed and demonstrated for these purposes, for different monitored components. Some of them are outlined in the following sections.

2.10.12.1—Gearbox Vibration

When the gearboxes experience deterioration or lack of lubrication, some change in the vibration and sound characteristics during operation should be noted. Abnormal vibration is an indicator of wear in the gears. Accelerometers can be used to collect data. Baseline information for gearbox accelerometers can be obtained from statistical analysis from several openings and closings of the bridge. For each opening during this period, maximums, minimums, standard deviation, and maximum RMS values can be collected and the histograms for maximum values and minimum values can be generated for handling large amounts of vibration data. In addition, frequency domain analysis is also conducted for tracking deviations in resonant frequencies.

2.10.12.2—Open Gear

Open gears can be monitored by low cost cameras and lubrication can be tracked using advanced computer vision methods that can be simply employed by bridge inspectors remotely. This novel method has been shown to provide excellent information about the open gear lubrication (see Reference 44).

abnormalities in system operation can be detected prior to major breakdown.

Advances in computer data links, diagnostic instrumentation, and interactive graphic displays in recent years offer many new possibilities to enhance the data gathered during traditional inspections, and can serve as an ongoing, daily, or periodic monitoring system for bridge evaluation or maintenance purposes. Such monitoring systems might be considered elaborate for movable bridge owners, but they offer a possibility to minimize downtime, prevent major failures, and can result in an efficient scheduling of maintenance. Consideration of this type of diagnostic monitoring system should be given for structures undergoing rehabilitation or new structures of unique or advanced design.

2.10.12.3—Span Lock Pressure

Deterioration or incorrect operation can cause failure, which disrupts the function of the bridge. It is possible to install pressure gauges at the span lock to measure the hydraulic pressure of the span lock to detect any leak or other anomalies with the pressure applied to span locks. In past studies of the statistical analysis of the pressure gauge data, it is observed that pulling (pulling the lock bar out of the receiver before a span opening) and driving (driving the lock bar into the receiver after a span opening) pressures are at particular levels specific to a span lock. Tracking the mean and standard deviation of these measurements for pulling and driving can provide useful information about the span lock operations (Reference 45).

2.10.12.4—Advanced Statistical Methods for Mechanical Components

A challenge for long-term monitoring of movable bridge data is efficiently interpreting the large amount of data. There are several advanced, data-driven techniques available for damage detection purposes. Previous studies indicate that only a few of the available data-driven damage detection techniques remain effective when applied to civil structures. Moving Principal Component Analysis (MPCA), Moving Cross Correlation Analysis (MCCA), and Robust Regression Analysis (RRA) have been observed as three of the most reliable data-driven algorithms. Other new data-driven approaches, such as the combined MPCA—Support Vector Machine (SVM) algorithm, are also available. These methods can easily be coded and employed to handle large amount of monitoring data along with several other methods that are continuously being developed and introduced (Reference 45).

PART 3: MOVABLE BRIDGE ELEMENT DESCRIPTIONS

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Part 3

MOVABLE BRIDGE ELEMENT DESCRIPTIONS

3.1—INTRODUCTION

Proper condition assessment of bridge elements is the cornerstone of sound bridge management. Bridge Owners nationwide have recognized the benefits of detailed condition assessments using raw inspection information, expanded performance measures, and bridge management system deterioration forecasting and evaluation.

The goal of movable bridge element descriptions found herein is to capture the condition of movable bridges in a simple, effective way that can be used consistently across the nation while providing the flexibility to be adapted to both large- and small-agency settings. Note that these movable bridge elements are meant to be Agency-Defined Elements (ADEs) to supplement and be used in conjunction with, not redundant to, the elements defined in the AASHTO *Manual for Bridge Element Inspection* (MBEI), Second Edition for fixed (non-movable) bridges.

Agencies are encouraged to use ADEs defined here or add new ADEs, as necessary, according to the needs of their movable bridge inventory, environmental risks (coastal storm, storm surge, seismic, etc.), and bridge management practices.

Unlike fixed bridges, movable bridges have element types that require different types of inspections by inspectors with varying qualifications. Movable bridge ADEs are divided into three categories: structural, mechanical, and electrical. Defects are described for each ADE. Note that there is some redundancy within the movable bridge ADEs with regard to discipline (e.g., structural, mechanical, electrical). This redundancy is unavoidable and in fact desirable due to the multi-disciplinary and complex nature of movable bridges. For example, it is beneficial for both mechanical and electrical inspectors to inspect a motor or a limit switch. It is also beneficial for both structural and mechanical inspectors to inspect trunnion bearing assemblies, and so on. Inspectors from different disciplines will focus on different aspects of the same ADE.

These movable bridge ADE descriptions are not intended to supplant proper movable bridge and element inspection training or the exercise of engineering judgment by the inspector or professional engineer.

3.1.1—Condition Assessment Philosophy: Multipath Distress and Defect Concepts

Part 3 of this Manual follows the methodology set forth in the MBEI. It uses a multipath distress language which provides the means to fully incorporate all possible defects within the overall condition assessment of the element. The overall condition of the element can be utilized in this aggregate form or broken down into specific defects present, as desired by agencies for Bridge Management System (BMS) use.

This Part provides a comprehensive set of movable bridge ADEs designed to be flexible in nature to satisfy the needs of all agencies. The complete set of ADEs captures the components necessary for an agency to manage all aspects of their movable bridges. All of the ADEs have the same general condition assessment characteristics:

1. The standard number of condition states (CS) is four.
2. The standard general descriptions for condition states are Good (Condition State 1), Fair (Condition State 2), Poor (Condition State 3), and Severe (Condition State 4).
3. Units of measure are length in feet, area in square feet, and each for enumerated elements.

3.1.2—Agency-Defined Elements

The ADEs presented in this Manual provide the flexibility for an agency to define custom elements that meet the needs of their movable bridges which, by nature, are unique structures. The ADEs shown were gathered from agencies with the largest populations of movable bridges and the most experience managing these structures, and are presented here to provide guidance to states and local agencies with less experience in managing these structure types.

3.1.3—How to Use This Manual

Movable bridge inspection based upon this Manual consists of defining the elements (i.e., pieces of the bridge), recording the total quantities that exist for the bridge, and assessing the condition of each element. The condition of each element is determined by performing a field inspection and recording quantities of the element that have identified defects which correlate to the defect severity defined in this Manual. The condition assessment is complete when the appropriate portion of the total quantity is stratified over the defined condition states. For agencies utilizing BMSs, the appropriate element defects and environment can be recorded for use in deterioration modeling.

In this Manual, the element condition represents the aggregate condition of the defined element inclusive of all defects. The specific listing of all defects is optional; however, the element condition must be inclusive of all defined defects. Element defects are typically used when the element reaches Condition State 2 or worse, and they essentially act to break down the overall element condition into one or more specific observed problems. The defects defined within this Manual always assume the units of the element with which they are associated. Because most movable bridge elements are each, most often multiple defects may operate in the same defined space, and the inspector is encouraged to report all defects.

This Manual attempts to cover all bridge elements found on movable bridges in the United States. However, movable bridges are unique structures and agencies are encouraged to review what elements are needed for their structures, dependent upon the anticipated maintenance, preservation, rehabilitation, and element replacement needs of the individual structure.

The granularity of the defect details is typically not specified with defect-descriptive language for Condition State 4, as this state is reserved for severe conditions that are beyond the specific defects defined for Condition States 1 through 3. Elements with some or all of the quantity in Condition State 4 often have operational, safety, and load capacity implications warranting an operational and/or structural review. Within this Manual, the term “structural review” is defined as a review by a person qualified to evaluate the field-observed conditions and determine the impacts of the conditions on the performance of the element. Structural reviews may include a review of the field inspection notes and photographs, nondestructive evaluations, mechanical and electrical tests, as-built plans, or other analyses as deemed appropriate to accurately evaluate the performance of the element. Agencies may establish additional guidance to aid the inspector in determining the field circumstances where operational or structural review is warranted, taking into consideration the education, training, and experience of their inspection staff.

3.2—MOVABLE BRIDGE ELEMENTS

This Chapter provides a list of commonly used movable bridge elements which can be considered for use by an agency when creating ADEs. Movable bridges are unique structures requiring various disciplines for proper assessment including structural, mechanical, and electrical. Therefore, this Chapter indicates which elements belong to which discipline. Some elements are inspected by multiple disciplines and therefore are repeated in the following tables with different element numbers. Tables for structural, mechanical, and electrical elements are provided in the following subsections and include suggested element numbers, descriptions, and units. In the MBEI, element identification numbers 800 or above are reserved for ADEs. In this Manual, element number groups 801-829, 830-859, and 860-890 are reserved for structural, mechanical, and electrical ADEs, respectively. It is up to the Owner to determine if the movable bridge ADEs indicated below are needed to supplement MBEI elements.

3.2.1—Movable Bridge Structural Elements

The following table shows structural elements unique to movable bridges

Element Number	Element Name	Description	Unit
801	Machinery Base Support	Independent frame/support that supports the machinery, including all associated weldments, hardware, anchor bolts, pedestals, and grout pads.	Each
802	Span Locks – Structural	All span locks, toe locks, heel stops, tail locks, and center locks present on the structure to hold the span securely closed.	Each
803	Bearings – Structural	Those elements used to transmit live load from the moveable span to the substructure, or to cushion the span while it is being closed including live load shoes, wedges, strike plates, guides, rollers, linkages, pins, and buffer cylinders.	Each
804	Counterweight Support – Structural	Structural steel elements used to support the counterweight and attachments.	Each
805	Counterweight	Counterweight structure, which includes balance blocks and span balance assessment.	Each
806	Access System – Structural	Members and components that make up the access system, including, but not limited to, ladders, stairs, landings, platforms, walkways, working surfaces, edge protection, and fall protection. The bridge access system is counted as one item per bridge.	Entire Bridge
807	Primary Movable Support Member – Structural	Structural supports for the trunnions, treads, tracks, and racks, either curved or straight.	LF
808	Rolling Track Girder	Structural support girder (often embedded in the substructure) that carries the curved segmental girder of rolling lift bascules.	Each
809	Tread Plates	Heavy steel plates at the planes of rolling contact that carry the full weight of the structure in line bearing while rolling.	Each
810	End Lifts	Swing bridge structural support for live load.	Each
811	Center Wedges	Structural support to stabilize the center of the spans to carry traffic and to help relieve a portion of the live load.	Each
812	Submarine/Aerial Cable – Structural	Cable that is used to carry power and control signals from one pier to the other pier on a bridge.	Each
813	Wire Ropes – Structural	High-strength metal wire ropes that support the span during lifting. These ropes are specific to operation of the movable span.	Each
814	Traffic Warning Gates – Structural	All structural components, support elements, and connections of the traffic warning gate.	Each
815	Hopkins Frame	Structural support for a Hopkins drive, found on certain trunnion bascule bridges. The frame is mounted vertically and pinned to the pier with clevises.	Each
816	Traffic Signals – Structural	Support system and connections with which the traffic signals are supported.	Each
817	Navigational Lights – Structural	Support system and connections with which the navigational light system is supported.	Each

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Element Number	Element Name	Description	Unit
818	Substructure Protection	Wood, steel, or concrete fender/dolphin systems and/or pier protection systems in or around the bridge elements.	LF
819	Counterweight Chamber – Structural	Structural support of the counterweight chamber.	Each
820	Machinery/Mechanical Equipment Room – Structural	Structural support of the machinery/mechanical equipment room.	Each
821	Electrical Equipment Room – Structural	Structural support of the electrical equipment room.	Each
822	Stairwell – Structural	Structural support of stairwells.	Each
823	Operator's House – Structural	The building providing climate control for the Operator and movable bridge operation controls.	Each
824	Lift-Span Tower	Structural towers supporting vertical lift movable bridges; measured by vertical feet of tower regardless of number of columns.	LF
825	Bumper Blocks	Blocks and associated hardware that provide a stop for the moveable portion of a bridge.	Each

3.2.2—Movable Bridge Mechanical and Operational Elements

Movable bridge mechanical and operational elements consist of those components which provide or arrest motion of the span and support the operation of those elements.

The following table shows common mechanical and operational elements for movable bridges.

Element Number	Element Name	Description	Unit
830	Open Gearing	All gears that are not enclosed in an oil-tight, dust-tight housing. Includes the rack or rack pinion. (Each gear and pinion set count as one unit.)	Each
831	Speed Reducers	Gear sets that are mounted with shafts and bearings in dust-proof, oil-tight housing.	Each
832	Shafts	Shafts that serve to transmit torque from one part to another.	Each
833	Shaft Bearings	Members and elements that support the shaft.	Each
834	Shaft Couplings	Rigid or flexible connection that joins the shafts together.	Each
835	Brakes	Members including limit switches used to stop the span and hold the span in the open/closed positions.	Each
836	Emergency Drive and Backup Power Systems – Mechanical	Members that function as a backup drive and power system in case of failure of the main drive and/or power system.	Each

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Element Number	Element Name	Description	Unit
837	Hydraulic Power Units	Pump, electric motor, valves, filters, fluid, reservoirs, and accessories that make up the Hydraulic Power Unit. Includes all limit switches that assist in controlling the units which are incidental to this item.	Each
838	Hydraulic Piping System	Pipe, tubing, and flexible hose, including fittings, manifolds, and piping supports which conduct fluids for a fluid power system.	Each
839	Hydraulic Cylinders/ Motors/Rotary Actuators	Components which convert fluid pressure into mechanical force and motion. Includes all limit switches that assist in controlling this element, span cylinder anchorages, and pin-connected weldments mounted to the pivot gear.	Each
840	Lock Machinery	All machinery used to drive the locks—including span locks, center locks, toe locks, heel stops, and tail locks—on the structure. Includes all limit switches that control the movement of the locks.	Each
841	Bearings—Mechanical	Those elements used to transmit live load from the moveable span to the substructure or to cushion the span while it is being closed, including live load shoes, wedges, strike plates, guides, rollers, linkages, pins, and buffer cylinders.	Each
842	Trunnion/Pivot	Large-diameter shaft, pin, or gudgeon about which structural elements rotate. Includes trunnion journals, trunnion bearings, and pivot bearings.	Each
843	Traffic Warning Gates – Mechanical	Components that alert vehicular traffic to impending bridge operation. This element includes all equipment required to operate the traffic/barrier/resistance gates, including all limit switches that control the operation of the traffic gate.	Each
844	Operator's House – Operational	Considers the operations of the various systems in the Operator's house (smoke and fire systems, plumbing system, controls systems, and HVAC system) that are separate from bridge operations.	Each
845	Machinery Room – Operational	Physical location where movable bridge electrical and mechanical operation elements are located that are accessible to personnel. Inspection includes operational and safety considerations.	Each
846	Sheaves	Large-diameter annular-grooved drums over which the cable ropes connecting the span and counterweight pass.	Each
847	Balance Chain	Heavy chain used to counteract the weight of ropes as they pass from one side of a sheave to the other.	Each
848	Balance Wheel and Track	Metal wheel and track system that provides stability from tipping for unbalanced loads, either due to dead loads or wind effects on center-bearing swing spans.	Each
849	Sump Pumps	Equipment that removes water that infiltrates into the counterweight pit.	Each
850	Wire Ropes – Mechanical	High-strength metal wire ropes that support the span during lifting. These ropes are specific to operation of the movable span.	Each

3.2.3—Movable Bridge Electrical Elements

Movable bridge electrical elements consist of the electrical components which provide or arrest motion of the span, support operation, and traffic control.

The table below shows common electrical elements for movable bridges.

Element Number	Element Name	Description	Unit
860	Transformers and Thyristors	Members that step down the voltage of the incoming power to a level compatible with the bridge equipment.	Each
861	Conduit and Junction Box	Members which enclose, support, and protect the power and control wiring.	Entire Bridge
862	Programmable Logic Controllers	General-purpose industrial microprocessor-based control systems.	Each
863	Control Console	Console which controls the operation of the moveable bridge. This element includes interlocks, span limit switches, span position indicator devices, pilot devices, metering, and associated terminations and wiring.	Each
864	Traffic Signals – Electrical	Components that signal vehicular traffic when to stop and start including lights, gongs, air horns, and sirens.	Each
865	Traffic Warning Gates – Electrical	Components that alert vehicular traffic to impending bridge operation. This element includes all equipment required to operate the traffic/barrier/resistance gates, including all limit switches that control the operation of the traffic gate.	Each
866	Navigational Lights – Electrical	Lights for navigation mounted on the bridge or fender system. This is not limited to lights on movable bridges. This element includes clearance gauge lights, power system, and backup power system.	Each
867	Span Drive Motors	Components that convert electrical energy into mechanical energy specifically for the span drive motors. Includes all limit switches that assist in controlling this element.	Each
868	Electric Motors/ Auxiliary Motors	Components which convert electrical energy into mechanical energy. Includes all limit switches that assist in controlling this element.	Each
869	Lock Motors	Components which are used to drive the locks—including span locks, center locks, toe locks, heel stops, and tail locks—on the structure.	Each
870	Emergency Drive and Backup Power Systems – Electrical	Components that convert motive power (mechanical energy) into electrical power for use in external circuits. Includes all components of the generator including ATS, batteries, charger, fuel tank, sensors, exhaust/intake louvers, and other generator accessories.	Each
871	Machinery/Motor Brakes	Components that inhibit motion by absorbing energy from a moving system.	Each
872	Operator's House/ Generator House – Electrical Systems	Electrical systems in the Operator's house, including electrical controls, electrical cabinets such as MCC, control cabinets, lighting and heating systems, etc.	Each

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Element Number	Element Name	Description	Unit
873	Submarine/Aerial Cable – Electrical	Cable that is used to carry power and control signals from one pier to the other pier on a bridge. Includes cable reels and droop cables.	Each
874	Conductors	Conductors (wiring) used to carry power and control signals throughout the bridge.	Entire Bridge
875	Lightning Protection System	Components used to protect the electrical system from storm-related electrical surcharges including conductors, rods, and necessary anchorages.	Entire Bridge
876	Motor Controllers	Components used to control the operational speeds of motors, including tachometers, variable speed drives, and associated switches.	Each

3.3—MOVABLE BRIDGE DEFECTS

In the MBEI, four-digit numbers are used for defects. Number series 2400 is reserved for movable bridge defects. In this Manual, number groups 2400-2420, 2421-2450, and 2451-2499 are reserved for structural defects, mechanical defects, and electrical defects, respectively.

3.3.1—Defect Description for Structural Elements

Defects for structural elements are described in the MBEI, which include descriptions for concrete, prestressed concrete, steel, masonry, timber, and other materials. These defect descriptions are not reproduced here to avoid conflicting descriptions as the manuals are updated. The structural defect specific to movable bridges is shown below, namely the condition of the Operator's house.

Defect	Condition State			
	1	2	3	4
	GOOD	FAIR	POOR	SEVERE
Leakage (2401)	House is weatherproof with no leaks.	House weather stripping and seals have begun deteriorating, but no leaks are apparent.	Light water intrusion or evidence of recent light water intrusion is observed, but does not immediately risk damaging the structure or the mechanical or electrical equipment.	Water intrusion or evidence of recent water intrusion is significant and risks damaging the structure or the mechanical or electrical equipment.

3.3.2—Defect Descriptions for Mechanical Elements

The following defect descriptions are provided for mechanical elements.

Defect	Condition State 1 GOOD	Condition State 2 FAIR	Condition State 3 POOR	Condition State 4 SEVERE
Corrosion (2421)	None.	Light corrosion present. None of the major mechanical elements require remedial action.	Moderate corrosion present. Major mechanical elements may require prompt replacement.	Heavy corrosion present. Immediate replacement of major mechanical elements may be required.
Connections (2422)	Fasteners and keys are intact and tight.	Some fasteners related to major mechanical elements may be loose. No missing fasteners. Minor cracking in the paint at the hub and shaft interface.	Fasteners or keys are loose. Some fasteners or keys related to major mechanical elements may be missing. Prompt repair of major mechanical elements may be required.	Many Fasteners or keys are loose. Fasteners or keys related to major mechanical elements are missing. Immediate repair of major mechanical elements may be required.
Leakage (2423)	None.	Equipment housing, pipes, and/or fittings may have an isolated location of minimal leakage.	Equipment housing, pipes, and/or fittings have an active leak but do not impact the operation of the unit.	Equipment housing, pipes, and/or fittings have indications of leakage such that the equipment needs to be taken out of service.
Damage (2424)	None.	Minor damage noted such as pitting or scoring. Hoses may exhibit light abrasion. None of the major mechanical elements require remedial action.	Moderate damage such as pitting and scoring with plastic flow. Hoses may exhibit moderate abrasion. Major mechanical elements may require prompt replacement or adjustment.	Heavy damage present. Components may be cracked or broken. Overstress of components occurring. Hoses may exhibit heavy abrasion. Major mechanical elements may require immediate replacement.

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Defect	Condition State 1 GOOD	Condition State 2 FAIR	Condition State 3 POOR	Condition State 4 SEVERE
Operation (2425)	Operates smoothly. Major mechanical elements are properly adjusted.	Operates with minor flaws, such as light vibration or noise. Equipment may be slightly out of adjustment. Filters or breathers may require replacement. Manual or hydraulic levers may be slightly difficult to move. None of the major mechanical elements require remedial action.	Operates with significant flaws, including vibration, noise, or undesirable heating. Auxiliary operating systems may be nonfunctional. Equipment out of adjustment. Filters or breathers may be missing. Manual or hydraulic levers may be very difficult to move. Major mechanical elements may require prompt replacement or adjustment.	Does not operate or operates in an erratic or uncontrolled manner. Various pieces of equipment may be significantly out of adjustment or nonfunctional. Required pieces of equipment may be missing. Major mechanical elements may require immediate replacement.
Lubrication (2426)	Lubricants are fresh, clean, and well distributed. Oil levels are appropriate.	Lubricants exhibit minor contamination. Oil levels slightly low. Minor lubricant leaks may exist. Application of grease is excessive or barely adequate on major mechanical elements.	Lubricants exhibit moderate contamination. Oil levels low. Moderate lubricant leaks may exist. Application of grease is spotty and inadequate in places on major mechanical elements.	Lubricants exhibit heavy contamination. Oil levels extremely low. Heavy lubricant leaks may exist. Application of grease is inadequate in many places on major mechanical elements.
Wear (Mechanical) (2427)	None.	Light wear present. Clearances related to major mechanical elements are within operational limits. No remedial action required.	Moderate wear present. Clearances related to major mechanical elements are near operational limits. Prompt replacement of components may be required.	Heavy wear present. Clearances related to major mechanical elements exceed operational limits. Immediate replacement of components may be required.

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Defect	**Condition State**			
	1	**2**	**3**	**4**
	GOOD	**FAIR**	**POOR**	**SEVERE**
Alignment (2428)	Components are aligned within manufacturer's recommended operational tolerances or code requirements. Components exhibit proper contact.	Certain components slightly outside of manufacturer's recommended operational tolerances or code requirements. No operational issues noted. None of the major mechanical elements require realignment.	Components outside of manufacturer's recommended operational tolerances or code requirements. Some shaft or coupling movement noted during operation. Components may exhibit improper contact. Major mechanical elements may require realignment.	Components well outside of manufacturer's recommended operational tolerances or code requirements. Significant shaft or coupling movement noted during operation. Unusual noises noted during operation. Overstress of components occurring. Components may exhibit extremely poor contact. Immediate replacement or realignment of major mechanical elements may be required.
Housekeeping (2429)	The machinery access areas are clean, sanitary, and free of debris and trip or fall hazards. Machinery guards are intact.	The machinery access areas are generally safe but may have minor debris or inconvenient access. There may be minor mechanical issues related to weather exposure.	The machinery access areas have safety issues. Machinery guards may be out of place. There may be significant issues related to weather exposure. Prompt repairs may be required.	The machinery access areas have significant safety issues such as unsanitary waste, excessive guano, debris, or missing machinery guards. Alternatively, there are unsafe trip or fall hazards or machinery is inadequately protected from weather. Immediate repair may be required.

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Defect	Condition State			
	1	2	3	4
	GOOD	FAIR	POOR	SEVERE
House Mechanical Defect (2430)	The heating, ventilation, and air conditioning (HVAC) system and plumbing are functioning properly with no significant deterioration observed.	Deterioration of the HVAC and plumbing systems is observed, but the systems are expected to continue operating properly.	The HVAC and/or plumbing systems are not functioning properly, and this condition is not currently interfering with the ability of the bridge staff to operate the bridge safely and comfortably.	The HVAC and/or plumbing systems are not functioning properly, and this condition is interfering with the ability of the bridge staff to operate the bridge safely and comfortably.

3.3.3—Defect Descriptions for Electrical Elements

The following defect descriptions are provided for electrical elements.

Defect	Condition State			
	1	2	3	4
	GOOD	FAIR	POOR	SEVERE
Corrosion (2451)	No corrosion	Minor corrosion.	Moderate corrosion with minor section loss.	Heavy corrosion with section loss and a perceived danger of component failure.
Damage (2452)	Electrical components are not damaged.	Electrical components have minor damage that does not affect the intended operation or mounting security of the equipment.	Electrical components have moderate damage that affects the intended operation or mounting security of the equipment but does not appear to pose an immediate safety concern or risk of system failure.	Electrical components have significant damage that affects the intended operation or mounting security of the equipment such that operating the equipment poses a risk of injury to personnel or further damage to the equipment or structure.

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Defect	Condition State			
	1	2	3	4
	GOOD	FAIR	POOR	SEVERE
Operation (2453)	Operating normally and meets all standards.	Functions adequately with minor issues not requiring immediate repair or adjustment.	Functioning; however, operation is affected, and conditions have degraded to the point where maintenance is needed to maintain reliability.	Not functioning or functioning erratically in a way that could potentially create a safety hazard or risk. The element should be repaired or replaced immediately.
Wear (Electrical) (2454)	Electrical components are not worn, motor current is below nameplate values, and electrical conductor insulation and motor insulation resistance values exceed the minimum values recommended by NETA.	Electrical components exhibit minimal wear that does not affect the intended operation of the equipment. The electrical conductor and motor insulation resistance values measure at the minimum values recommended by NETA. Motor current is at or near nameplate values.	Electrical components exhibit moderate wear that appears to be beginning to affect the intended operation of the equipment without creating an immediately dangerous condition to the public, bridge personnel, or the bridge. The electrical conductor and motor insulation resistance values measure 50 percent below the minimum values recommended by NETA. Motor current is above nameplate values.	Electrical components exhibit excessive wear that seriously affects the intended operation of the equipment. The electrical conductor and motor insulation resistance values measure less than 50 percent below the minimum values recommended by NETA. Motor current is significantly above nameplate values.

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Defect	Condition State			
	1	2	3	4
	GOOD	FAIR	POOR	SEVERE
Accessibility and Labeling (2455)	All covers to electrical enclosures are properly secured in place. Arc fault labeling and working clearances conform to NFPA-70 (NEC) requirements. Electrical equipment and wiring identification labels are in place and legible.	All covers to electrical enclosures are in place, though some fasteners are missing. Not all arc fault labeling is in place. Some working clearances do not conform to NEC requirements. Some equipment or wiring identification labeling is either missing or is not legible.	All covers to electrical enclosures are in place, but many fasteners are missing. Few arc fault labels are in place. Many working clearances do not conform to NEC requirements. Many equipment or wiring identification labels are either missing or are not legible.	One or more covers to electrical enclosures are not in place. There are no arc fault labels on any enclosures. Most working clearances do not conform to NEC requirements. Most equipment or wiring identification labels are either missing or are not legible.
Support and Electrical Terminations (2456)	All electrical equipment is properly supported, and all terminations are properly made, are clean, and appear tight.	Some electrical equipment supporting fasteners are loose or missing, but there is no danger of the equipment mounting(s) failing. Some electrical terminations are not clean or have mild corrosion.	Several electrical equipment mounting fasteners are missing, and equipment mounting could potentially fail. Some electrical terminations are improperly made, are loose, are dirty, or appear to be overheating.	Electrical equipment supports have failed and electrical equipment is hanging from conduits, wires, or other nonstructural elements not designed to support the equipment. Many electrical terminations are improperly made, are loose, are very dirty, have severe corrosion, or appear to be severely overheating.

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Defect	Condition State			
	1	2	3	4
	GOOD	FAIR	POOR	SEVERE
Functional Obsolescence (2457)	The bridge electrical control equipment currently meets all code requirements, is supported by the manufacturer, and all replacement parts are readily available or on site. The technology of the electrical equipment is adequate for the installed purpose(s).	The bridge electrical control equipment meets all code requirements, but there are indications that some of the bridge electrical control equipment will soon be phased out by the manufacturer, or the availability of parts may soon be a problem and there is not a supply on site. The technology of the electrical equipment is marginally adequate for the installed purpose(s) and better technology is available. (Special cases, such as obsolete equipment that is fully functional and adequately supported with spares, can be considered as Fair at the discretion of the Owner.)	The bridge electrical control equipment does not meet all code requirements and/or there are indications that some of the bridge electrical control equipment has been phased out by the manufacturer and the availability of parts has become a problem. There is a lack of supply on site. The technology of the electrical equipment is dated and no longer considered appropriate for the application.	The bridge electrical control equipment does not meet all code requirements and/or most of the bridge electrical control equipment is not supported by the manufacturer and no parts are available. The technology of the electrical equipment is considered antiquated and could even be dangerous to the public, bridge personnel, or equipment in the installed configuration.
House Electrical Defect (2458)	The house electrical system, including receptacles and lighting, are functioning properly with no significant deterioration observed.	Deterioration of the house electrical system is observed, but the systems are expected to continue to operate properly.	The HVAC and/or plumbing systems are not functioning properly, and this condition is not currently interfering with the ability for the bridge staff to operate the bridge safely and comfortably.	The HVAC and/or plumbing systems are not functioning properly, and this condition is interfering with the ability for the bridge staff to operate the bridge safely and comfortably.

Appendix A3

MOVABLE BRIDGE MECHANICAL AND ELECTRICAL ELEMENT INSPECTION REPORT EXAMPLES

The element inspection report for a movable bridge can have many structural, mechanical, and electrical elements. Appendix B of the AASHTO *Manual for Bridge Element Inspection* (MBEI) provides examples for fixed bridge structural element inspections. In this Appendix, example element condition states and defects are shown for the structural elements specific to movable bridges, and shown for the mechanical and electrical elements of a sample movable bridge. Structural defects covered in the MBEI are indicated with *.

The following examples show element inspection reports showing movable bridge-specific structural, mechanical, and electrical element quantities, condition states, and defects. Elements are shown in grey shaded rows, and defects for the elements are shown directly below the element in non-shaded (white) rows. There can be multiple defects listed for each element condition state. Element inspections follow the multipath distress language to fully incorporate all possible defects within the overall condition assessment of the element. This is especially relevant to movable bridge elements as the quantity is often "each" for the element. Examples of multipath distress are shown in the following element quantity and condition state table for Element 807, Primary Movable Support Member – Structural, where the element has both corrosion and mechanical alignment defects at the same location; and Element 835, Brakes, where the element has both alignment and mechanical wear at the same location.

A3.1—Example 1: Movable bridge with a double-leaf trunnion bascule

The example bridge is a double-leaf trunnion bascule bridge as shown in Figure A3.1-1. The drive machinery is mounted on a Hopkins Frame (a vertical frame pinned to the bascule pier floor and linked to the center of rotation of the leaf). The movable spans feature forward live load shoes and a pair of span locks.

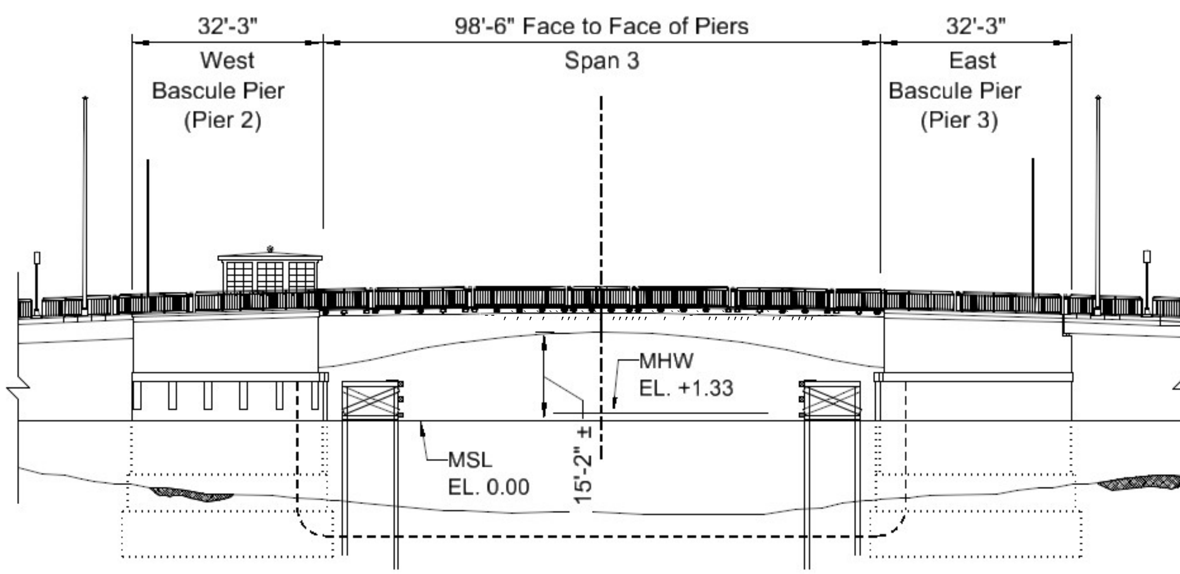

Figure A3.1-1—Example Draw Span Elevation View

Element Number	Element Description	Unit of Measure	Total Quantity	Condition State 1	Condition State 2	Condition State 3	Condition State 4
Structural Elements							
802	Span Locks – Structural	EA	1	1	0	0	0
803	Bearings – Structural	EA	8	6	2	0	0
1000*	Corrosion				2		
804	Counterweight Support – Structural	EA	4	0	2	2	0
1000*	Corrosion				2	2	
805	Counterweight	EA	2	0	2	0	0
1000*	Corrosion				2		
806	Access System – Structural	EB	1	0	0	1	0
1000*	Corrosion					1	
1020*	Connections					1	
807	Primary Movable Support Member – Structural	LF	28	7	3	18	0
1000*	Corrosion					16	
1020*	Connections					2	
7000	Damage				3		
812	Submarine/Aerial Cable – Structural	EA	3	3	0	0	0
815	Hopkins Frame	EA	2		2	0	0
1000	Corrosion				2		
818	Substructure Protection	LF	341		171		170
1140*	Decay/Section Loss				171		170
823	Operator's House – Structural	EA	1	0	1	0	0
2401	Leakage	EA			1		
Mechanical Elements							
831	Speed Reducers	EA	2		2		
2426	Lubrication				2		
832	Shafts	EA	12	0	12	0	0
2421	Corrosion				10		
2427	Wear (Mechanical)				2		
833	Shaft Bearings	EA	18	12	4	2	0
2421	Corrosion				4		
2425	Operation					2	
834	Shaft Couplings	EA	6	4	0	2	0
2421	Corrosion					2	

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Element Number	Element Description	Unit of Measure	Total Quantity	Condition State 1	Condition State 2	Condition State 3	Condition State 4
835	Brakes	EA	6	2		4	
2428	Alignment					1	
2427	Wear (Mechanical)					4	
836	Emergency Drive/ Backup Power Sys-tem – Mechanical	EA	3	3			
840	Lock Machinery	EA	1	0	0	1	0
2427	Wear (Mechanical)					1	
841	Bearings – Mechanical	EA	8	2	2	4	
2425	Operation					4	
2427	Wear (Mechanical)				2		
860	Transformers and Thyristors	EA	3	3	0	0	0
861	Conduit and Junction Boxes	EB	1	0	0	1	0
2454	Wear (Electrical)					1	
863	Control Console	EA	1	0	1	0	0
2453	Operation		1		1		
866	Navigation Lights	EA	1				1
2453	Operation						1
867	Span Drive Motors	EA	2		2		
2451	Corrosion				2		
2453	Operation				2		
868	Electric Motors/ Auxiliary Motors	EA	6	0	5	1	0
2451	Corrosion				3		
2453	Operation				2	1	
870	Emergency Drive/ Backup Power Sys-tem – Electrical	EA	1	0	1	0	0
2453	Operation				1		
873	Submarine/Aerial Cable – Electrical	EA	3	3			
874	Conductors	EB	1	1			

A3.2—Example 2: Movable bridge with a vertical lift span

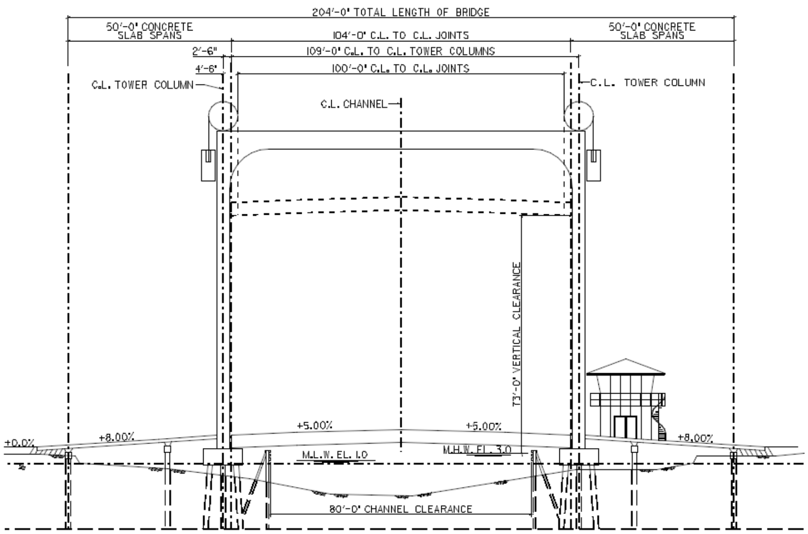

Figure A3.2-1—Example Vertical Lift Span Elevation View

The bridge is a 204-ft-long crossing consisting of a central, steel, vertical lift span that is 104 ft long and is flanked by two 25-ft-long, cast-in-place concrete approach spans with flared geometry on each side. The structure carries two lanes of traffic. The operating machinery, which drives the four sheaves on each corner of the lift tower, is located on a platform at the top of the central span. The Operator's house is located on the northeast corner of the lift span. When the bridge is open, approximately 73 ft of vertical clearance is proved above the high-water line.

Element Number	Element Description	Unit of Measure	Total Quantity	Condition State 1	Condition State 2	Condition State 3	Condition State 4
Structural Elements							
801	Machinery Base Support	EA	5	5	0	0	0
802	Span Locks – Structural	EA	4	4	0	0	0
803	Bearings – Structural	EA	4	4	0	0	0
805	Counterweight	EA	2	2	0	0	0
806	Access System – Structural	EB	1	1	0	0	0
812	Submarine/Aerial Cable – Structural	EA	3	3	0	0	0
813	Wire Ropes	EA	16	16	0	0	0
814	Traffic Warning Gates – Structural	EA	4	4	0	0	0
816	Traffic Signals – Structural	EA	4	4	0	0	0
817	Navigational Lights – Structural	EA	10	10	0	0	0

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Element Number	Element Description	Unit of Measure	Total Quantity	Condition State 1	Condition State 2	Condition State 3	Condition State 4
818	Substructure Protection	LF	362	362	0	0	0
820	Machinery/Mechanical Equipment Room – Structural	EA	1	1	0	0	0
821	Electrical Equipment Room – Structural	EA	1	1	0	0	0
822	Stairwell – Structural	EA	1	1	0	0	0
823	Operator's House – Structural	EA	1	1	0	0	0
824	Lift-Span Tower	LF	195	195	0	0	0
Mechanical Elements							
830	Open Gearing	EA	4	4	0	0	0
831	Speed Reducers	EA	5	5	0	0	0
832	Shafts	EA	10	10	0	0	0
833	Shaft Bearings	EA	10	10	0	0	0
834	Shaft Couplings	EA	10	10	0	0	0
835	Brakes	EA	2	2	0	0	0
836	Emergency Drive and Backup Power System – Mechanical	EA	1	1	0	0	0
840	Lock Machinery	EA	4	4	0	0	0
841	Bearings – Mechanical	EA	4	4	0	0	0
843	Traffic Warning Gates – Mechanical	EA	4	4	0	0	0
844	Operator's House – Operational	EA	1	1	0	0	0
845	Machinery Room – Operational	EA	1	1	0	0	0
846	Sheaves	EA	4	4	0	0	0
Electrical Elements							
860	Transformers and Thyristors	EA	1	1	0	0	0
861	Conduit and Junction Boxes	EB	8	8	0	0	0
863	Control Console	EA	1	1	0	0	0
864	Traffic Signals – Electrical	EA	4	4	0	0	0
866	Navigation Lights – Electrical	EA	10	10	0	0	0

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Element Number	Element Description	Unit of Measure	Total Quantity	Condition State 1	Condition State 2	Condition State 3	Condition State 4
867	Span Drive Motors	EA	2	2	0	0	0
868	Electric Motors/ Auxiliary Motors	EA	1	0	1	0	0
2453	Operation				1		
870	Emergency Drive and Backup Power Systems – Electrical	EA	1	0	0	1	0
2453	Operation					1	
871	Machinery/Motor Brakes	EA					1
2452	Damage						1
872	Operator's House/ Generator House – Electrical Systems	EA	1	1	0	0	0
873	Submarine/Aerial Cable – Electrical	EA	3	3	0	0	0
874	Conductors	EB	1	1	0	0	0

A3.3—Example 3: Movable bridge with a swing span

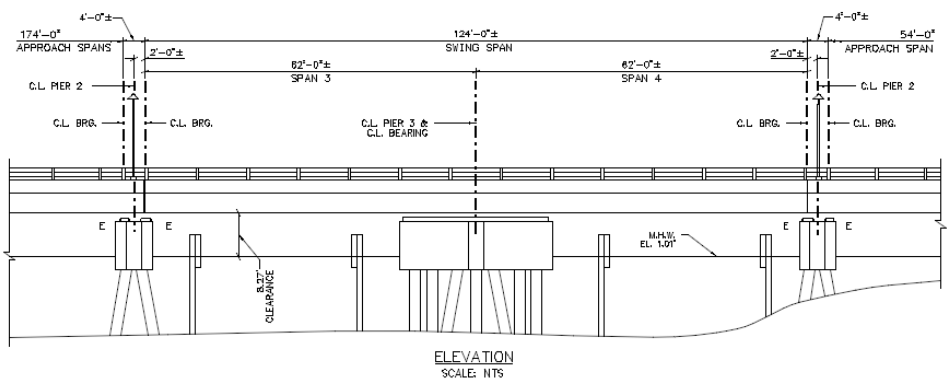

Figure A3.3-1—Example Swing Span Elevation View

The bridge consists of five spans, including a 124-ft deck girder swing span over a navigable waterway. The bridge has a clear roadway width of 23 ft-0 in. and carries two lanes of traffic. The swing span is operated by opposing hydraulic cylinders that push/pull a pivot girder in tandem abound a center pivot bearing. The ends of the swing span are supported by spherical end shoes and bearings when in the closed position. End lift cylinders position the ends of the span to engage the spherical shoes.

Element Number	Element Description	Unit of Measure	Total Quantity	Condition State 1	Condition State 2	Condition State 3	Condition State 4
801	Machinery Base Support	EA	1	0	0	1	0
1000*	Corrosion					1	

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Element Number	Element Description	Unit of Measure	Total Quantity	Condition State 1	Condition State 2	Condition State 3	Condition State 4
802	Span Locks – Structural	EA	6	3	3	0	0
7000*	Damage				3		
803	Bearings – Structural	EA	6	0	0	6	0
1020*	Connections					6	
812	Submarine/Aerial Cable – Structural	EA	2	1	1	0	0
1000*	Corrosion				1		
814	Traffic Warning Gates – Structural	EA	2	2	0	0	0
816	Traffic Signals – Structural	EA	2	2	0	0	0
817	Navigational Lights – Structural	EA	14	14	0	0	0
818	Substructure Protection	LF	536	532	4	0	0
7000*	Damage				4		
820	Machinery/Mechanical Equipment Room – Structural	EA	1	1	0	0	0
821	Electrical Equipment Room – Structural	EA	1	1	0	0	0
822	Stairwell – Structural	EA	1	1	0	0	0
823	Operator's House – Structural	EA	1	1	0	0	0
Mechanical Elements							
837	Hydraulic Power Units	EA	1	0	1	0	0
2423	Leakage				1		
838	Hydraulic Piping System	EA	1	0	1	0	0
2423	Leakage				1		
839	Hydraulic Cylinders/Motor/Rotary Actuators	EA	2	2	0	0	0
840	Lock Machinery	EA	6	3	3	0	0
2424	Damage				3		
841	Bearings – Mechanical	EA	6	5	0	1	0
2425	Operation					1	

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Element Number	Element Description	Unit of Measure	Total Quantity	Condition State 1	Condition State 2	Condition State 3	Condition State 4
843	Traffic Warning Gates – Mechanical	EA	2	0	2	0	0
2424	Damage				2		
2427	Wear (Mechanical)				2		
844	Operator's House – Operational	EA	1	0	0	0	0
845	Machinery Room – Operational	EA	1	0	0	0	0
848	Balance Wheel and Track	EA	8	4	0	4	0
2428	Alignment					4	
Electrical Elements							
861	Conduits and Junction Boxes	EB	1	0	1	0	0
2451	Corrosion				1		
862	Programmable Logic Controllers	EA	1	0	1	0	0
2453	Operation				1		
863	Control Console	EA	1	0	1	0	0
2453	Operation				1		
864	Traffic Signals – Electrical	EA	2	2	0	0	0
866	Navigational Lights – Electrical	EA	14	14	0	0	0
868	Electric Motors/ Auxiliary Motors	EA	1	1	0	0	0
873	Submarine/Aerial Cable – Electrical	EA	2	1	1	0	0
2456	Support and Electrical Terminations				1		
874	Conductors	EB	1	0	1	0	0
2452	Damage				1		

PART 4 – EVALUATION

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CHAPTER 4.1—ASSESSMENT OF INSPECTION, TESTING, AND EVALUATION RESULTS

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 data points 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

C4.1.2

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 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 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.

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 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

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.

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 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.

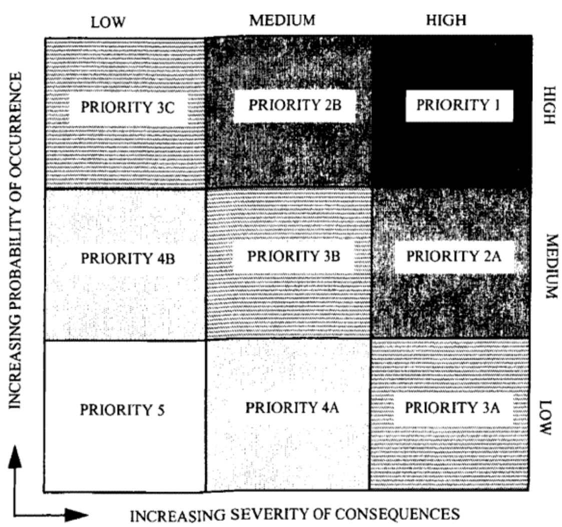

Table 4.1.4-1 – Priority ranking matrix

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,

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.

3, 4, and 5 follow. The relative priority of the A, B, and C items in each 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).

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.

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.

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.

CHAPTER 4.2—OPERATING CRITERIA FOR IN-SERVICE MOVABLE BRIDGES

4.2.1—GENERAL

The AASHTO *LRFD Movable Highway Bridge Design Specifications* (Reference 6) 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 the engineer 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/replacement of existing movable bridges and their components in a manner consistent with public safety and good engineering practice.

Reference 6 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.

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 2) 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.

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.

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."

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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 of motion. 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.

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 historical 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.

Operators 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 2) 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 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 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.

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.

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 6) and the discussion in Chapter 4.2. This chapter provides additional guidance for adapting the Reference 6 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 8. 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 6.

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 6. 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 historical code data. The strict application of Reference 6 design criteria is not uniformly appropriate to such analysis.

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 for 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.

Engineering judgment is required 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-bridge 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 8 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 necessary rating procedures should be based on the requirements of References 6 and 8.

C4.3.3

Reference 8 contains recommended allowable stresses for aged structural steel members. The relationship between structure age and yield strength is presented in Reference 8 and should be maintained for use in related formulas contained in Reference 6.

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 6 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 6 as discussed in Chapter 4.2. The design criteria selected from Reference 6 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 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

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 of 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.

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 6) 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 6. 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 6 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 6 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 8.

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 6. 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 85, which was published in 1927. This information is based upon properties of wire rope manufactured in the early 1900s 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 1920s 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 6, of the minimum specified ultimate strength, given in Table 4.3.5.1.1-1, 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 6.

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 Table 4.3.5.1.1-1.

For the types of rope in Table 4.3.5.1.1-1, 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

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 6. 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 6 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.

AASHTO's original movable bridge design specification was published in 1938 (Reference 7e), with subsequent versions published in 1953, 1970, 1978, 1988, and 2007 (Reference 6). *Movable Bridges, Volume II—Machinery* by Hovey (Reference 85) 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* may be compared with current Reference 6 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 7e) 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.

Table 4.3.5.3-1 – Allowable stresses in machinery parts in U.S. customary units; all stresses are psi

Material	1970 THRU 1988 AASHTO References 7g and 7h	1953 AASHTO Reference 7f	1938 AASHTO Reference 7e	1927 Hovey Reference 85
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 4.3.5.3-1 – Allowable stresses in machinery parts in SI units; all stresses are MPa

Material	1970 THRU 1988 AASHTO Reference 7n	1953 AASHTO Reference 7f	1938 AASHTO Reference 7e	1927 Hovey Reference 85
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 Standard Specifications for Movable Highway Bridges published in 1970, 1978, and 1988 have identical allowable stresses for these items

Table 4.3.5.3-1 – Allowable stresses in machinery parts (continued)

1988 AASHTO
Reference 7h

-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 7f)

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

(A) Spur gears and Bevel gears

For full-depth involute teeth

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

or

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

For stub involute teeth

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

or

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

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 7e

-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:

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

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

	Values of S_a	
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:

$$W_t = S\,p\,f\,y_t\,\frac{d}{D}$$

In which

W_t = 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_t 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 85

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:

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

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

	Values of S_a	
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:

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

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_s 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 $^2/_3$

4.3.5.4—Hydraulic Analysis

Hydraulic systems should be analyzed by the methods contained in Reference 6. Systems that exhibit working pressures over 3,000 psi (20 600 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 (20 600 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 6, LRFD Movable Highway Bridge Design Specifications.

Older hydraulic systems that are designed with pressures which do not conform to Reference 6 should be considered as likely to experience early failure unless the maximum working pressure rating of all components (as defined in Reference 6) 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.

C4.3.5.4

Flexible hoses and hose fittings for high pressure lines should be rated for 5,000 psi (34 333 kPa) as required by Reference 6, or should be noted as not conforming to current practice in the inspection report.

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, and 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 have 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 occurrences, 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 (References 63, 121, 145)
- Collision: Truck, train, or navigational vessel (References 7, 121, 136)
- Overload: Open or closed positions (Reference 122)
- Seismic: Open or closed positions (References 7b, 7c, 123, 140)
- Fracture: Due to fatigue or brittle fracture (References 34, 36, 58, 59, 62, 64, 124)
- Operational failure
- Wave/storm surge forces (References 5, 119)

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 HEC-20 (References 63 and 145). These documents should be used by the engineer/evaluator to assess the movable bridge's vulnerability 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

C4.4.2.2

The channel layout, approach geometry, water depths, winds, and currents should be 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.
- 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 Section 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 7d).

3.14 of the AASHTO *LRFD Bridge Design Specifications* (Reference 7d). 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).

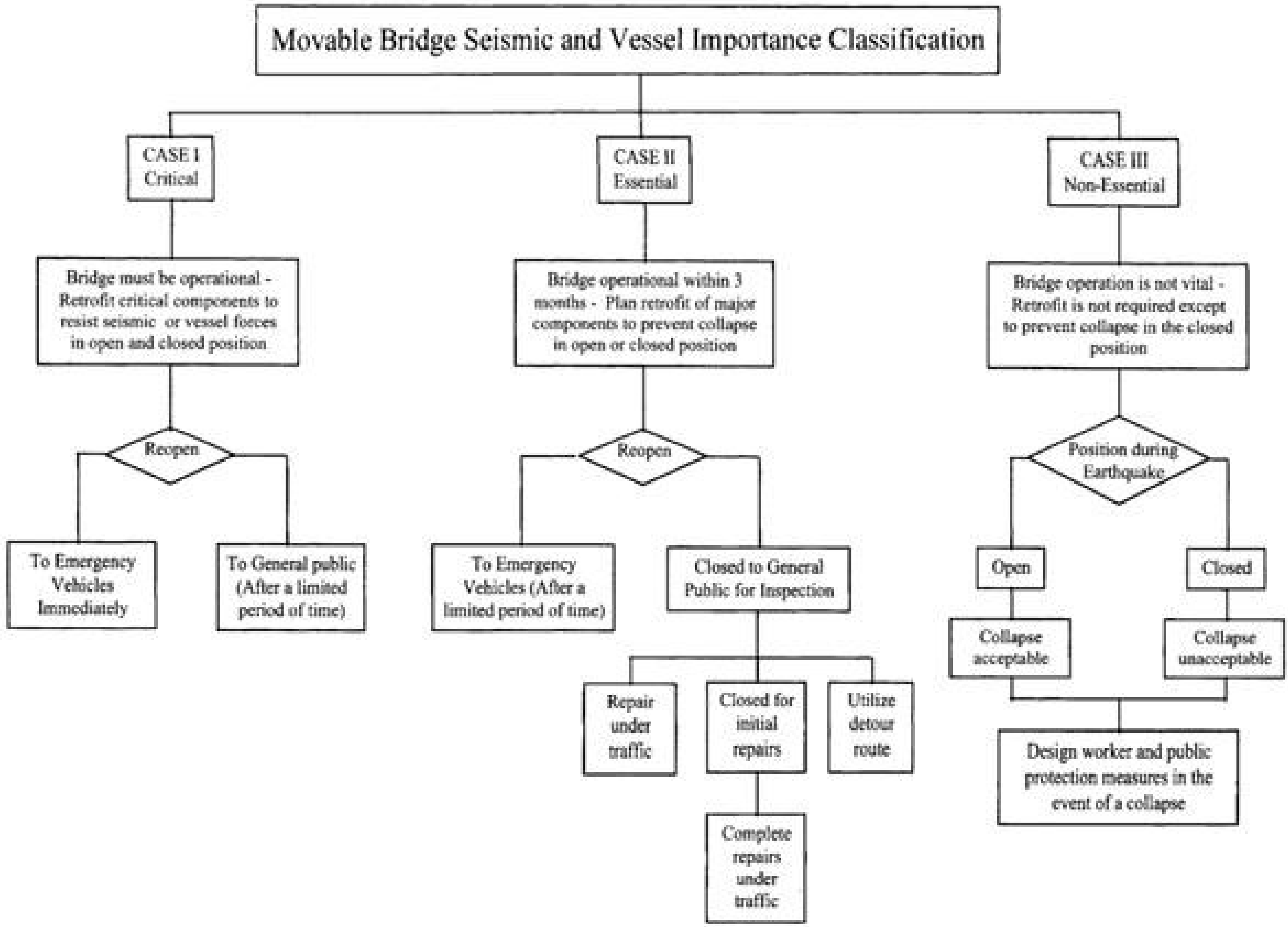

Figure 4.4.2.2-1 – Movable bridge seismic and vessel impact categories

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 122).

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 122). Some of these conditions may include: posting of adjacent bridges near the movable bridge under consideration; or 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. Many existing movable bridges were constructed prior

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 critical or essential 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 6) 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 6 and 7 and as described below. Reference 6 provides 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 12).

Critical bridge components should be evaluated by the capacity/demand ratio method for each potential mode of failure during a seismic event. 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 6a and 7b).

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 4.5.2.2-1):

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 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 risk to mariners, vehicles, and pedestrians. Providing seismic restraints during 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.

should be 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 (References 8, 64).

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

- **Redundancy:** ability to redistribute loads (Reference 8, 64)
- **Fatigue resistance:** type of details and fatigue category (References 7b, 34, 36, 58, 59)
- **Number of cycles:** ADTT and navigation openings (References 36, 58)
- **Material toughness:** Charpy V-Notch resistance of material (Reference 36)
- **Temperature:** bridge location and minimum service temperature (Reference 36)
- **Rate of applied load:** impact considerations at floor beams and upon closing (Reference 36)
- **Secondary stresses:** evaluate out-of-plane movements.
- **Main member type:** internal load paths within member configuration (Reference 62)
- **Bridge type:** movable span type and details (References 6, 62)
- **Skew angle:** tendency to creep (Reference 59)
- **Connections:** type and condition (Reference 34)
- **Corrosion:** condition and rating evaluation (Reference 8)

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 those described in Sections 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 the 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

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 mechanical damage to the span lock and structural damage to the span lock supporting members and might also overstress the main span drive components.

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 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 3) 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

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 bascule bridge. The figure shows how the vessel crabs (transits on angle) when transiting the bridge due to wind and current effects.

maneuverability.

- Impact of docks and wharves in the immediate vicinity of the bridge, and vessels moored to them on the ability of 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 C4.5.2-1 – Large ship transiting a bascule bridge

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

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

C4.5.3.1

Bridge Permit Laws: Most bridges built over navigable waters that exist today were permitted under the following 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 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.

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.

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.

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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 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.

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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

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.

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.
- 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.
- The FCC rules require a station radio log to be kept.

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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. All stations are required to monitor both channel 16 and the working channel 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 channel 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 exceeds 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

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 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 118.
- **RACONs and Radar Reflectors:** Aboard commercial vessels and large recreational and sailing vessels, 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.

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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 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 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.

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

4.5.7—DRAW BRIDGE OPERATIONS UNDER EMERGENCY SITUATIONS

33 CFR 117.15 and 33 CFR 117.31 require 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, the drawtender shall take all reasonable measures to have the draw opened, regardless of the operating schedule of the draw, for passage of the vessels listed above.

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.

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

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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 so, for example, the wind pressure at 40 knots (21 m/s) is approximately 44 percent of the pressure at 60 knots (31 m/s).

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.

CHAPTER 4.6—TRAFFIC CONTROL

4.6.1—GENERAL

Some traffic control measures are unique to existing movable highway bridges. The design of traffic control for new movable bridges is covered in Reference 6 and its references to the FHWA Manual on Uniform Traffic Control Devices (Reference 65). Reference 65 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 them are covered in Reference 6. 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.

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.

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Reference 65, 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.

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 6 and the MUTCD (Reference 65). 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 6 and 65. 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 6 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 9), 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 6), Section 1.4.4.4 Traffic Gates and Barriers for additional information.

4.6.4—EVALUATION

Reference 65 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 6 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 6 and 63.

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 6 and 65. 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 alternative.

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 6 and 65 (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 65) requirements.

Presence of Intersecting Streets or Driveways in Close Proximity to the Movable Span: The MUTCD (Reference 65) 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 65).

Bridge Sites With Compromised Approach Stopping Site Distance: The MUTCD (Reference 65) 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 65).

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.

C4.7.1

The *AASHTO LRFD Movable Highway Bridge Design Specifications* (Reference 6) specifies that wire diagrams, operator's instructions, 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

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.

- Notifications to authorities: contact telephone numbers
- Required documentation: sample forms
- Damage assessment procedure: contact telephone numbers
- Bridge closure authority: contact telephone numbers
- 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 required 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 for completing 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, 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, and procedures 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,

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 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.

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 6.

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

SAMPLE TABLE OF CONTENTS
BRIDGE OPERATIONS MANUAL
SWING SPAN BRIDGE

I. SEQUENCE OF OPERATION
- Normal Sequence of Operation..
- Emergency/Special Sequence of Operation.......................................
- Use of Safety Interlock Bypasses ....
- Operator Test Procedures...
- Detailed Bypass Instructions for all Anticipated Possible Operational Fault Scenarios..

II. EMERGENCY AND REPAIR CONTACTS...................................
- Vessel or Vehicle Accident Procedures and Contact Data...............
- Other Emergency Procedures:
  - Operational Failure...
  - Weather Emergency...
- Equipment Manufacturers Addresses and Telephone Numbers...
- Agency Contacts (USCG, USACOE, Fire, Police, Ambulance etc.)..
- Maintainers and Internal or Contracted Emergency Response Teams...

III. MAINTENANCE TO BE PERFORMED BY OPERATORS........
- Lubrication Schedule for Operator Maintenance (if any)...............
- Inspection of Fluid Levels and Pressures...
- Trouble Shooting Procedures to be performed by Operators.........

IV. DETAILED SCHEMATICS AND MAJOR COMPONENT DATA...
- General Electrical Schematics and Conduit Layout........................
- General Hydraulic Schematic..
- Layout of Operator's House Showing Location of all Major Equipment..
- Control Desk..
- Motor Control Consoles...
- Motor, Brakes and Limit Switches...
- Emergency Power (Generator and Automatic Switching)...............
- Traffic Control Schematics and Sequence of Operation..
- Navigation Control Schematics and Sequence of Operation...........

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

I. GENERAL MAINTENANCE INSTRUCTIONS
- Scope..
- Safety..

II. STRUCTURAL ITEMS..
- Structural Concrete..
- Structural Steel..
- Structural Timber..

III. MECHANICAL EQUIPMENT..
- Main Drive Assembly..
- Center Bearing..
- Center Wedge Assembly..
- End Lift Assembly..

IV. HYDRAULIC SYSTEM..
- Hydraulic System Controls..
- Hydraulic Power Units..
- Piping, Fittings, and Manifolds..

V. ELECTRIC MOTORS AND BRAKES..
- General Items..
- Dielectric Strength..
- Main Drive Assembly Electric Motor..
- Center Wedge Assembly Electric Motor..
- End Wedge Assembly Electric Motor..
- Main Drive Assembly Brakes..
- Motor Disk Brakes..

VI. ELECTRICAL CONTROL EQUIPMENT..
- Limit Switches..
- Electrical Cables..
- Switchboards, Panelboards, and Control Cabinets..
- Circuit Breakers..
- Motor Starters..
- Contact Tips..
- Fuses..
- Contactors..
- Relays..
- Mechanically Operated Devices (Switches)..
- Meters and Instruments..
- Solenoids..
- Resistors and Rheostats..
- Equipment Grounding..
- Control Console..

SAMPLE TABLE OF CONTENTS (CONT.)
BRIDGE MAINTENANCE MANUAL

VII. ELECTRICAL LIGHTING, SIGNALS, AND WARNING DEVICES.......
Traffic Gates..........
Traffic Signals..........
Street Lighting..........
Navigation Lights..........
Sirens, Horns and Bells..........

VIII. MAINTENANCE SCHEDULES..........
Schedule for Lubrication, Lubrication Charts and Drawings..........
Schedule for Electrical Maintenance, Schematic Diagrams and Checklists.

IX. FIGURES AND PHOTOGRAPHS..........

X. APPENDIX..........
Nondestructive Testing..........
General Electric Motor, Generator Rebuild (Basic Overhaul)..........
Rules to Follow in Maintaining Electrical Apparatus..........
Six Basic Electrical Preventive Maintenance Operations..........
Electrical Safety..........
Federal Movable Bridge Operation Regulations..........
Copy of Bridge Operator's Manual..........

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CHAPTER 5.1—MOVABLE BRIDGE MAINTENANCE

5.1.1—GENERAL

Bridge maintenance is defined as those activities necessary to preserve the existing serviceability of the structure and to maintain a level of acceptable performance. For a movable bridge these activities should, as a minimum, include: inspection, testing, cleaning, lubrication, aligning, painting, component adjustment, and parts replacement. Carrying out these activities effectively involves a coordinated effort of collecting and analyzing condition data of the bridge, scheduling routine maintenance, prioritizing the special maintenance tasks required, allocating the necessary equipment, and using trained personnel to perform the tasks.

C5.1.1

A movable bridge represents a substantial financial investment, not only in terms of initial cost of design and construction, but also in the annual costs required for inspection, maintenance, and upkeep. The inherent complexity of the structure, coupled with often limited resources available to bridge owners to maintain these structures, provide justification for developing a cost effective maintenance program.

A movable bridge maintenance program is a vital component of an effective bridge management program. A properly executed maintenance program based on frequent inspections and continuous preventive maintenance practices provides protection not only for the bridge owner, but for the general public as well. The cost of such a program is small relative to the cost of major repair, rehabilitation, or unscheduled bridge closure.

5.1.2—MAINTENANCE OBJECTIVES AND GOALS

The objective of a maintenance program is to keep the structure in good operating condition. A properly designed maintenance program can extend the operational life of the bridge, reduce unscheduled repairs, eliminate unsafe conditions, and increase the performance reliability. The specific goals of such a program should emphasize:

- Developing a maintenance team comprised of properly trained and equipped personnel capable of carrying out maintenance objectives in an efficient and economical manner.
- Establishing desired levels of maintenance service, including performance of scheduled testing, inspection, preventive maintenance, component adjustment for wear, and routine parts replacement in a consistent and timely manner to maintain reliable performance of the structure as designed.
- Providing component failure maintenance actions to replace worn or failed parts in a timely manner to minimize unscheduled downtime.

- Providing a method by which management can evaluate planned versus actual performance and develop corrective procedures as required.

5.1.3—MAINTENANCE ACTIVITIES

Generally there are two primary maintenance activities that should be performed on a movable bridge: component failure maintenance and preventive maintenance. Component failure maintenance is a responsive action to a failed system or component. Preventive maintenance involves regularly scheduled, planned activities that are intended to maintain functional systems and components in a normal operating condition. A preventive maintenance program encompasses regular evaluation and/or prediction of useful life of functional systems and components to detect and/or anticipate potential problems and schedule corrective action before a component failure occurs.

A description of various bridge and component testing procedures and advanced inspection methods is provided in Chapter 2.10.

C5.1.3

The underlying concept of an effective bridge maintenance program is not so much based on the level of effort and sophistication of the maintenance activities, but more the timing and proper implementation of these activities. The "worst first" approach, where attention is continuously focused on addressing the needs of the component or system in the worst condition, may suffice for the short term. However, in the long run this approach is ineffective due to the high cost of constant repair and replacement. Alternatively, preventive maintenance tasks such as cleaning, lubricating, painting, and performance testing, which extend component life and are carried out on a regular basis, can be more effective from a performance and cost standpoint than the resulting costs of replacement due to unexpected component failure.

5.1.3.1—Component Failure Maintenance (Repairs)

Component failure maintenance activities are intended to restore the bridge to an acceptable level of operation as quickly as possible in the event of unexpected system or component failure.

Component failure maintenance is responsive and can be costly when compared to planned preventive maintenance, but certain steps can be implemented to reduce this undesirable effect, as follows:

- Establish contingency plans that outline the necessary steps to restore the bridge to service, including: a contact list of key engineering and maintenance personnel, a notification list of affected government and emergency response agencies, pre-approved bridge detour plans, and standard repair or retrofit procedures for probable failure events.
- Maintain a spare parts inventory of components. Critical, long lead time components whose failure could result in bridge closure should be kept on hand to minimize unacceptable delays. Consideration should also be given to stocking other noncritical components that require a long lead time for delivery.
- Establish "on-call" contracts to expedite special engineering and supplier or contractor services.

- Establish a list of special manufacturers, machine shops, and fabricators with "on-call" contracts for replacement or duplication of unique parts.

5.1.3.2—Preventive Maintenance

The objective of a preventive maintenance program is to continually maintain the components in a state of good repair so that component failure would be very unlikely. To accomplish this objective, maintainer responsibilities should include:

- Cleaning, lubricating, painting, and adjusting bridge components and systems to maintain acceptable levels of operation under service conditions.
- Periodic inspection and performance testing of structural, mechanical, hydraulic, and electrical components in a manner such that potential problems are discovered and corrective action is taken in a timely manner.
- Observation of the functional systems and components under various conditions of operation in order to increase understanding of the performance of the bridge.
- Performing maintenance on a regularly scheduled basis to minimize deterioration and/or wear.
- Replacing components or parts on a regularly scheduled basis.
- Proper record keeping and documentation of maintenance activities and testing results to permit performance evaluation and "fine tuning" of the system.

C5.1.3.2

The ideal preventive maintenance program, which eliminates component failure maintenance, is difficult to implement on complex machinery designed without redundancy when useful life data on components is scarce or nonexistent. Reliable prediction of useful life data for critical components is a worthwhile goal because maintenance activity can be based upon cyclical replacement of these components prior to a well-documented predicted failure date.

In cases where the life of critical components is not predictable, owners should be prepared to replace failures rapidly by stocking parts and having trained maintainers "on-call" to minimize bridge downtime.

5.1.4—ESSENTIALS OF A MAINTENANCE PROGRAM

Maintenance Manual: It is preferred that a bridge-specific maintenance manual be developed for use by maintainers to accomplish both component failure and preventive maintenance tasks. Some owners may find it appropriate to develop a more general manual that covers procedures at more than one structure of a particular type. Documentation should include written, graphical, and pictorial data that defines the maintenance and repair procedures for the various systems or components, including information on routine preventive maintenance activities for the various bridge components, tools and testing equipment, acceptable tolerances, safety procedures, repair/replacement parts, and a step-by-step sequence required to complete the maintenance or repair work. The document should be instructional and factual, avoiding discussion on theory of operation or any design features. Chapter 4.7 provides discussion on the development of bridge-specific operations and maintenance manuals along with sample documents.

C5.1.4

Manuals, training, and other essentials are simplified if owners develop standard procedures for similar systems on similar movable bridges. Where feasible, standardization is useful because some or all parts can be interchangeable from one bridge to another, thus simplifying and reducing the need for stocking critical replacement components.

Trained Maintainers: Properly trained maintainers are essential for effectively performing the diverse activities required for a movable bridge maintenance program. Personnel selected for the maintenance staff should undergo both on-the-job and classroom instruction that encompasses the full range of their assigned maintenance activities. Informal training conducted by the bridge owner could include apprentice programs, teaming trainees with experienced maintainers, and rotating assignments to provide exposure to the various maintenance specialties. This informal instruction could also include periodic visits by equipment manufacturers providing on-the-spot operational and maintenance instructions on their particular equipment. Formal instruction should typically include lectures, case studies, group problem solving, and written examinations.

Maintenance Information Management: Collecting and maintaining a comprehensive database on maintenance activities is necessary for evaluating inspection findings and appraisals, work prioritization, allocating resources, performance evaluations, and redirecting or "fine tuning" maintenance procedures in response to assessment of their effectiveness. In developing such a maintenance management system, the focus should be on minimizing the amount of effort required for personnel to satisfy the reporting requirements while still providing the needed data. This minimization effort can be accomplished through the use of recent advances in data collection and telecommunication technology. The use of portable electronic clipboards, telemetry systems, digitizing cameras, or bar-coding techniques can offer practical and efficient means of collecting, transmitting, and storing field data. NCHRP Report 334 (Reference 87) provides detailed descriptions of advanced maintenance field data collection and reporting systems.

CHAPTER 5.2—STRUCTURAL MAINTENANCE

5.2.1—GENERAL

The structural elements of the bridge include the deck, superstructure, substructure, fender system, and other components that support electrical, mechanical, and hydraulic devices.

Routine preventive maintenance efforts should focus on structural components that are subjected to direct working loads and forces, corrosive action, and dirt and debris buildup. Portions of the structure that are particularly vulnerable include catwalks and railings, bearings, superstructure and substructure components located directly below open joints or grating, and drainage systems.

An important aspect of the maintenance procedure should include identifying the root cause of any problem detected, and the elimination of such causes. Chronic problems that are encountered may require extensive repair or retrofits that are beyond the scope of traditional maintenance procedures. Complex maintenance and repair procedures should be addressed to the maintenance engineer. Any conditions which are either critical or poor should cause immediate filing of a deficiency report (See Chapter 2.7) with recommendations for the type and urgency of corrective action, unless the crew is successful in correcting the defect the same day it is observed.

C5.2.1

The *AASHTO Maintenance Manual For Roadways and Bridges* (Reference 7) provides a summary of the problems that occur in the various bridge components and presents the proper maintenance action.

Routine preventive maintenance that includes cleaning, patching, waterproofing, or repairing of structural components can go a long way toward increasing their service life and avoiding costly repairs in the future. However, these benefits are gained only if the repairs are properly performed as per manufacturers' specifications for the materials and components used for the specific application.

Further, it is essential for maintenance personnel to understand that repairs implemented without determining root cause do not rectify the problem, but only the effects of the problem. Repairs that may affect structural, mechanical, or electrical integrity should be reviewed by an engineer.

5.2.2—STRUCTURAL CONCRETE

The primary concern with durability of concrete is the corrosion of embedded reinforcement steel. Effective corrosion control methods to prevent moisture and deicing chloride infiltration are essential in reducing the likelihood of major repairs. These include a regular program of high pressure water cleaning, sealing and patching deteriorated areas, and application of protective coatings.

Several of the general maintenance practices that should be performed on structural concrete are as follows:

- Regular high pressure waterblasting of concrete to keep concrete components free of debris buildup, deicing agents, dirt, and waterborne debris. These elements in combination with moisture accelerate the deterioration process.
- Coat concrete surfaces with a vapor-barrier, damp-proofing or waterproofing coating. These protective sealants include, but are not limited to, epoxy resin, polymer-modified portland cement, and linseed oil coatings. Water-based elastomeric membranes can also serve as protective sealers for concrete. These coatings require periodic application.

C5.2.2

A determination by an engineer as to what is a structural repair and what is a "cosmetic" or nonessential repair may help to limit repair quantities to a manageable level. Typically, spalls on massive concrete elements like abutments and solid shaft piers may not need repair if structural reinforcing steel is not exposed and aesthetics or public safety risk from falling concrete are not a problem.

If surface spalling, delamination, or other deterioration is widespread on structural concrete elements, or if undermining of the bearing elements is observed (greater than 15 percent of the total bearing area), maintenance personnel should consult with an engineer for specific repair procedures.

- Spalls in concrete that are not deeper than the outermost layer of reinforcing bars should be cleaned of all loose concrete, and patched.
- Spalls in concrete deeper than the outermost layer of reinforcing bars should be cleaned of all loose, unsound concrete; the deteriorated steel reinforcement cleaned and sealed with a corrosion inhibitor; and the entire area patched with epoxy grout or special concrete mix. Severely deteriorated reinforcement should be spliced with new bars. Consideration should be given to installation of welded wire fabric to reinforce the patch.
- Cracked and spalled concrete in the area of the bridge bearings should be cleared of all loose concrete and anchor bolts cleaned of any corrosion. Use a quick setting, nonshrink, cementitious mortar to reestablish bearing integrity.
- Structural cracks wider than 30 mils (0.762 mm) should be injected with a bonding material to restore capacity. Injection should be performed in accordance with the injection material manufacturer's specifications.
- FRP application can provide both strengthening and improved durability.

5.2.3—STRUCTURAL STEEL

Periodic cleaning is the best maintenance practice for steel components. Additionally, steel components must be well protected to prevent corrosion. Painting is a general all-purpose method for protecting steel against corrosion and should be used for applications other than those involving special problems of accessibility or severe exposure.

Maintenance personnel should refer to the Steel Structures Painting Council's *SSPC Painting Manual* which provides specifications covering the various coating systems available, surface preparation, application, and other considerations involved in painting. The value of proper surface preparation cannot be overemphasized. The steel should be cleaned of corrosion, salt, leachings, or other chemical contaminants. Maintenance personnel should be prepared to perform power tool cleaning, and water or sandblast cleaning as required.

Steel corrosion is further accelerated by the accumulation of dirt or debris that maintains moisture in contact with the steel surface. Also, the accumulation of dirt can hide underlying defects and make inspection difficult. A regular program of cleaning can be as effective as painting. Several general corrosion maintenance practices that should be performed on steel components include:

- Sandblast or waterblast areas of the structural steel showing rust staining, rust flakes, and/or cracked or flaking paint. Prime and paint as required. Areas exhibiting severe corrosion should be discussed with an engineer.

C5.2.3

In general, maintenance repairs that involve strengthening deteriorated or cracked steel members by adding plates or other structural members may have adverse effects on span or leaf balance. Cracks in critical structural members or in machinery frame welds may warrant closure of the bridge or posting of weight restrictions until the condition can be corrected.

The use of weathering steel (A588) can reduce overall maintenance costs if properly maintained. Surfaces should be free from moisture or debris buildup, or the protective oxide coating may not form.

Extensive corrosion problems can result from inadequate or poorly functioning drainage systems. Bridge drainage systems should be periodically cleaned, flushed, and checked to confirm that runoff is kept away from superstructure elements.

Most of the welding done by maintenance welders may not require specific welding procedures. However, welded crack repair of high strength, quenched or tempered steel may require special welding procedures including chemical analysis; electrode

- Remove built-up dirt, deicing agents, and other debris with high pressure waterblasting. Keep expansion joints, rockers, and pins free from dirt and debris buildup.
- Adjust or shim live load shoes that do not fully bear on their bearing plates during dead load application.
- Steel members with minor kinks can be repaired by heat straightening, reinforced with plating, or encased.

selection; and preheat, interpass, and postheat application. In general, it is a good practice to consult a metals technical specialist before performing maintenance welding.

Sandblasting is problematic if the existing paint contains lead. No sandblasting or other cleaning procedures should be undertaken without prior investigation of the existing paint for lead content.

Accumulations of bird nests and droppings should be removed. Bird screens, cages, or noise emitters may serve to discourage birds in some cases.

5.2.4—STRUCTURAL TIMBER

The principal types of deterioration of timber components are decay, marine-borer attack, excessive deflection, checking, splitting and/or loose fasteners due to shrinkage of the timber, and deterioration of the connecting hardware. Several of the general maintenance practices that should be performed on structural timber are as follows:

- Structural timber components should be pressure treated or covered with other types of coatings to protect the wood from the effects of weathering, water damage, and parasite infestation. Bare untreated timber will deteriorate rapidly unless it is a resistant species such as cedar, teak, or one of the tropical hardwood species. Even in the case of resistant species, penetrating coatings that increase resistance to water penetration and shrinkage are beneficial.
- Timber elements exhibiting parasite damage, fire damage, impact damage, cracking, sagging, or other deterioration that affect their structural integrity should be reinforced or repaired.
- Boring devices or probes should be used in areas of wetting and drying cycles to determine if interior damage from parasites is occurring. Holes resulting from such probes should be plugged with glued-in dowels with similar strength characteristics to the material removed. The glue used should be rated for marine use.
- Debris which can retain moisture (dirt, animal waste, etc.) should be removed from timber elements to allow for better air circulation and drying action. Ponding of water on horizontal timber surfaces is always undesirable and measures should be taken to eliminate ponding if it is present.
- Replacement connection hardware should be hot-dip galvanized. Fasteners may become loose due to timber shrinkage and should be checked for tightness during routine inspections and re-torqued as necessary.

C5.2.4

The most effective way to avoid weathering and parasite damage to timber structural members is through application of a protective coating. The two most common coatings are paint and pressure treatment. Maintenance personnel should be aware that using these coatings can give false indication as to the true integrity of the member. Particularly in tidal regions, the surface of timber protected with paint or pressure treatment can appear to be intact. However, deterioration of the interior can be extensive due to parasites that can bore through the protective coating to the unprotected interior. Only probing or coring can give a true indication as to the integrity of the timber member. If boring or probing is done, the holes left behind should be plugged so as not to inadvertently leave access for parasites.

When performing repair or replacement of timber components, appropriate species of wood and protective treatment should be specified to confirm long term performance.

5.2.5—MACHINERY SUPPORTS AND FRAMES

Machinery supports and frames are not usually moving parts, and therefore may be overlooked during mechanical maintenance work. However, they are subjected to corrosion and cyclical machinery stresses that may cause fatigue failure. Such failure has the potential to cause damage to supported machinery components.

As required (but not less than at the same interval as each routine inspection), perform routine maintenance as follows:

- During operation of the span, check for movement of the supports on the concrete or superstructure, or for movement of a machinery component on its support. If movement is detected, foundation bolts or other fasteners may be loose or cracked. Replace and/or tighten bolts or nuts or repair damaged components.
- If a support deflects noticeably, it may be cracked around the mounting flanges, especially near bolt holes, fillets, and/or welds. Any suspected area should be observed closely during span operation. Cleaning might be required for better visibility. A crack will open up, normally, during operation, making it more visible. Testing is generally required to determine the extent of the flaw.
- Supports partially embedded in concrete or resting on concrete are subjected to severe corrosion at the concrete interface. Corroded areas should be blasted, cleaned, and painted. Severely deteriorated support components should be reinforced as required to reestablish full capacity.
- Check the structural frame, clevis feet, and pins on a Hopkins frame for movement, cracks, corrosion, or wear. Correct any anomalies promptly.

C5.2.5

Machinery bolts and foundation bolts for machinery supports are often specially fitted turned bolts that are an unusually tight fit. Normal fit, high strength A325 or A490 bolts are not acceptable substitutes.

As per the AASHTO *LRFD Movable Highway Bridge Design Specifications* (Reference 6), bolts for connection of machinery parts to each other or to their supports should be high strength finished bolts (A499). The bolts should have turned shanks, cut threads, and semi-finished, washer-faced. hexagonal heads and nuts. The dimensions of all bolt heads and nuts should be in accordance with the heavy series and threads should be in accordance with the coarse thread series of the ANSI code. The fit between turned bolts and their holes for fastening trunnion and counterweight sheave bearings to their supports and all turned bolts that carry shear should be class LC6 (Reference 6).

5.2.6—FASTENERS

Fasteners are used to connect structural members; hold machinery elements and supports in place; secure ship ladders, walkways, and platforms; and provide anchorage for bearings. Fasteners come in different forms such as anchor bolts, turned bolts, and rivets. They may stretch from overloads, or work loose from vibration or shrinkage of timber members.

- Tighten loose fasteners and replace broken, sheared, or missing fasteners, or fasteners found with greater than 20 percent section loss. Prime and paint replacement fasteners.

C5.2.6

Owners should consider stocking a sufficient number of replacement fasteners of unique types that cannot be quickly obtained, to allow rapid response to failure.

5.2.7—SHIP LADDERS, WALKWAYS, AND PLATFORMS

Access platforms should be well maintained, since these are essential for inspection and maintenance work and may be hazardous to personnel if poorly maintained. Specific maintenance of ship ladders, walkways, and platforms should be as follows:

- Remove grease, hydraulic fluid, and lubricant spills after routine maintenance operations. Remove any buildup of dirt, construction or maintenance debris, animal waste, etc.
- Deteriorating base metal on ladder rungs, ladder protective cages, walkway grating, or platforms should be cleaned and painted to arrest corrosive action. If deterioration affects the structural integrity or stability of the element, repair/ rehabilitation is necessary. During replacement of existing elements, consideration should be given to the use of galvanized and/or FRP replacement members to provide more resistance to corrosion damage.

C5.2.7

Buildup of debris on platforms, ladders, and walkways can present serious safety hazards to maintenance personnel. Lubricant spills, construction or maintenance debris, tools, or other items left behind may not be noticed by personnel. Pigeon or rodent droppings, as well as buildup of dirt and deicing agents, can accelerate deterioration of the steel components and connections. Therefore, dirt, debris, and spills should be removed by the crew immediately after completing the necessary maintenance operations.

5.2.8—COUNTERWEIGHT AND COUNTERWEIGHT PIT

Maintenance of the counterweight and counterweight pit is essential for proper operation of the movable bridge. Maintainers should:

- Maintain concrete and steel components in accordance with Section 5.2.2 and Section 5.2.3, respectively.
- Remove water that has infiltrated into the counterweight pit. If water infiltration is a recurring problem, consideration should be given to installation of sump pumps.
- Check operation of the counterweight pit sump pump. Clean intake screen and check discharge hose and replace as required.
- Clean counterweight pockets of water or debris buildup.
- Protective coatings should be applied to portions of the counterweight that are in the splash zone.

C5.2.8

Widespread spalling, scaling, or deterioration on the concrete counterweight can affect leaf balance. Corrosion of steel counterweight support members is common at the interface with the counterweight concrete, and can result in severe loss of section in the steel members. Maintainers should make an extra effort to clean and paint these areas regularly to avoid the need for difficult and expensive reinforcement or repair work in this localized area of chronic corrosion damage.

5.2.9—FENDER SYSTEM AND OTHER PIER PROTECTIVE DEVICES

The fender system and other pier protection devices are essential for safety of the bridge, to protect against accidental impact from a vessel. Various materials may be used for fender systems including timber, concrete, steel, composite lumber, rubber, and HDPE. For maintenance of the fender system and other pier protection devices, maintainers should:

C5.2.9

Any malfunctioning or missing warning lights, signals, or navigation lights should be reported immediately and recommended for immediate repair.

- Replace the components that show severe damage from cracks, splits, splintering, fungus growth, parasite infestation, weathering, warping, fire damage, and impact damage. These conditions may be particularly evident on the structural components located within the tidal zone.
- Replace missing fasteners. Identify locations where steel fasteners protrude into the channel and present a snagging hazard to passing marine traffic. Loose fasteners should be tightened or replaced as required. Steps should be taken to countersink protruding fastener components and recess any steel connection plates on the channel side.
- Check the fender system as well as any other pier protection devices for broken, damaged, or loose components, as well as other debris that, if dislodged, may become a floating hazard to marine traffic or that, if allowed to remain in place, may serve to act as a snagging hazard to passing marine traffic. Such hazards should be promptly removed and replaced with new, properly connected components.
- Report nonfunctional navigational lights on the fender system or other nonfunctional lights to the electrical maintenance personnel via deficiency report.
- Review the operator's log for entries that indicate any impacts on the fender system or other pier protection devices. These areas should receive detailed inspections to determine the extent of damage and the presence of hazardous conditions to marine traffic (debris, protrusions, etc.). The maintenance inspector should also assess any reduction in the overall effectiveness of the fender system or protection device.
- Consideration should be given to painting the exterior faces of fender components above the high water mark with retroreflective paint, or installing high visibility signing devices to aid navigation during low visibility conditions.
- Check for debris or ice buildup that could result in abnormal loading of the fender system. Remove any accumulated debris as required.

5.2.10—OPERATOR’S (TENDER’S) HOUSE

The operator’s (tender’s) house should be regularly maintained to provide a safe and comfortable environment for the bridge tender. Regular maintenance should include the following items:

- Sweep and wash floors
- Keep windows clean and free from dirt and debris buildup
- Check condition of doors and windows, and their working mechanisms; repair or replace as required

5.2.11—STEEL GRID DECKS

Grid decks are the most common type of steel deck. They include welded grid decks, riveted grate decks, concrete filled decks, and exodermic decks.

The most common problem with steel grid decks is cracking of the welds that connect main bearing bars, cross bars, and supplemental bars within the grid, and/or cracking of welds to support framing members. In riveted grating, where bent bars are connected with rivets, the rivets sometimes shear. Dirt and debris can collect in the open grid pockets over the superstructure, resulting in deterioration of these members as well as the grid. Sections can also be damaged by vehicles dropping or dragging items. Therefore, the following items should be checked:

- Check welds for cracks. Repair as required. Check riveted grid for loose, broken, or missing rivets. Repair or replace as required. Replacement of deck sections may be necessary if excessive deterioration has occurred.
- Clean grid pockets of dirt and debris.
- Evaluate the condition and effectiveness of the grid deck wearing surface (grooves, studs, concrete fill or overlay, etc.).

C5.2.11

Skid resistance can be increased by welding small studs to the steel grid deck. If skid resistance is deemed to be inadequate, warning signs should be placed as necessary to warn vehicles of the potential hazard.

5.2.12—OTHER DECKS

Other deck types have been utilized on movable bridges including steel orthotropic decks, aluminum decks, and fiber reinforced polymer (FRP) decks.

The most common problems with these decks are the debonding of the overlay, and development of fatigue cracks in the web elements or connecting welds. Sections can also be damaged by vehicles dropping or dragging items. Therefore, the following items should be checked:

- Check welds for cracks. Repair as required. Check for loose, broken, or missing connections. Repair or replace as required. Replacement of deck sections may be necessary if excessive deterioration has occurred.
- Evaluate the condition and effectiveness of the deck wearing surface.

CHAPTER 5.3—MECHANICAL MAINTENANCE

5.3.1—GENERAL

The hostile environment in which movable bridge mechanical equipment operates can significantly reduce the service life of a component if it is not properly maintained. Unexpected breakdowns of mechanical components, and the long lead time associated with the ordering and fabrication of many replacement parts, can result in extensive delays to navigational and vehicular traffic. Avoiding these circumstances requires a regular mechanical maintenance program of inspection, testing, cleaning, lubrication, adjustment, and scheduled component replacement prior to failure to keep mechanical components in serviceable operating condition.

5.3.2—LUBRICATION

The basic goal of the lubrication program is to provide clean lubricant at all times between moving parts which is capable of withstanding the temperatures and bearing pressures imposed in bearing areas by the lubricated parts. The type of lubricant and frequency of lubrication must be selected in a manner such that the lubricant is still present and uncontaminated at the end of the lubrication cycle. If previously applied lubricant is not present on the needed surfaces, or is contaminated with abrasive grit or other deleterious substances, the lubrication type and/or frequency of application are probably inadequate. The ultimate test of any maintenance lubrication plan is uninterrupted long-term performance of the machinery components.

Lubricants are defined as any substance for reducing friction by providing a smooth film coating over moving parts. Lubricants perform a variety of functions. The primary, and most obvious, function is to reduce friction and wear in moving machinery. In addition, lubricants can:

- Protect metal surfaces against rust and corrosion.
- Control temperature and act as heat-transfer agents.
- Flush out contaminants.
- Transmit hydraulic power.
- Absorb or dampen shocks.
- Form seals.

Each lubricant type has its own physical properties that affect its performance in different applications. Lubricants are graded according to the function they are to perform, and classified within those grades according to the temperature range at which they best perform. The use of lubricants for applications that are beyond their operating specifications can have an adverse effect on the machinery. For instance, grease that is too tacky or viscous

C5.3.2

Proper lubrication, done on a regular basis, in accordance with a properly designed lubrication schedule, will greatly extend the life of any mechanical component or system of components. Development of a lubrication chart and lubrication logs similar to those shown at the end of this chapter is strongly recommended for movable bridges. A carefully designed chart, which is diligently followed by maintainers, and use of the lubrication log data for QC/QA improvement of lubrication methods and personnel training can result in significant long-term savings on repairs and component replacement.

Consideration should be given to installing automatic lubrication systems, especially for critical operating or difficult to access components. Simple, gravity feed or pressure type automatic lubricators with small reservoir units are available. These automatic lubricators mount on bearings in place of grease fittings, and dispense the correct amount of oil or grease to the bearings as required, if they are properly designed and maintained.

Caution should be used with automatic lubrication devices. Some of the available types of automatic lubricators may not provide sufficient pressure to properly can put extra strain on an electric motor forced to turn against heavy viscous resistance. A lubricant that is too thin, or low in viscosity, will not prevent wear on moving parts. An understanding of the types of lubricants and their advantages and limitations is required prior to selecting a lubricant for a particular application.

lubricate some types of bearings (particularly large trunnion bearings). In addition, the use of automatic lubrication removes the human element, and does not allow the application of judgment during the lubrication process to determine whether lubrication is successful. It is suggested that, if automatic lubrication systems are to be used, they be tested during routine and in-depth inspections to verify proper function.

5.3.2.1—Lubrication Chart

In order to achieve optimal performance from a mechanical component, the correct amount and type of lubricant must be applied at the proper intervals. A lubrication chart, which pictorially identifies the key lubrication points of the bridge and the proper type, quantity, and frequency of lubrication, should be developed for each bridge.

The types of lubricants commonly used on movable bridges, are given below:

- **Type 1:** NLGI No.2 grease with rust and oxidation inhibiting additives, 280 Worked Penetration at 77°F (25°C), 475°F (246°C) (or higher) ASTM Drop Point, water resistant, anti-wear/extreme pressure.
- **Type 2:** NLGI No.1 grease with rust and oxidation inhibiting additives, 325 Worked Penetration at 77°F (25°C), 475°F (246°C) (or higher) ASTM Drop Point, water resistant, anti-wear/extreme pressure.
- **Type 3:** Heavy duty industrial gear lubricant, anti-wear, high pressure, rust and oxidation inhibited, AGMA No.5 EP, SUS 1175 at 100°F (37.8°C) viscosity, ISO VG 220.
- **Type 4:** Unleaded, diluent type, nonchlorinated open gear grease, SUS 7,000 at 210°F (98.9°C) viscosity, water resistant, anti-wear/extreme pressure.
- **Type 5:** Film forming, with protection against the corrosive effects of both salt water and fresh water, resistant to throw-off, and adherent without being tacky or stringy, NLGI No.1, SUS 120 at 100°F (37.8°C) viscosity.
- **Type 6:** Heavy duty, high pressure, rust and oxidation inhibiting, anti-wear hydraulic fluid, ISO VG 46 Grade, SUS 238 at 100°F (37.8°C) viscosity.
- **Type 7:** Moderately alkaline diesel oil with alkaline detergent dispersant additives and oxidation inhibitors, SAE 40, VI 100, SUS 700 at 100°F (37.8°C) viscosity.
- **Type 8:** Heavy duty industrial gear lubricant, anti-wear, high pressure, rust and oxidation inhibited, AGMA No.8 EP, SUS 3726 at 100°F (37.8°C) viscosity, ISO VG 680, SAE Gear Oil No. 140

C5.3.2.1

Chapter 4.7 provides additional discussion on lubrication charts. The lubricant type numbers given in the text are provided only to facilitate identification in Table 5.3.2.1-1 and in maintenance forms. Owners may use any designation system they are familiar with as long as the system is compact and consistent within their organization. Since the brand and type of some lubricants is likely to change in response to QC/QA decisions and other factors, it is not generally advisable to base lubrication charts or other lubrication guidelines on the particular specifications of one brand of lubricant. The determination of acceptability of any lubricant should in general be based upon monitored performance data from lubrication logs and other practical considerations.

- **Type 9:** Aviation hydraulic oil, SUS 70 at 100°F (37.8°C) viscosity, VI 200.
- **Type 10:** 10W/40 (or similar) API service CD, CC, SF, SE, or SD fully deterrent, all-weather oil formulated to retard the formation of sludge, varnish, and carbon deposits.

In the absence of specific lubrication and lubricant information, Table 5.3.2.1-1 may be used as a general guide in selecting the type of lubricant to be used in lubricating a specific movable bridge component.

Sample lubrication charts are provided at the end of this chapter that show the location, type, and frequency of lubrication for one lift span in a warm climate. Similar charts can be developed for other bridges based upon type of structure, component type, and component manufacturer's recommendations for the specific geographic location, climate, and frequency of bridge operation.

Table 5.3.2.1-1 – Component and lubricant types

Component	Lubricant Type
Bearings Grid Coupling Lock Bars and Guides Motor Bearings Traffic Gate Bearings	1
Gear Couplings Buffer Cylinders Lock Operators	2
Enclosed Gears Gear Motors Center Bearings (Swing Span)	3
Open Gears	4
Wire Rope	5
Hydraulic Lock Operators	6
Diesel Engines	7
Traffic Gate Reducers	8
Brakes Thruster Oil	9
Auxiliary Power Engine	10

5.3.3—MECHANICAL COMPONENTS

Typical components that should be specifically addressed in the mechanical maintenance program and lubrication charts include, but are not limited to:

- Bearings

C5.3.3

Maintenance and lubrication type and frequency recommendations herein were developed based upon maintenance documents developed by Florida and

- Shafts
- Couplings
- Enclosed gears (gearboxes)
- Open gears
- Brakes
- Buffer cylinders
- Auxiliary power (engine–generator, gasoline, LPG, or diesel driven)
- Live load shoes and strike plates
- Fasteners
- Sump pumps
- End jacks, center wedges, span locks, and other special machinery
- Wire ropes
- Balance wheels
- Support rollers

5.3.4—BEARINGS

Bearings are machinery components that provide a low friction interface between rotating and non-rotating parts. Bearings support applied loads, maintain alignment of the members, and minimize frictional power losses. Two primary types of bearings are used on movable bridges: sleeve bearings and anti-friction (ball or roller) bearings. These bearings may be mounted in a variety of housings, the most common types being the pillow-block or flange housings.

One other type of bearing, common only to center bearing swing bridges, is the spherical bronze and hardened steel center bearing.

One factor common to all bearings is the need for a constant supply of lubricant.

Maintenance: The following items should be checked as required (but not less than once every six months):

- Check bearing sleeves for lubrication, cracks, scoring, or severe wear.
- Clean and spot paint exterior surfaces as required.
- Check condition of the cap and mounting bolts, and tighten if required.
- Make sure lubrication fittings are not plugged and are operating properly. If necessary, flush with kerosene or other approved solvent. Do not use gasoline or other volatile solvents. When bearings or other components are cleaned internally or flushed with a solvent, it should be noted in the lubrication log.
- If serviced by an automatic lubrication system, check the lubricant level and verify that fresh lubricant is present in all bearings. If no automatic system is present, the bearing should be greased with a hand-held gun and the grease applied until a fresh bead of grease appears around the end

California. These states have published guidelines for maintenance of their movable bridges that were adapted for use in this Manual. The guidelines presented should be taken as minimum standards that require modification and application of local knowledge, engineering judgment, and sound QC/QA procedures in order to develop reliable lubrication and maintenance practices on an individual movable bridge.

of the bearing or seal. Wipe off any excess. Check extruded grease for contamination visually and by rubbing a small amount between clean fingers to feel for particulate grit. Results should be noted in the lubrication log.

- The frequency of lubrication for sleeve bearings should be based on the openings/month (O/M) of the bridge, as given in Table 5.3.4-1.

Openings per Month	Lubrication Internal
750	1 Week
300–749	2 Weeks
0–300	1 Month

Table 5.3.4-1 – Lubrication frequency for bearings

Note: If the center bearing of a swing-span is not lubricated by means of an immersed oil bath, it is strongly recommended that this type of system be installed as soon as possible.

5.3.5—SHAFTS

Little maintenance is required of shafts except to protect them from corrosion. A visual inspection for cracks and other defects should be part of a preventive maintenance program. Cracks are the main cause of shaft failures. Cracks usually begin at a point of high stress concentration, such as a keyway or shoulder (a point where the shaft changes diameter). Often a keyway ends at a shoulder producing an especially high stress. Areas subject to heavy corrosion and points having flaws can also cause shaft failures. A preventive maintenance program should include visually inspecting all shafts for cracking and loose keys or set screws.

5.3.6—COUPLINGS

Couplings prevent stress buildup in the shafts and bearings resulting from misalignment. Flexible couplings compensate for parallel misalignment, angular misalignment, or a combination of both. The most common types of couplings used in movable bridges are: gear, chain, grid, and jaw couplings as described in Chapter 2.8.2. Some of the most common causes for flexible coupling failure are extreme misalignment, torque overload, improper type of coupling for the application, and lack of lubrication.

When lubricating the machinery, inspect the couplings for lubrication leaks. If a leak is present and the amount of lubricant escaping is significant, the seals and/or gasket may be defective. Disassemble the coupling, clean with lubricating solvent, and replace the defective components. Lubricate with fresh Type 1 or Type 2 lubricant.

Maintenance: The following items should be checked as required (but not less than once every six months) when lubricating the coupling:

- Check flange bolts for tightness.
- Inspect the keys and keyways for signs of cracking.
- Inspect the seals and gaskets, replace if leaks are excessive.
- Clean any excess grease.

As required (but not less than once every two years):

- Remove the coupling covers. Check lubricant for contamination or metal particles.
- Clean off old lubricant with lubricating solvent.
- Visually inspect mating parts, replace if worn.
- Furnish new gaskets and reassemble the covers.
- Lubricate with fresh grease as per the manufacturer's recommendations.
- Clean gear teeth when necessary.

5.3.7—ENCLOSED GEARS

Enclosed gears, also called speed reducers or gearboxes, are used to multiply the output torque and reduce the output speed of the main drive motors.

Speed reducers are gear sets that are mounted in dust-proof, oil-tight housings. The sealed housings minimize wear from environmental conditions and provide rigid mountings for shaft bearings.

Maintenance:

- Check seals for signs of leakage and discoloration within the housing. A small amount of oil seepage during operation is desirable to lubricate the shaft seals. If a severe leak is present, replace the seal. On units with stuffing boxes, tighten the two gland bolts, evenly, just to stop the leak. Do not tighten these glands more than necessary! Over tightening of bolts will create increased friction, causing premature failure of the seal and possible scoring of the shaft journal.
- Make sure the vent breather is operating properly. Clean filter material as required.
- Check oil level. Add oil if required. Do not overfill! When adding oil, make sure it is of the same type and grade as in the reducer. Mixing of different oils is not recommended. Fill to the center of the oil level indicator. Do not allow the oil level to fall more than ¼ in. (6.35 mm) below the center of the oil level indicator for adequate lubrication.
- Clean the oil level indicator. Note: A speed reducer should never be operated without an oil level indicator installed!
- Look for cracks on the feet of the housing.
- Watch the reducer feet during operation. If the mounting bolts are loose, a small amount of movement may be

C5.3.7

Different manufacturers may use different additives in lubricants. If the lubricant manufacturer is changed, the maintainer should be sure that the new lubricant is compatible with the existing. If compatibility between lubricants cannot be verified, drain, flush, and replace the existing lubricant entirely with the new.

detectable during operation, especially during starting and stopping. Tighten any loose bolts.
- Check casing bolts for rust and tightness. Torque any loose bolts to the manufacturer's recommended torque. Do not over tighten! Gasket failure may result.
- Watch the shaft extensions during operation for radial or axial movement. Excessive movement indicates worn bearings. Report to the proper authorities for corrective action.
- Listen for any unusual noises.

As required, check and correct the following items:
- Clean casing. Spot paint as required.
- If oil looks dirty or milky white, change the oil. Clean any sludge or other contaminants from inside surfaces of the case before adding new oil. Make sure no moisture enters the speed reducer during oil change.
- While the sump is drained, remove the inspection cover and visually inspect the interior components. Be extra careful not to allow any contaminants to get inside the sump. Replace the gasket.
- While the inspection cover is removed, flush the interior of the speed reducer with clean lubricating solvent. Drain completely. This will remove any moisture present inside the reducer. It will also remove all old lubrication.
- Overhaul the speed reducers (seals and bearings) as required.
- Change the oil every five years.

5.3.8—OPEN GEARS

Open gears (speed reducers) are often subject to abnormal wear and corrosion because of unprotected exposure to water, dirt, debris, and the elements. The gears are subject to misalignment caused by the wear of supporting bearings due to the same effects of abnormal wear caused by water and dirt. The maintenance of open gears, pinions, and racks is time consuming and difficult, but is vitally important in extending the life of these parts.

Maintenance: Prior to re-lubricating open gears, it is very important that the gears be cleaned thoroughly. This cleaning can be accomplished by wiping with a rag for some lubricant types or by using an approved solvent. While the gears are clean, prior to applying new grease, the gears should be inspected for any signs of extreme wear, corrosion, or misalignment. After the application of new grease, an inspection should be made of the gears subsequent to the operation of the movable span. This inspection should not only check for the proper application of new grease, but should also check for the proper meshing of the gears. Any indication that the gears are not showing a uniform pattern of pressure along

C5.3.8

If the open gearing is exposed to roadway runoff and debris, consideration should be given to installation of protective covers, enclosures, or other measures to protect the gears. Lubricant wiping from the teeth during operation, immediately after application, is an indication that heavier lubrication is needed, that gear bearing pressures are excessive, or both.

the pitch lines indicates improper alignment and should be corrected.

5.3.9—BRAKES

Span brakes are used to prevent the bridge from closing when in the open position, and also prevent opening when in the closed position until the span locks are driven. Brakes also act as a safety device intended to hold the span during an emergency such as motor failure. Motor brakes usually are designed to hold the span during temporary stops by the operator. See Chapter 2.8.2 for component details of different brake types.

Maintenance: As required (but not less than once per year), check and correct:

- Thruster oil level (change if dirty): Use Type 10 aviation hydraulic oil unless otherwise directed by the bridge maintenance manual or brake manufacturer.
- Tighten loose bolts and replace broken bolts.
- Adjust push rod seals (repack if necessary).
- Spring adjustment.
- Adjust shoe clearance if necessary.
- Thruster travel and time for brake to fully engage: Adjust thruster orifice or travel as required.
- Condition of the shoes: Clean and polish any rust on brake drum and disc. Replace if worn.
- Spot paint as required.

When required, completely overhaul the brake unit to include new seals, shoes, oil, and paint.

Maintenance for Solenoid and Magnetic Clapper Brakes: As required (but not less than once per year), the following items should be checked and deficiencies corrected:

- **Collections of dirt, gum, or grease:** Clean out by using a small clean paint brush; vacuum cleaner; or clean, lint-free rags.
- **Excessive heating of parts, evidenced by the discoloration of the metal parts, charred insulation, odor or blistering:** Replace any burnt parts, solenoid, or magnets.
- **Freedom of moving parts (no binding or sticking):** Operate manually (make sure that power is turned off). Clean moving parts as required. Do not lubricate the unit unless required by the manufacturer.
- **Corrosion of metal parts:** Replace any badly corroded parts.
- **Loose fasteners:** Tighten loose mountings and connections.

- **Worn or broken mechanical parts:** Replace as required.
- **Voltage to the solenoid coil or clapper magnets:** Correct the source of over/under voltage. The coil should be replaced if it shows signs of damage.
- **Lubrication:** Moving parts should be lightly oiled with light machine oil (apply drops with a toothpick to the bearing surfaces). Do not spray the light machine oil.

5.3.10—BUFFER CYLINDERS

Buffer cylinders are used to absorb shock during the closing of the bridge. Buffer cylinders are mounted vertically on the span on bascule and vertical lift bridges and horizontally on the rest piers on swing span bridges.

Maintenance: As required, but not less than once every six (6) months, check the following and correct deficiencies as necessary:

- Smooth movement of the piston rod.
- Adjust the piston rod contact with the strike plate.
- Check the piston rod for scoring, rust, and lubrication.
- Check for air leaks.
- Check pressure gauge (should read between 25–35 psi (170–245 kPa)).
- Replace pressure gauges if not working properly.
- Replace air valves if not working properly.

Buffer cylinders should be replaced in groups. All cylinders that are required to perform simultaneously should be replaced as a set.

5.3.11—AUXILIARY POWER

Most movable bridges are designed with an auxiliary power plant to provide power to the bridge in case of failure of the primary power. Auxiliary power usually consists of an internal combustion engine, electric generator, and auxiliary equipment. The engine can be powered by either diesel fuel, gas (natural or LPG), or gasoline. Diesel fuel is preferred. Gas or gasoline systems require adequate ventilation to avoid the risk of explosive vapor accumulation.

Maintenance: The maintenance depends upon the prime mover. One item that is common with all of the types of prime movers is the lubrication. The engine generator sets should be exercised at least once a month. Preferably, this should be done under load. However, because the operating time of movable bridges is usually of a very short duration, this is not always possible. The engine should be operated for a sufficient time to bring the engine up to operating temperature. The most damage that can be done to an engine is to operate it for a short time and then shut it down. This causes the unburned fuel to wash down the cylinder walls. It also increases the amount of moisture that is drawn into the crankcase which causes added corrosion.

In order to increase the life of the engine, a regular changing of the lubricating oil is necessary. The oil and oil filter should be changed at least every six months. When the oil and oil filter are changed, the maintainers should visually check the engine–generator set for proper water level in the radiator, the air filter for cleanliness, and for any signs of excessive leaks in the hoses and around the bearings of the engine and the generator. A visual check of belts, spark plug wires, and other accessories should be made at this time. The type and viscosity of oil should be as recommended by the engine manufacturer. In the absence of any specific recommendation by the engine manufacturer, a multipurpose oil suitable for diesel, gasoline, natural gas, or LPG fueled engines (10W/40 (or similar); API service CD, CC, SF, SE, or SD fully detergent, all-weather oil formulated to retard the formation of sludge, varnish, and carbon deposits) should be used.

Air Motors: During routine maintenance, make the following checks:

- Caution: It is inadvisable to run air motors with no load. Do not run air motors with motor drive shaft disconnected from span drive.
- Verify that the air supply to the motor is at or near 90 psi (618 kPa) and that it contains lubricating oil.
- Check and refill lubricator.
- Check and replace or drain filter cartridges.
- Operate the system through an entire cycle and verify proper speed control, pressure, and operational characteristics.

5.3.12—LIVE LOAD SHOES AND STRIKE PLATES

Live load shoes and strike plates carry the weight of the traffic passing over the bridge, and, if provided, are generally located on both sides of the leaves or span.

Every time the machinery is lubricated, maintenance inspectors should check for full contact between the live load shoe and the strike plate, and shim the strike plate or live load shoe as required to obtain full contact. Adjustments should be made with no live load on the bridge. No vertical motion, clicking, banging, or other signs of lack of a full contact should occur with the passage of vehicles. Shims tend to deteriorate rapidly due to corrosive action and the repeated application of loads causing slight relative movement. This movement results in fretting corrosion. Because of this, the shims should be checked on a regular basis and replaced as required.

C5.3.12

The live load shoe adjustment usually has to be coordinated with the span lock adjustment. For most types of span locks, the adjustment of span locks and live load shoes cannot be done independently of one another.

5.3.13—FASTENERS

Fasteners are used to hold machinery elements and supports in place. Fasteners come in different forms: anchor bolts, turned bolts, high strength bolts, and rivets.

During every inspection the fasteners should be checked for tightness. Mounting and cap bolts should be checked for all their nuts to be secured by effective locks. They should not be single-nutted. Maintainers should immediately tighten any loose bolts. Bolts can become stretched from overloads, or work loose from traffic vibrations, and replacement may be required.

During each inspection check the fasteners for corrosion. Report any bolt or rivet that has lost cross sectional area.

Pedestals that have foundation bolts embedded in them should be checked for cracking during each maintenance and safety inspection. Severe horizontal forces transmitted through the bolts to the concrete may crack the pedestal. Concrete that is cracked should be repaired as soon as possible.

C5.3.13

See C5.2.6 for a discussion on stocking fasteners.

5.3.14—SUMP PUMPS

Sump pumps are used to dewater counterweight pits. Sump pumps are small, automatically operated pumps that are fitted with either floats or other types of liquid level controllers to detect the presence of water in the sump, and activate the pump.

Sump pumps that run infrequently generally do not require much maintenance. However, the following items should be checked every time the bridge is lubricated and repaired or corrected as necessary:

- Discharge line and fittings for breaks and leaks.
- Power lines for shorts and breaks.
- Suction screen for breaks or clogging.
- Pump operation should be tested by pouring water into the sump until the pump actuates automatically and monitored until the pump shuts down automatically.

5.3.15—END JACKS, CENTER WEDGES, SPAN LOCKS, & OTHER SPECIAL MACHINERY

There are many types of end jacks, center wedges, span locks, and other machinery especially designed for certain types of movable bridges. These types of machinery are usually comprised of the various components discussed in this chapter and their maintenance and lubrication should be similar to those components.

5.3.16—WIRE ROPES

Wire ropes, found primarily on vertical lift bridges, serve a dual purpose as suspender ropes and as operating ropes. Wire ropes are formed by spirally winding individual strands of wire into a rope configuration. As they are formed, they are usually wound around a core of jute saturated with lubricant. During this forming process, the strands are also lubricated. The lubricant prevents the individual wires from experiencing internal abrasion wear and/or corrosion and must be replenished in order to extend the life of the wire rope.

Maintenance: Wire ropes used for suspender ropes on vertical lift bridges should, as a general rule, be cleaned and lubricated at least every 2,000 openings or yearly, whichever occurs first. Maintainers should note any worn, broken, misaligned, and corroded strands and file a deficiency report if the number of damaged or broken wires exceeds the guidelines in Section 2.8.2.11.4. Because of the large ratio of sheave diameter to rope diameter, internal friction between individual strands is usually not a concern with suspender ropes. Corrosion of the outer wire layers is the primary problem encountered with suspender ropes.

The type of lubricant for wire ropes depends on many factors such as rope type, the temperature at which the rope is operating, and whether or not the rope is subject to reverse bending. The lubricant must be "thin" enough to provide protection against corrosion of the outer strands.

C5.3.16

The suspender ropes require thorough cleaning prior to lubrication. Any area that shows signs of requiring spot lubrication can be handled by the everyday maintenance person, but extensive cleaning and lubrication should be handled by personnel with the equipment and knowledge to perform this work. In selecting a lubricant, it is recommended that the services of a qualified rope manufacturer be engaged.

The maintenance interval that is appropriate for wire ropes is significantly affected by environmental conditions, load in the rope, sheave diameter, wire rope type and size, lubrication type, and quality of application procedures. Individual owners should modify the suggested intervals based upon performance in actual use at the particular bridge site.

5.3.17—BALANCE WHEELS

The balance wheels on center bearing swing spans maintain span stability in a near horizontal plane when the span is moving to the open position. They are not designed to carry any of the dead load or live load of the span. The wheels, generally made of cast iron, rotate on sleeve bearings. They ride on a circular track that is usually cast integrally with the operating rack. The wheels are set with a very small clearance between the wheel and the track. Maintainers should verify the required clearance between the wheels and track, and report any change in alignment.

Except for periodic lubrication of the bearings, and an occasional painting, the balance wheels require little maintenance. The bearings of the balance wheels should be lubricated in accordance with Table 5.3.2.1-1. The outer surface of the wheel and the treads may be coated with dry lubricant, or wiped with a rag saturated in a light weight (number 10) oil, and then wiped nearly dry to prevent corrosion.

5.3.18—SUPPORT ROLLERS

The support rollers for rim bearing swing spans carry the entire dead and live load of the span. The rollers are tapered and held in proper radial alignment by structural members or rods that are, in turn, held in place by a center casting, which rotates about a center pivot pin. The support rollers are usually made of cast steel, and are fitted with bronze bearings. Since the rollers are tapered, it is necessary to maintain their radial position with thrust bearings.

The primary maintenance required for support rollers is lubrication. Because of the heavy loads imposed on the rollers, it is impossible to maintain the paint on the surface of the support rollers and treads. Therefore, a frequent light coating of 10 weight oil on the surface that is then wiped almost dry to reduce adhesion of grit is a typical method to reduce corrosion. Special attention should be given to verify that the thrust bearings are receiving sufficient lubrication. The thrust bearings, center pivot bearing, and wheel bearings should be greased in accordance with Table 5.3.2.1-1.

5.3.19—MAINTENANCE LUBRICATION LOG

In order to evaluate the effectiveness of existing methods, and facilitate QC/QA measures for maintenance of mechanical components, it is often useful to have records of how often lubrication is performed, by whom, the type of lubricant used, comments on any problems or observations, and listing of any corrective measures. If a bearing grease fitting or grease passageway has experienced caking of lubricant and has been flushed out with solvents such as kerosene, it is important to have this information available for evaluators when corrective measures are being developed. A sample lubrication log is shown in Table 5.3.19-1.

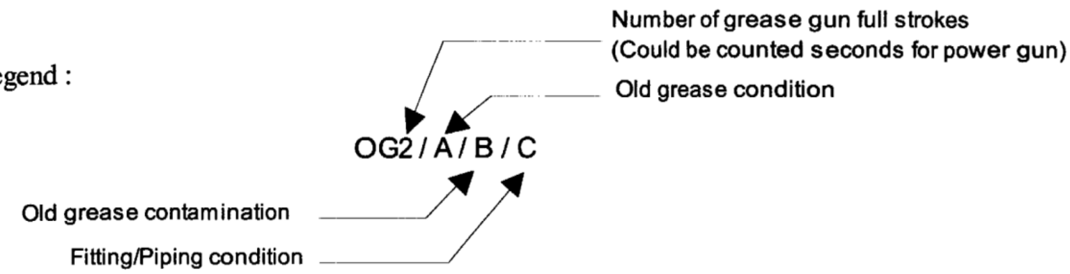
C5.3.19

The lubrication log is used to record lubrication data from the field for QC/QA purposes and to verify that recommended lubrication has been performed, and by whom.

Type of Lubricant :	NLGI #2, antirust, EP, Lithium Grease		
Brand Name:	Brand X - Litholube EP		
Component Type :	Trunnion Bearings - Sleeve Type		
Method of Application :	Standard hand held grease gun - button fittings		
Name of Person Filing Log :	John Q. Luber	Log Date :	08/08/96

LOCATION	AMOUNT	DATE	INITIALS	COMMENTS
NW Bearing	3 strokes on gun	07/15/96	FS	OG2/F/OK/OK
NE Bearing	4 strokes on gun	07/15/96	FS	OG4/P/AP/D Poor access- hard to lube.
SW Bearing	N/A	07/15/96	FS	OG N/A / C/UK/BNG Replace broken fitting.
SE Bearing	4 strokes on gun	07/15/96	FS	OG3/F/AP/OK
NW Bearing	2 strokes on gun	08/01/96	JQL	
NE Bearing	2 strokes on gun	08/01/96	JQL	
SW Bearing	10 strokes (tried to pump out old grease)	08/01/96	JQL	OG3/P/CD,CK/OK (new) Flush out old grease.
SE Bearing	3 strokes on gun	08/01/96	JQL	OG2/P/AP/OK

Sample Legend :



OG = Old Grease which extrudes from component as new grease is pumped in.
A = G = Good.
F = Fair.
P = Poor.
C = Critical.
B = AP = Grit or abrasive particles found in old grease extruding from bearing by feel.
CD = Color of old grease is dark - may have wear or dirt particles inside, or may be subjected to heat.
CL = Color of old grease milky - may have contamination.
FW = Free water droplets found in old grease.
CC = Chemical contamination suspected - (say why).
BR = Burned smell to old lubricant - suspect overheating.
CK = Old grease is hard - may be caking up.
UK = Unknown.
OK = No defects found.
C = L = Fitting appears loose.
B = Fitting broken but usable.
BNG = Fitting broken and unusable.
D = Fitting dirty, coated with lubricant and/or grit. Required solvent cleaning prior to lubrication.
OK = No defects noted.

Table 5.3.19-1 – Sample lubrication log

5.3.20—SAMPLE LUBRICATION CHART

The lubrication chart for a sample vertical-lift span bridge follows. This chart is a sample of the format for such a document, and is not intended to be used as a guide for selection of lubrication type. See Section 5.3.2.1 for general lubricant selection recommendations.

C5.3.20

The lubrication chart is a summary of the recommended areas to be lubricated and the type of lubricant recommended for each. It is intended for use by experienced maintainers and should be modified based upon performance QC/QA data developed from the lubrication log and other practical considerations. See Figures C5.3.20-1 to C5.3.20-5 for examples of lubrication charts.

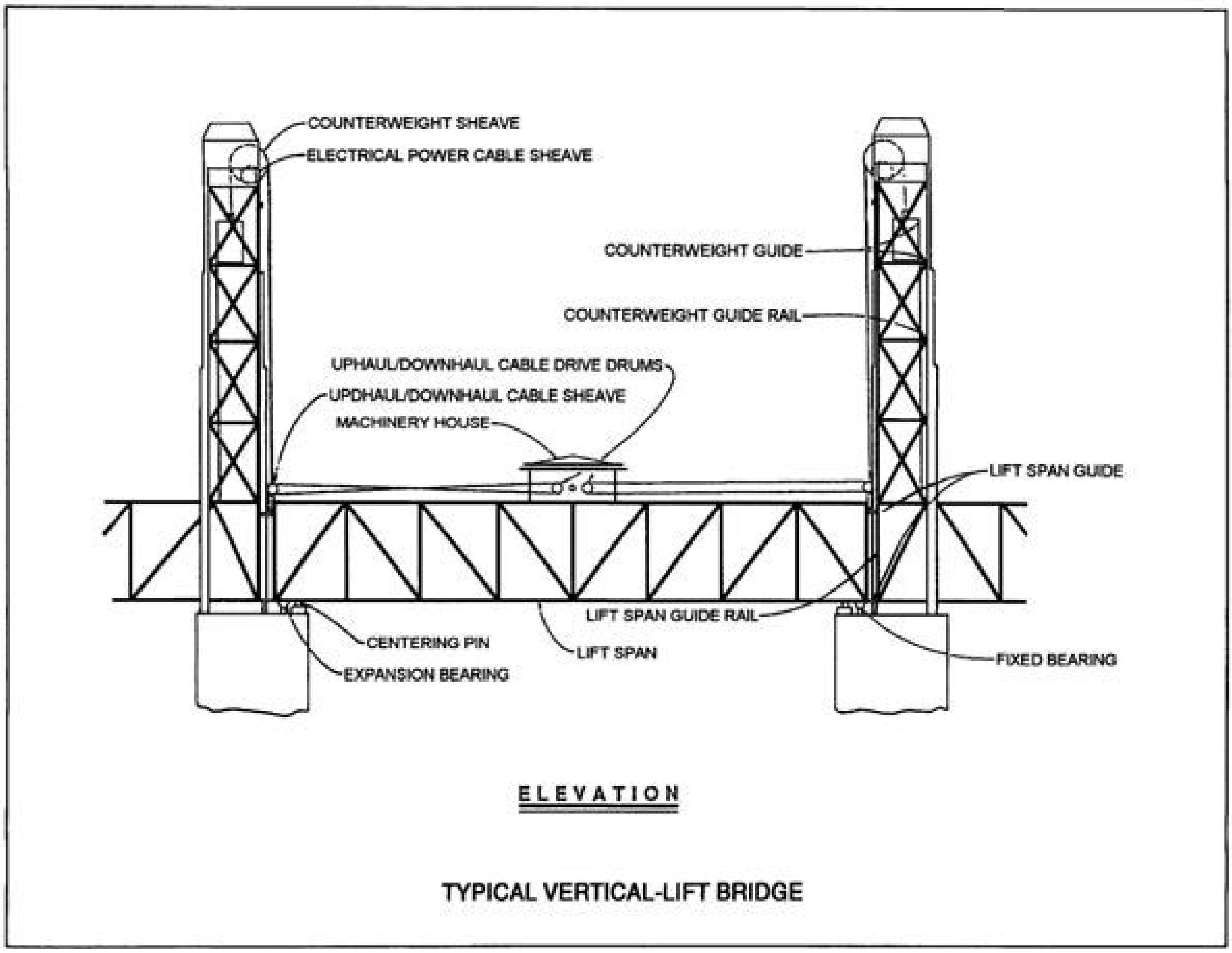


Figure C5.3.20-1 – Lift bridge lubrication chart

ITEM NO.	NAME	NO. OF GREASE FITTINGS	LUBRICATION INTERVAL	RECOMMENDED LUBRICANT
1	Pillow Block Bearing	25	Monthly	Grease: Multipurpose, EP Lithium NLGI Grade-2
2	Height Gauge Bearing	3	Monthly	Grease: Multipurpose, EP Lithium NLGI Grade-2
3	Speedometer Drive Bearing	1	Monthly	Oil: Gasoline Engine Type, Multi Viscosity, 15W40
4	Height Gauge Bevel Gear Set	1	Every 6 Months	Grease: Molybdenum Base, Multi-lube, NLGI Grade-light, Extreme Pressure Open Face Gear
5	Spur Gear and Pinion Set	4	Monthly	Grease: Molybdenum Base, Multi-lube, NLGI Grade-light, Extreme Pressure Open Face Gear
6	Right Angle Drive Gear Box	1	Monthly	Oil: Gasoline Engine Type, Multi Viscosity, 15W40
7(a)	Main Gear Box (Spur Gear Sets Bevel Gear Sets)	1	Every 6 Months or 1000 Openings	Grease: Asphaltic Gear Grease
7(b)	Main Gear Box (Gear Engage Coupler)	1	Every 6 Months or 1000 Openings	Oil: Gasoline Engine Type, Multi Viscosity, 15W40
8	Manual Hand Brake	7	Monthly	Oil: Gasoline Engine Type, Multi Viscosity, 15W40
9	Gear Engage Shaft Bearing	2	Monthly	Oil: Gasoline Engine Type, Multi Viscosity, 15W40
10	Throw Out Bearing	1	Monthly	Grease: Multipurpose, EP Lithium NLGI Grade-2
11	Overhead Hoist Trolley	7	Yearly	Grease: Multipurpose, EP Lithium NLGI Grade-2
12	Overhead Hoist	1	Yearly	Oil: Gasoline Engine Type, Multi Viscosity, 15W40
13	Uphaul/Downhaul Cable Sheave	8	Every 2 Weeks or 30 Openings	Grease: Multipurpose, EP Lithium NLGI Grade-2
14	Counterweight Sheave Bearing	24	Every 2 Weeks or 30 Openings	Grease: Multipurpose, EP Lithium NLGI Grade-2
15	Electrical Power Cable Sheave Bearing	12	Every 2 Weeks or 30 Openings	Grease: Multipurpose, EP Lithium NLGI Grade-2
16	Lift Span Guide Rail	4	Every 3 Months	Grease: Multipurpose, EP Lithium NLGI Grade-2
17	Counterweight Guide Rail	4	Every 3 Months	Grease: Multipurpose, EP Lithium NLGI Grade-2
18	Pedestrian Gate	5	Every 3 Months	Oil: Gasoline Engine Type, Multi Viscosity, 15W40
19	Fixed Bearing Pin	2	Monthly	Grease: Multipurpose, EP Lithium NLGI Grade-2
20	Expansion Bearing Pin	2	Monthly	Oil: Gasoline Engine Type, Multi Viscosity, 15W40
21	Centering Pin	2	Monthly	Grease: Multipurpose, EP Lithium NLGI Grade-2
22	Uphaul/Downhaul Cable	16	Yearly or 1000 Openings	Grease: Multipurpose, EP Lithium NLGI Grade-2
23	Counterweight Cable	96	Every 5 Years	Grease: Multipurpose, EP Lithium NLGI Grade-2

Note: All lubrication points on or inside electrical equipment (motors, limit switches, traffic gates, etc.) will be serviced by an electrician monthly.

TYPICAL LUBRICATION SCHEDULE

Figure C5.3.20-2 – Typical lubrication schedule

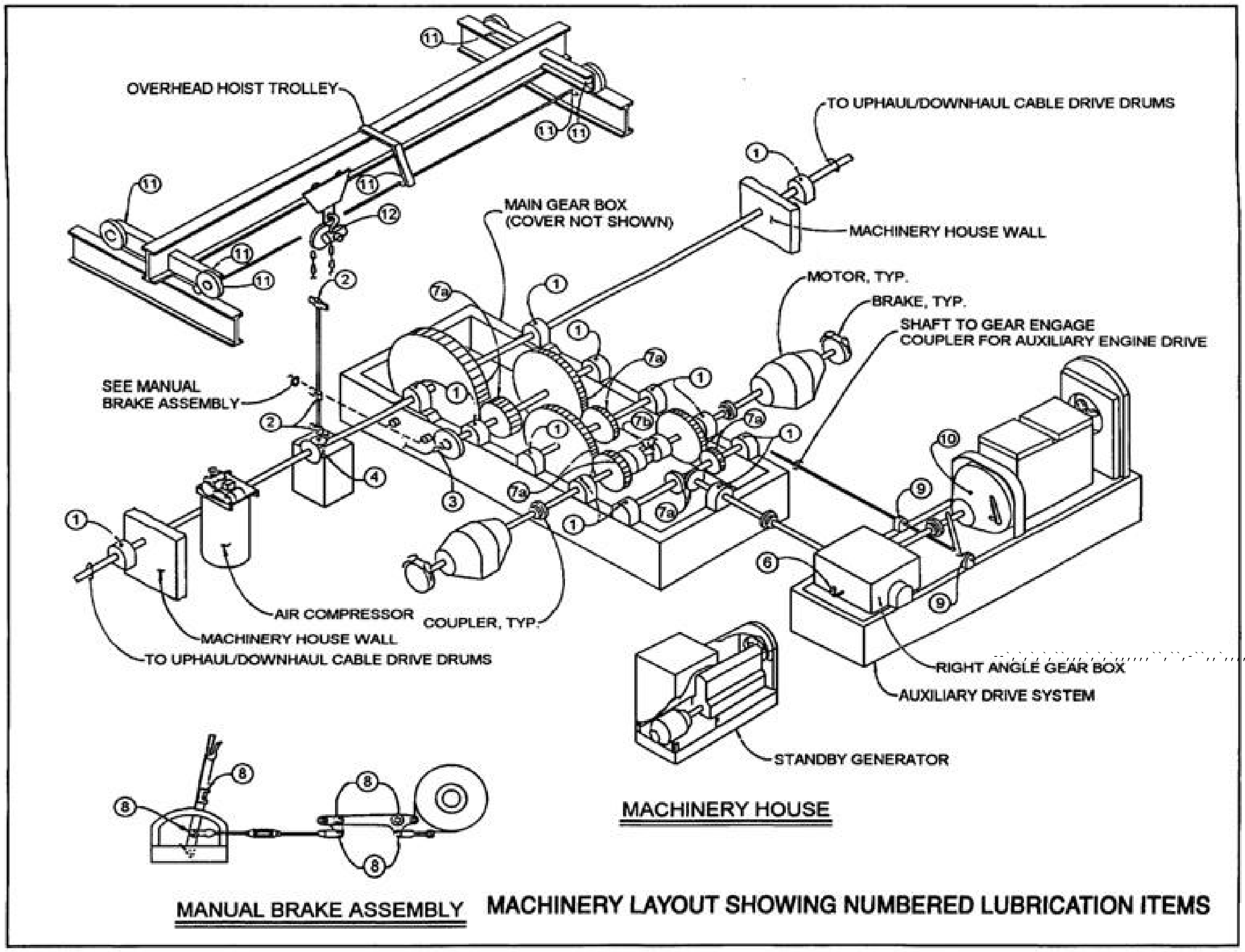


Figure C5.3.20-3 – Machinery lubrication items

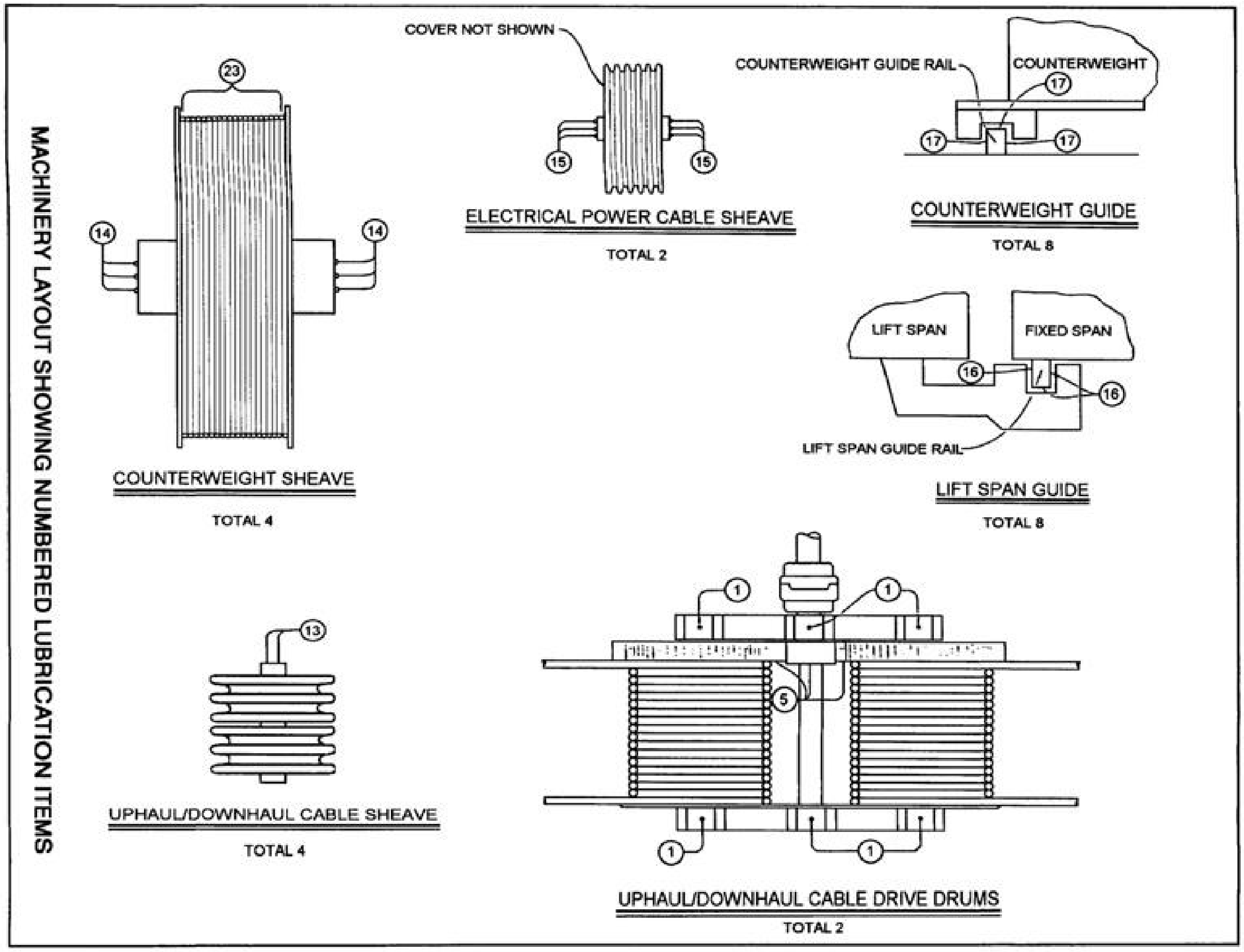


Figure C5.3.20-4 – Machinery lubrication items

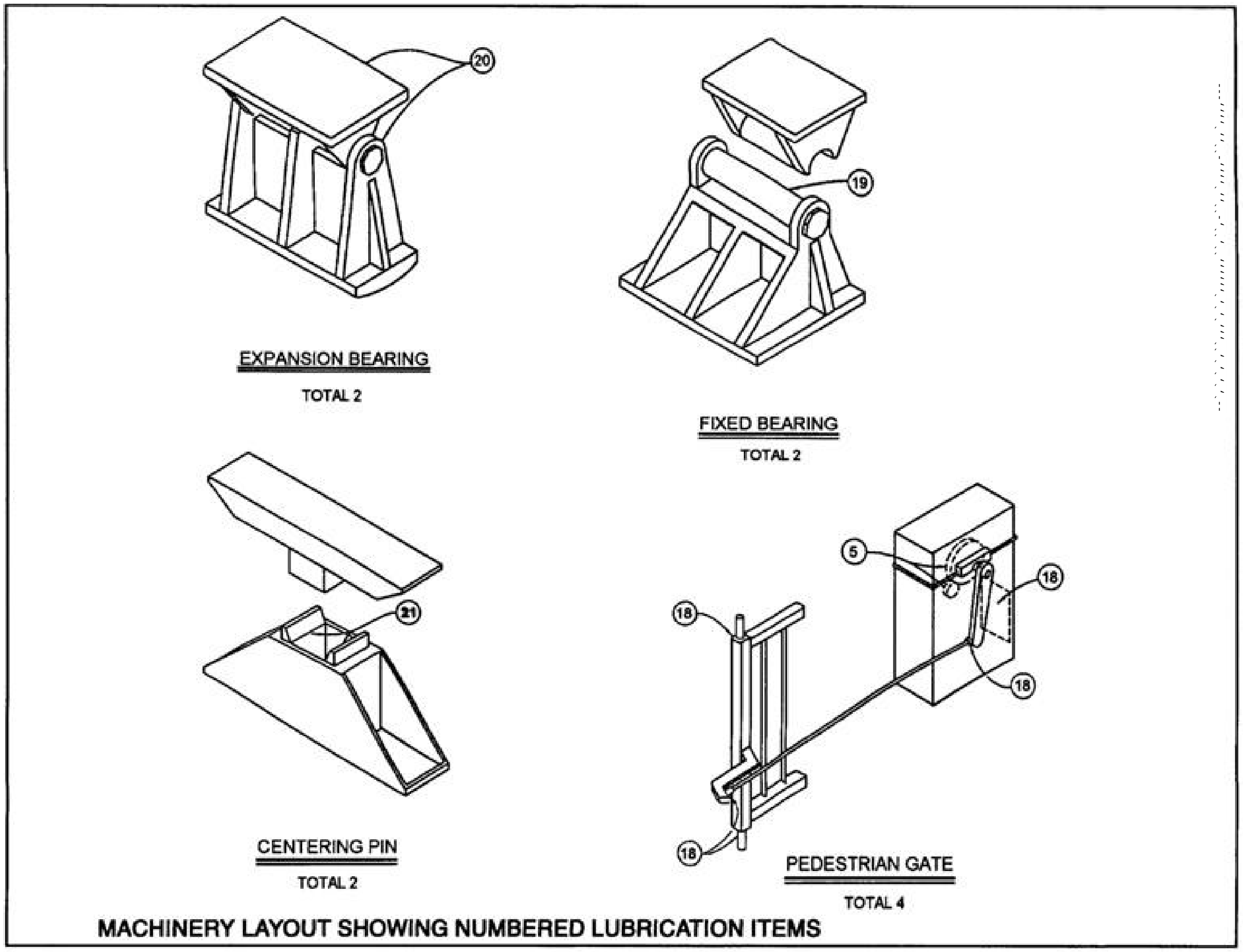


Figure C5.3.20-5 – Machinery lubrication items

5.3.21—OPERATOR'S (TENDER'S) HOUSE

The operator's (tender's) house mechanical systems should be regularly maintained to provide a safe and comfortable environment for the bridge tender. Regular maintenance should include the following items:

- Test smoke alarm system for proper function and inspect fire extinguishers for proper charge.
- Check plumbing, piping, and heating systems for leaking or loose joints.
- Replace heating and air conditioning system filters and perform manufacturer recommended routine HVAC maintenance as required.

CHAPTER 5.4—HYDRAULIC MAINTENANCE

5.4.1—GENERAL

Hydraulic systems that are not properly maintained are prone to leak and may blow a seal or fail to operate at any time, particularly during adverse weather conditions when operating loads from wind or ice increase the loads on the system.

Leakage and improper performance are unacceptable eventualities that can only be avoided by diligent maintenance, inspection, testing, cleaning, adjustment, and repair.

Inspection for maintenance is similar to safety inspection, but may involve considerably more disassembly. See Section 2.8.2.12 for basic inspection recommendations. Detailed procedures involving disassembly are covered in this chapter.

C5.4.1

This Manual is not intended to cover detailed individual inspection, testing, adjustment, and repair procedures for specific manufactured components. The operation and maintenance manuals should cover these items, if bridge-specific manuals are available for the structure. If manuals are not available, maintainers should obtain the necessary documentation from the manufacturer of the individual components. Most hydraulic components have unique proprietary design features that must be explained by the original component manufacturer, if proper maintenance is to be performed.

5.4.2—HYDRAULIC COMPONENTS

Typical hydraulic components that should be specifically addressed in the hydraulic maintenance program include, but are not limited to the following:

- Accumulators
- Valves
- Hydraulic cylinders
- Hydraulic pumps
- Hydraulic motors and rotary actuators
- Filters
- Rigid piping and tubing
- Hydraulic hose
- Reservoirs
- Radiators or other system cooling devices
- Hydraulic fluids
- Hydraulic system interlocking sensors and controls
- Hydraulic system checkout

C5.4.2

Unique designs and unusual systems, which are beyond the scope of this Manual, may be present on some existing bridges. Maintainers responsible for such systems should develop a detailed maintenance program that addresses the specific equipment present on the bridge. Assistance may be provided by experienced designers, manufacturers, and maintainers of hydraulic systems. Because specific details of individual components vary from manufacturer to manufacturer, specification information should be obtained from the manufacturer.

5.4.3—ACCUMULATORS

Accumulators should be performance tested by observing the pump cycle timing during each maintenance inspection. If pump cycle timing varies from one inspection to the next, the loss of gas cushion from within the accumulators may be the reason. The smaller the gas cushion within the accumulators, the shorter the time will be from pump shut-off at the high pressure switch cutoff point to pump restart at the low pressure pump start point.

C5.4.3

Caution: Accumulators are pressure vessels. Inspectors should use extreme care during inspection. Only qualified, trained maintainers should disassemble accumulators for inspection.

System pressures should also be recorded at pump stop and start to check that the pressure switch has not been reset or damaged. Checks should be made for leaks and/or pump damage that may cause rapid pump cycling. Bladder-type accumulators present on newer systems rarely have this problem. The older piston type or other accumulators may be sounded with a hammer handle or mallet to determine fluid level. This level should be marked on the tank exterior for monitoring.

A reliable method to verify a failed bladder type accumulator is to bleed hydraulic pressure and check the remaining gas pre-charge pressure against the original pre-charge pressure. Pre-charge pressure should be checked and adjusted periodically.

5.4.4—VALVES

A checklist for recurrent solenoid burnout of AC valves is presented in this section. Coil burnout is more common on AC than on DC valves because of the high inrush current. Until the armature can pull in and close the air gap in the magnetic loop, the inrush current is often five times as high as the steady state, or holding, current after the armature has seated. Inrush is approximately the same as holding current on a DC valve.

Coil does not match operating voltage: Improper match between the electrical source and the coil solenoid is sometimes a cause for coil burnout. Check these possible causes:

- **Voltage too high:** The operating voltage should not be more than 10 percent higher than the coil voltage rating. Excessive voltage causes excessive coil current, which may overheat the coil.
- **Voltage too low:** The operating voltage should be no less than 10 percent below the coil voltage rating. Low voltage reduces the mechanical force of the solenoid. It may not be able to overcome the spring pressure and continue to draw inrush current, and be unable to actuate the valve.

The low voltage test should be made by measuring the voltage directly on the coil wires while the solenoid is energized, and with its armature blocked open so it is drawing in rush current. Energize the solenoid just long enough to take a voltage reading. Also take a no-load reading with the solenoid coil disconnected from the feed wires. A difference of no more than 5 percent between these two readings indicates excessive resistance in the wiring circuit or insufficient volt-ampere capacity in the control transformer.

Overlap in energization: On some double solenoid valves, if both solenoids are energized at the same time and held in this state for a short time, the last coil to be energized will burn out from the excessive inrush current.

This burnout condition will occur only on double solenoid valves where the two solenoids are yoked to opposite ends of a

C5.4.4

Valve inspection is covered in Section 2.8.2. Normal valve maintenance should not require disassembly. However, as valve seals and springs age, pressure and flow control valves require adjustment to maintain design system pressures. Performance tests of valves can be done using manufacturers' recommended procedures and the manual override features built into some remote valves to facilitate diagnostic tests. Disassembly for replacement of seals and other internal parts should only be done by trained specialists, who have been given appropriate instruction by the valve manufacturer, or other parties with pertinent knowledge about the individual valve model being serviced.

common spool. If each solenoid is free to immediately close its air gap, neither will bum out if both are simultaneously energized.

Careful attention must be given to electrical circuit wiring to make certain that the system does not energize both solenoids at the same time.

Even with correct circuit design and interlocking circuits, a relay with sticking contacts, or slow release, could be responsible for a momentary overlap of energization on each cycle and eventual premature coil burnout.

Rapid cycling: Since inrush current is much more than holding current, a standard AC coil on an air gap solenoid may overheat and burn out if required to cycle too frequently. The extra heat generated during inrush periods cannot dissipate fast enough. The gradual buildup of heat inside the coil winding may, in time, damage the coil insulation.

High cycling applications can be roughly defined as those requiring the solenoid to be energized more than 5 times per minute. On these applications, oil immersed solenoids are required. The coil of this type operates cooler because heat is conducted more rapidly from the winding through the oil.

Dirt in oil or atmosphere: A small solid particle lodged under the solenoid armature may keep it from fully seating against the core, causing coil current to remain higher than normal during the holding period. Be sure that solenoid dust covers remain tightly in place to protect against dust deposited from the air.

Small dirt particles in the oil may lodge on the surface of the valve assembly, glued there by varnish circulating in the oil, or the varnish itself may cause excessive spool drag and excessive coil current. Varnish often forms in systems where the oil is allowed to run too hot.

Environmental conditions: Abnormally high or low ambient temperatures to which a solenoid is exposed for an extended period of time may cause the coil to burn out.

- **High temperature:** Coil insulation may be damaged and one layer of wire may short to the next layer. A heat shield between the valve and the heat source may give some protection against radiated heat. Oil immersed solenoids afford the best protection against heat conducted either through metal surfaces or from surrounding high temperature.
- **Low temperature:** Cold ambient temperatures cause hydraulic fluid to become more viscous, possibly overloading the solenoid valve capacity. Mechanical parts of the valve or solenoid structure may distort, causing the valve spool to stick and burn out the coil. Hydraulic systems in cold climates should be designed to keep fluid temperature within the acceptable range for the fluid and all components. If high viscosity during cold weather is believed to be a cause for component failure, the system

should be heated to control hydraulic fluid temperatures within the acceptable range.

Dead end service: Fluid circulating through a solenoid valve helps carry away electrical heat. Some valves depend on fluid flow to keep excessive heat from accumulating, and if used on dead end service, where the solenoid may remain energized for a long time without any fluid flow, the coil may be prone to burn out.

Atmospheric moisture: High humidity, along with frequently changing ambient temperature, may form corrosion due to condensation on metal parts of the solenoid structure, causing the armature to drag or the spool to stick. Humidity also tends to deteriorate standard solenoid coils, causing shorts in the windings.

Changing to molded coils or oil immersed solenoids may correct this type of problem. Keep solenoid protective covers tightly in place, and it may be advisable to seal the electrical conduit openings after the wiring is installed.

5.4.5—HYDRAULIC CYLINDERS

Figure 5.4.5-1 shows an exploded view of a typical double acting hydraulic cylinder. The key to maintenance of hydraulic cylinders is to keep them and the fluid clean. Cylinders are precision machined and polished both internally and on the piston shaft so that seals seat positively without leakage, and also to prolong seal life. Nothing will lead to faster development of leaks than the intrusion of abrasive grit in the hydraulic fluid, or grit adhered to the piston shaft building up and bypassing the wiper seal. The environment at most movable bridges is hostile and prone to intrusion of gritty particulates that are wet and salt contaminated. Every effort should be made by maintenance forces to control the inflow of this hazardous material to the area of all hydraulic components, but particularly to the area where hydraulic cylinders are present. Hydraulic cylinders should be kept clean and completely free of grit and contaminants that might adhere to the piston shaft.

C5.4.5

Cylinder inspection is covered in Chapter 2.8.2. The discussion about valve disassembly for part replacement presented in C5.4.4 applies to cylinders, pumps, motors, and other manufactured components.

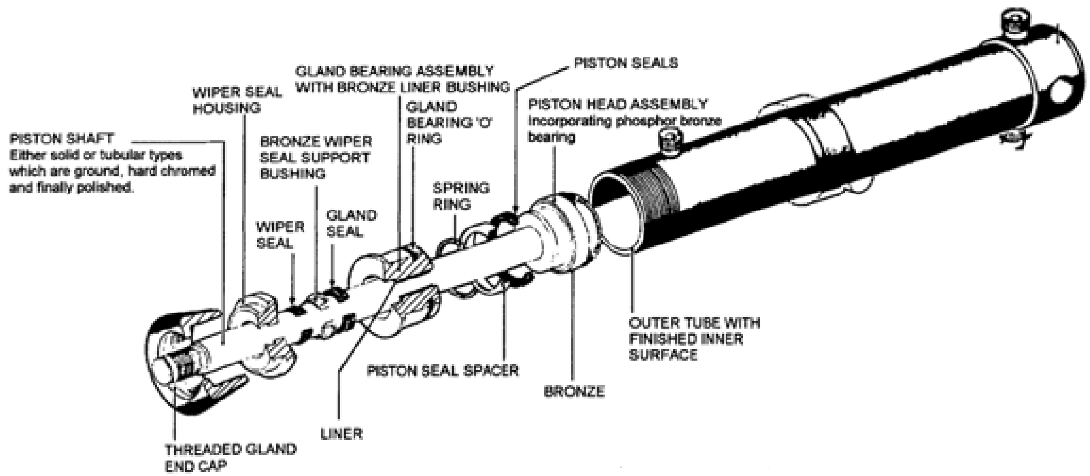


Figure 5.4.5-1 – Typical double-acting cylinder

The following additional items should be checked periodically by maintenance forces:

- Cylinder end fittings and mounts should be checked for cleanliness and for wear. Alignment of the cylinders and attachments should be checked at the same time. Misaligned cylinders wear very quickly and will soon begin to leak due to rapid seal wear.
- Gland end caps should be checked for leakage. A primary area of concern is that the cylinder is never disassembled without careful cleaning. It is imperative that any contaminants be thoroughly cleaned off the exterior before the cylinder is disassembled. Internal parts should be cleaned carefully with a lint-free cloth before reassembly.
- Wiper seal and housing should be examined for surface deterioration and/or signs that grit has passed through and adhered to the piston shaft.
- Maintainers should examine the fully extended piston shafts during every maintenance inspection. The shaft should have a mirror polished surface without any scratches, striations, or scoring. If scoring is found, every effort should be made to immediately determine and correct the cause. Damaged piston shafts or internal surfaces of the cylinder will wear seals rapidly. Damaged surfaces may be refinished, but this is expensive and requires component removal and a significant amount of downtime, unless spares are installed in the interim.

5.4.6—HYDRAULIC PUMPS

The pump is the component most subject to wear and the one most likely to give trouble. On systems where the pump has to be replaced more often than seems necessary, one or more of the following problems may be the cause:

Pump cavitation or air leaks: Cavitation or fluid aeration by air leakage cause an inability of the pump to draw a full charge of hydraulic fluid. When a pump starts cavitating, its noise level increases and it may become very hot around the shaft and front bearing. Cavitation is a process in which tiny gas or vapor bubbles implode at the pump outlet, causing metal erosion, leading ultimately to pump destruction. The inspector will probably be able to hear a buzzing, rattling sound in the pump if there is cavitation. The sound is as though a handful of stones were tossed into the pump. A worn pump may also cause noise (see Table 2.8.2.12.6-1 for additional details). Other symptoms of cavitation or aeration are erratic movement of the cylinders, difficulty in building up full pressure, and a milky appearance of the hydraulic fluid. If cavitation is suspected, check these points:

- Check the condition of the pump inlet strainer. Clean it even if it does not look dirty. Use a solvent and blow dry with an air hose using only dry, clean air. Varnish deposited in the wire mesh could be restricting the hydraulic fluid flow even though it may be almost invisible. If brown varnish deposits are found on the internal surfaces of the pumps or valves, this is a sure indication that the system has been operating at too high a temperature. A heat exchanger or other system designed to reduce maximum operating temperature to within the acceptable range for the fluid should be installed.
- Check for restricted or clogged pump inlet plumbing. If hoses are used on the inlet side, be sure they are not collapsed. Only hoses designed for vacuum service should be used at the pump inlet. They have an internal wire braid or other special design features to prevent collapse.
- Be sure the air breather on the reservoir is not clogged with dirt or lint. On systems where the air space above the hydraulic fluid is relatively small, the pump could cavitate during its extension stroke if the breather becomes clogged.
- Hydraulic fluid viscosity may be too high for the particular pump. Some pumps cannot pick up prime on heavy hydraulic fluid or will run in a cavitated condition.
- Cold weather start-up can be particularly damaging to a pump. Running a pump across a relief valve for several hours to warm up the hydraulic fluid can severely damage the pump if it is running in a cavitated condition during this time.
- Check the pump inlet strainer size. Be sure the original strainer has not been replaced with a smaller size.

Increasing its size (number of square inches of filtering surface) may help.

- The use of a higher quality hydraulic fluid may reduce the formation of varnish and sludge.
- Determine the recommended speed of the pump. Make sure the original electric motor has not been replaced with one that runs at a higher speed.
- Be sure the pump has not been replaced with one that delivers a higher flow rate that overloads the inlet strainer. Increase the inlet size if possible.

Air Leaking into the System: The air that is in a newly assembled system should purge itself after a short time. The system should be run perhaps 15 to 30 minutes under very low pressure. Air will dissolve in the hydraulic fluid, a little at a time, and be carried to the reservoir from where it can escape. The air purging process should be accelerated by bleeding air from high points in the system, especially on the cylinders.

Air, which comes into the system from continuous air leaks, will cause the hydraulic fluid to assume a milky appearance a short time after the system is started. To find where air is entering the system, check the following:

- Be sure the hydraulic fluid reservoir is filled to its normal level, and that the pump intake is well below the minimum hydraulic fluid level. The NFPA reservoir specifications call for the highest point on the strainer to be at least 3.0 in. (76 mm) below minimum hydraulic fluid level (Reference 115).

  Check the hydraulic fluid level when all cylinders are extended to be sure it is not below the "low" mark on the level gauge. However, do not overfill the reservoir when the cylinders are extended; it may overflow when the cylinders retract.
- Air may be entering around the pump shaft seal. Gear and vane pumps, which are pulling hydraulic fluid by suction from a reservoir, will have a slight vacuum behind the shaft seal. When this seal becomes badly worn, air may enter through the worn seal. Piston pumps usually have a small positive pressure, up to 15 psi (103 kPa), inside the case and behind the shaft seal. Air is unlikely to enter through this route.
- Check for air leaks in the pump inlet plumbing, especially at union joints. Check for leaks in hoses used at the inlet line. An easy way to check for leaks is to squirt hydraulic fluid over a suspected leak. If the pump noise diminishes after you seal around a fitting temporarily with fluid, you have found a leak. Check also around the inlet port. Screwing a tapered pipe fitting into a straight thread port will damage the thread, causing a permanent air leak, which is difficult to repair.

- Air may enter through the rodseal of a cylinder. This can happen on cylinders mounted with the rod up that are not properly counterbalanced. On the downstroke, the gravity load may cause a partial vacuum in the rod end of the cylinder. Cylinder rod seals are not designed to seal air out.
- Be sure the main tank return line discharges well below the minimum hydraulic fluid level, and not on top of the hydraulic fluid. On new designs, it may be helpful to enlarge the diameter of the main return line a few feet before it enters the tank. This causes the hydraulic fluid velocity to decrease, which minimizes turbulence in the tank.

Hydraulic fluid leakage from the pump: In case of hydraulic fluid leaking from the pump, maintainers should consider the following procedures:

- **Leakage around the shaft:** On piston pumps and on other pumps that take the inlet hydraulic fluid from an overhead reservoir, there is usually a slight internal pressure behind the shaft seal. As the seal becomes worn, external leakage may appear. This will usually be more pronounced while the pump is running, and may disappear while the pump is stopped. Leakage is unacceptable and should be corrected by installing new seals.

  Other pumps, such as gear and vane types, usually run with a slight vacuum behind the seal. A worn-out seal may allow air to leak into the hydraulic fluid while the pump is running, and hydraulic fluid to leak out after the pump has been stopped. Both conditions are unacceptable and new seals should be installed.
- **Prematurely worn shaft seals** may be caused by excessive hydraulic fluid temperature. At hydraulic fluid temperatures of 200°F (93°C) and higher, a rubber shaft seal will have a very short life. Few seals are designed to operate above 200°F (93°C). Abrasives in the hydraulic fluid may wear out shaft seals quickly, and may also produce circumferential scoring on the shaft. If abrasives are present, they will settle out of a hydraulic fluid sample drawn from the reservoir after the sample has been allowed to stand for an hour. Check all crevices and cracks in the reservoir where dust could enter. The most common entry point is through the reservoir air breather. In extreme cases, the reservoir may have to be sealed air tight, and a slight air pressure of no more than 1.0 psi (7.0 kPa) maintained in the reservoir air space.
- **Leakage around a pump port:** Sometimes leakage at these ports may be caused by damaged threads. Once threads have been damaged, it is very difficult to obtain a leak tight seal. The pump may require replacement if leakage is chronic. Check the tightness of fittings in the ports. If dry seal (National Pipe Taper Fuel or NPTF) pipe threads are used, there should seldom be a need for any kind

of thread sealant. If a sealant is used, teflon sealant that comes in the form of a paste is preferred. Do not use teflon tape, which can foul valves if it enters the system. Beware of screwing tapered pipe threads too tightly into a pump or valve body casting. In the past, this has been the cause for many cracked pump housings.

- If the leakage is from a small crack in the body casting, this has most likely been caused by over tightening a tapered pipe fitting, or from operating the pump in a system where high pressure spikes have been generated as a result of shocks.

Pump delivering little or no flow: In case of a pump delivering little or no flow, maintainers should consider the following procedures:

- The shaft may be rotating in the wrong direction. Shut down immediately. Reversed leads in a three-phase electric motor are a common cause for wrong rotation. Pumps must be run in the direction marked on their nameplate or case.
- The pump inlet may be clogged or restricted. Check the strainer for dirt, and check for a collapsed inlet line.
- Hydraulic fluid may be low in the reservoir. Check the level when all the cylinders are extended.
- Stuck vanes, valves, or pistons may occur either from varnish or water in the hydraulic fluid causing corrosion. Varnish indicates the system is running too hot.
- The hydraulic fluid may be too thin, either from the wrong choice of hydraulic fluid, or from its thinning out at high temperature. A system with this problem may operate normally the first few hours after start-up, then gradually slow down as the hydraulic fluid gets overheated and loses viscosity.

Mechanical trouble: Check for broken shafts or couplings, sheared keys or pins, etc.

Pump running too slow: Most pumps deliver flow rate proportional to the RPM. Some vane-type pumps depend on centrifugal force to extend the vanes into contact with the cam surface, and will deliver little flow at slow speeds.

If the driving electric motor has been replaced, make sure it is the correct speed for the pump.

Pump noise has recently increased: If the pump noise has recently increased, the maintainers should consider the following procedures:

Cavitation of the pump inlet. Refer to the corrective measures previously described.

Air leaking into the system from low hydraulic fluid or other causes previously described.

Mechanical noise caused by loose or worn couplings, loose set screws, badly worn internal parts, etc.

The system may be running with the hydraulic fluid temperature too high.

The pump may be running at higher than its rated speed.

Short pump life: If the pump requires frequent replacement, the maintainers should consider the following procedures:

The pump may be operating above rated maximum pressure. This is a problem, especially if the pump must maintain this pressure for a high percentage of the total running time.

Hydraulic fluid of incorrect viscosity or of poor quality.

Running the system at excessively high temperatures.

Inadequate filtering: Check hydraulic fluid for contamination, and add more or better filters if necessary.

Improper maintenance, particularly failure to regularly clean: Replace the pump inlet strainer and all filters.

Misalignment of the pump shaft with the motor or the engine shaft.

The pump may be running too fast (or too slow): Check RPM.

Inlet cavitation from causes other than those listed above.

Air or water leaking into the system.

5.4.7—HYDRAULIC MOTORS AND ROTARY ACTUATORS

These components should be maintained similarly as previously stated for pumps. Hydraulic motors and actuators are basically hydraulic pumps that are running backward, pressure generates motion instead of the other way around.

5.4.8—FILTERS

Systematic filter maintenance, along with fluid replacement, can eliminate many potential causes of hydraulic system failures. Typical newer installations use ISO 15/13/11 for servo valve applications, ISO 16/14/12 for span drive applications and ISO 17/25/13 for auxiliary drive applications (Reference 7).

Most hydraulic systems continually re-circulate the same hydraulic fluid. Although the systems are “closed”, they are not dirt proof. Harmful dirt and foreign particles may be built-in, introduced, or produced by wear. Built-in contaminants (or dirt) result largely from the manufacture of the equipment, and include core sand, weld splatter, metal chips, lint, and abrasive dust. Introduced contaminants enter the system through seals, hydraulic fluid filler tubes, and breather caps in reservoirs. Lint and other foreign matter may enter when the system is opened.

The hydraulic fluid used for replenishing might contain dirt. Wear contaminants include small particles of metal and sealing materials that result from the wear of moving parts within the system. Hydraulic fluid breakdown can result in the formation of sludge and acids. Acid results from chemical reactions within the hydraulic fluid caused by water, air, heat, and pressure, as well as incompatible hydraulic fluids. Sludge is not generally abrasive. However, it is recognized as the source of resinous

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Periodic sampling and testing of hydraulic fluid can verify filter effectiveness. See Chapter 2.10, Testing and Advanced Inspection Methods.

and gummy coatings on moving parts, and can clog valves and passages. Acids can pit and corrode critical moving parts.

Pressure drop: All system components through which there is flow have a pressure drop. This drop is the net pressure required for the hydraulic fluid to flow from the inlet to the outlet of the component. In filters, this includes the pressure drop across the housing and the filter element. It varies with the flow rate, hydraulic fluid viscosity, and amount of dirt in the filter.

Dirt capacity: This is the maximum amount of contaminant that can be collected by a barrier type filter element without producing a pressure drop that affects the hydraulic system function or damages the filter element. Initially, the pressure drop increases only slightly with increasing contaminant collection.

Filter element maintenance recommendations can be based on either a time interval or pressure drop readings. Service interval recommendations, based upon hours of operation, should be conservative because many factors, which cannot be accurately predicted, affect the rate of contaminant collection. Alternately, for full flow filters, differential pressure readings indicate the actual amount of contaminant collection, and thus are a more realistic basis for element servicing.

With increased emphasis on prevention of bridge downtime, the need for much higher standards of hydraulic fluid cleanliness is ever present. Since pumps and valves have clearances on the order of 5 micrometers (2.0×10^{-4} in.), it is easy to understand the need for maintaining contaminant particles below this size. To meet this demand, filters are available capable of filtering down to the 1 micrometer (4.0×10^{-5} in.) level for flow rates over 100 GPM (6.31 lit/s) and for systems with 5,000 psi (34.47 MPa) pressure.

Owners experiencing problems with contamination of hydraulic system fluid should consider the use of portable recirculating units, which are capable of reducing the contaminant level of the hydraulic fluid to the 1 micrometer (4.0×10^{-5} in.) level, and that can rapidly process the oil in the system at one bridge after another.

5.4.9—RIGID PIPING AND TUBING

Maintaining hydraulic fluid-conducting pipes, tubing, and fittings is a high priority aimed at providing maximum uptime and a minimum of hydraulic fluid leaks and downtime.

Beyond system integrity (or leak-proofness) and adequate service life, these components should provide minimal loss of power and minimal pressure drop as they convey the hydraulic fluid through the system. This means that the fewer the fittings and couplings, the better, since each contributes to the pressure drop. This requirement also calls for minimizing the number of sharp turns in the hydraulic fluid lines, and maintaining the

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Flow rates can be verified by various means. The simplest is timed discharge into a container of known volume. This process can be used during fluid changes as a method to rapidly remove a portion of the fluid and to flush the system, as long as care is exercised to avoid running the reservoir inlet dry. The formula Q = VA, where Q is the flow rate in cubic feet per second (m^3/s), V is the velocity in feet per recommended bend radius of each tube or pipe, whether it is original equipment or a replacement.

For the same reason, tubing and pipes must be sized properly to permit adequate flow without boosting hydraulic fluid velocity above good design practice levels; generally not more than 15 ft./sec (4.5 m/sec) in pressure lines, and not more than 5 ft./sec (1.5 m/s) in suction lines.

In movable bridge hydraulic systems, a number of different types of lines are used. Thus, the fittings, and other hardware needed to connect them, cover a broad range of types, each with specific advantages, and most with some disadvantages. In making the connections from one line to another through fittings or couplings, it is not acceptable for any amount of hydraulic fluid to leak from the system when the fitting is fully tightened. Flared fittings, tapered pipe thread, and a number of types of fittings currently in service are sometimes leak prone. Where possible, replacement pipe, tubing, and fittings should conform to current AASHTO specifications (Reference 6).

Copper and brass pipe or fittings are unacceptable for hydraulic plumbing.

Pipe: Pipe has been used for many years and continues to be popular. The current trend is away from tapered pipe threads to straight threads or flanged ends that seal with an "O" ring. The objection to taper threads is that they often develop leaks that are hard to repair in the field. Components built overseas often have BSP (British Standard Pipe) ports that have a straight thread sealed with soft packing.

To minimize thread leaks, the NPTF thread form (also known as Dryseal) was developed to replace the standard NPT (National Pipe Taper) thread form used for so many years. Both of these thread forms are physically interchangeable, but the thread shape of the NPTF is modified to reduce spiral leakage around the crest of the threads. For hydraulic plumbing, the NPTF thread form should always be used. Threads are cut with sharp crests, and the seal is achieved by the actual distortion of the mating threads. This means that disassembly is problematic on such systems. To further minimize thread leakage, a joint compound should be used. Teflon sealant that comes in paste form is preferred, and if some of it should get inside the pipe, it will dissolve. Teflon tape is not recommended as it over-lubricates the threads and may cause the joint to be over-torqued. Sometimes part of the tape may be squeezed off inside the pipe causing contamination in the system. Hand threading may produce ragged threads that are apt to leak, and should be avoided.

Tubing and tube fittings: Tubing and tube fittings are typically less durable than pipe and should be replaced with materials conforming to current AASHTO specifications (Reference 6) when repaired or rehabilitated. Replacement parts should have a safety factor of 4 over working pressure.

second (m/s), and A is the interior cross sectional area of the discharge line in square feet (m^2), can be used to calculate flow velocity. If 13.1 CF (0.371 m^3) of fluid discharge from a 2 in. (50.8 mm) ID pipe in one minute, then the flow velocity V = Q/A = 13.1 CFM/.02182 SF = 600.5 FPM = 10 FPS (V = Q/A = 0.371 m^3/min/2.0268 × 1 m^2 = 183.044 m/min = 3.051 m/sec). Tables can be easily prepared to show that 6.55 CF (0.19 m^3/min) in one minute equals 5 FTISEC (1.5 m/s) and 19.65 CF (0.56 m^3/min) in one minute is 15 ft./sec (4.5 m/sec). If the values for Q illustrated are too much for the system, calculate a table for 30 or 15 seconds instead.

5.4.10—HYDRAULIC HOSE

Although more expensive than pipe or tubing, hose is used extensively in these situations:

- To simplify connections between components mounted at odd angles to each other
- In making plumbing runs in confined compartments where rigid plumbing would be difficult to install
- To connect hinge-mounted cylinders that must swing during their stroke
- To minimize hydraulic shock

Hose is measured and specified by its inside diameter. Its outside diameter will vary according to the number of layers of wire braid and rubber, which must be used to obtain the pressure rating. Hose and fittings should have a safety factor of 4 over working pressure. Allowable working pressure is calculated by using the burst pressure rating and dividing by 4.

A metal fitting must be used on each end of a hose to connect it into the system. Replacement fittings and hoses should conform to the current AASHTO requirements (Reference 6).

Rubber slowly deteriorates from exposure to solvents, water, ozone, sunlight, and heat. Hoses are, therefore, not as permanent as metal plumbing, and should be replaced at intervals as recommended by the manufacturer to avoid leakage.

The safe operating pressure for hydraulic hose is significantly reduced if bends are more severe than recommended. A typical bend radius for a 1 in. (25.4 mm) hose would be about 12 in. (0.3 m), or 12 times the ID.

Hose manufacturers can provide a large body of information to users concerning both good operating practice and the most likely causes of premature hose failure. Hose replacement suggestions include the following:

- Users should not mix hose ends among various manufacturers and should identify fittings.
- When replacing a hose assembly, users should not shorten or lengthen the assembly, unless there is a known problem with the existing hose length.
- Users should clamp down long sections of hose to support them and prevent abrasion.
- Users should not permit twisting stresses on the hose. If both ends have threaded connections, one end should have a swivel-type fitting.
- Users should not replace a hose assembly without finding out why the original hose failed. If the failure has been caused by overpressure, abrasion, or incorrect bend radius, the replacement hose will also fail.
- Users should use fittings and terminal blocks to eliminate abrasion points and allow for smooth, generous bends.

- Users should not put a kinked, pinched, or crimped hose back into service. It will work for a short time, but will soon fail from invisible damage to the braid.

A listing of common reasons for hose failure includes:

- Improper application
- Improper assembly and installation
- External damage from lack of shielding during repairs to other bridge components
- Faulty equipment causing overpressure, pressure spikes, or vibration
- Faulty hose due to old age or excessive shelf life
- Excessive temperature exposure, which leaches plasticizers from hose
- Aerated oil, which oxidizes the hose
- Excessive exposure to cold, which cracks the hose walls
- High frequency pressure impulses, which break the reinforcing wires randomly
- Insufficient bend radius or hose twisted during installation

5.4.11—RESERVOIRS

Reservoirs should be checked frequently for water contamination, or bubbles in the oil. Filler breather caps should be checked for cleanliness during each scheduled maintenance inspection, and cleaned or replaced as needed. In general, the reservoir tank should not be opened too frequently (to avoid introducing contaminants); however, when problems are suspected, an internal inspection is necessary. Never open the filler cap without first thoroughly cleaning the cap and the exterior of the tank as necessary to prevent intrusion of grit into the reservoir. Check the interior of the reservoir with a flashlight for internal corrosion above the level of the fluid, and for bubbles, moisture, and other problems in the fluid. Obtain a sample of the fluid and observe for color, consistency, smell (does it smell burned or unusual), grit particles, etc. after the system has been run to stir up the fluid. Laboratory testing as described in Chapters 2.8.2 and 2.10 should be done periodically. Do not run the system with the reservoir filler open. After the system has run, check the fluid level and temperature. If the temperature exceeds 140°F (60°C), design of a retrofit cooling system may be required. If the temperature exceeds 200°F (93°C), component damage is likely and corrective action is necessary as soon as possible. Check for varnish formation inside the reservoir and filter cases if the temperature is elevated. The suction line strainer should be inspected and maintained free of obstructions and debris as explained in other sections of this chapter.

5.4.12—HYDRAULIC FLUIDS

To perform well, a hydraulic fluid must do the following:

- Transfer hydraulic fluid power without large line losses. This means viscosity should not be too high.
- Lubricate the moving parts, and hold up well under applied bearing pressures between parts. This means viscosity should not be too low.
- Absorb, carry, and transfer the heat generated within the system.
- Be compatible with the hydraulic components, seals, and design requirements.
- Remain stable against a wide range of possible physical and chemical changes, both in storage and in use. Resistance to oxidation is particularly significant. Burning, of course, is an oxidation process. Slower oxidation reactions give rise to hydraulic fluid degradation with resultant formulation of such troublesome reaction products as sludge, varnish, and gum, or the formation of corrosive fluids that can attack metallic components. Other changes that need to be resisted include physical wear and pitting on pipes, tubing, and components; excessive swelling or shrinking of seals, gaskets, and other components; significant viscosity variations; foaming; and evaporation.

Petroleum-based oils protect well against rust, have excellent lubricity, seal well, dissipate heat rapidly, and are easy to keep clean by filtration or gravity separation of contaminants.

Petroleum oil is a serviceable industrial hydraulic fluid when specifically refined and formulated with various additives to prevent rust, oxidation, foaming, wear, and other problems, so long as heat and fire hazards are not critical.

For movable bridge use, replacement fluid selection should be based upon manufacturers' recommendations. It is unacceptable to mix two or more different hydraulic fluids in use or to install a type of hydraulic fluid that has not been suggested by the hydraulic equipment manufacturer. Just because fluids are of the same basic type does not mean fluids from two different manufacturers are compatible, as they may contain incompatible additives.

Checking the quantity of hydraulic fluid in the system is important. Insufficient hydraulic fluid can limit complete extension of the cylinders. Low hydraulic fluid levels can also draw air into the system, creating spongy cylinder action and possibly setting up conditions for hydraulic system problems.

When checking the hydraulic fluid quality, maintenance forces should inspect the cleanliness, color, thickness or viscosity, and perhaps the odor of the hydraulic fluid (see Chapter 2.8.2). Beyond these checks, there are numerous standard laboratory tests that can be used to determine everything from foaming tendencies and load carrying ability

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Systems that are not fitted with 10 micrometer (4.0×10^{-4} in.) filters or which show evidence of contamination are subject to rapid wear and significant reductions in component life. Contaminated systems should be flushed using the methods presented in ASTM D4174. Hydraulic oil replacement schedules should be developed by owners based upon system performance in their inventory, but in general the oil should be replaced whenever the laboratory tests show undesirable results. Oil may become corrosive due to water contamination due to condensation.

to type, size, and quantity of particle contamination; amount of oxidation; and thermal stability.

The key to checking hydraulic fluids in service is to look for changes in the hydraulic fluid properties. Such changes represent warning signals that generally will indicate a need for corrective action.

Suggestions for the handling of hydraulic fluids include:

- Use only one type and grade hydraulic fluid, recommended by the hydraulic equipment manufacturer, from one fluid manufacturer. Do not mix hydraulic fluids! Do not change sources without manufacturer assurance in writing of compatibility.
- Store hydraulic fluid containers inside and on their side to minimize the entry of water and dirt. Always keep containers covered tightly.
- Clean the container cap and the drum top thoroughly before opening.
- Use only clean hoses and containers to transfer hydraulic fluid from cans or drums to the hydraulic reservoir; use a hydraulic fluid transfer pump equipped with at least a 25 micron (0.001 in.) filter. Finer filters are better if you can accept the flow rates.
- Use a No. 200 (0.003 in. or 0.075 mm) mesh screen on the reservoir filler pipe.
- Replace hydraulic fluids in-kind at the recommended intervals; drain the system when it is warm and has been recently run, to remove a maximum of contaminants. If a new brand of fluid is to be added, remove all the old fluid first unless it is certain that the fluids and all their additives are 100 percent compatible.
- Flush and refill the system exactly as recommended. Be certain to fill to the proper level, as overfilling is as troublesome as under-filling!
- Service hydraulic filters and air breathers at the recommended intervals. Inspect filter elements that have been removed from the system for signs of failure, excessive contamination, or signs that the fluid has been flowing through the bypass, which may indicate the need for shortening the service interval and the possibility of other system problems.
- Train maintainers in the proper use of all fittings and other techniques to eliminate contaminant entry. Fittings should be wiped clean before use, and should be covered or cupped when not in use. The same care should be exercised in replacing hydraulic system components, or in general maintenance. Dirt, lint, and other contaminants must not enter the system.
- Check the hydraulic system thoroughly to eliminate leaks or contaminant entry points. Keeping leaking hydraulic fluid out of the waterway is very important!

- Never return leaked hydraulic fluid to the system!
- Use common sense precautions to prevent the entry of dirt into components that have been temporarily removed from the system.
- Make sure that all clean-out holes, filler caps, and breather cap filters on the reservoir are properly fastened.
- Do not run the system unless all normally provided filtration devices are in place.
- Make certain that the hydraulic fluid used in the system is of a type recommended by the manufacturers of all components.

5.4.13—HYDRAULIC SYSTEM INTERLOCKING SENSORS AND CONTROLS

Interlocking, switches, and controls should be performance-tested during each maintenance inspection. System parameters such as pressure, temperature, pump cycle time, and cylinder performance should be evaluated. If performance testing shows out-of-specification results, the interlocking, control switches, etc. should be adjusted to return the system within operating limits specified in the maintenance manuals. If components cannot be properly adjusted, they should be replaced. The system should not be left to run with temperature or pressure specifications exceeded by more than 90 percent.

5.4.14—HYDRAULIC SYSTEM CHECK OUT

This section describes a step-by-step check out procedure for hydraulic systems, which have previously been working satisfactorily but which have developed trouble. This information is not intended as a diagnostic check for new systems, which may have been incorrectly designed.

Figure 5.4.14-1 shows the basic circuit and basic major components typical of most hydraulic systems. For check out of a system, it is necessary to install a portable pressure gauge in the pump pressure line as shown.

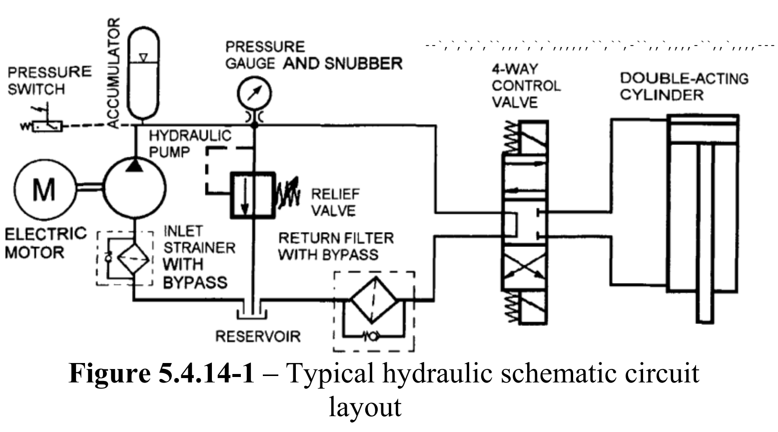


Figure 5.4.14-1 – Typical hydraulic schematic circuit layout

Symptoms of trouble: Many failures in a hydraulic system show similar symptoms: a sudden or gradual loss of high pressure, resulting in a loss of cylinder speed and/or force. The cylinder(s) may not move at all, may move too slowly, or may stall under light loads. Often the loss of power is accompanied by an increase in pump noise, especially as it tries to build up pressure against a load.

Any major component—pump, relief valve, cylinder, four-way valve, or filter—could be at fault. In a highly sophisticated system, there are often other minor components that could be at fault, but these possibilities are too numerous to be covered in this brief discussion.

By following a step-by-step procedure in the order given here, the problem can usually be traced to a general area, then if necessary, each component in that area can be tested, or can be temporarily replaced with a similar component known to be good. It makes good sense to first check the areas that give the most frequent trouble on most systems, and that is the basis on which this procedure is based.

- **Step 1—Pump inlet strainer:** One field trouble encountered often is cavitation of the hydraulic pump, caused by a buildup on the inlet strainer. Not only can this happen on a system that has been in service for a long time, it can happen on a new system after only a few hours of operation. It produces increased pump noise, loss of high pressure, loss of cylinder speed, or some combination thereof.

  If there is not a strainer located in the pump inlet line, it will usually be found immersed below the hydraulic fluid level in the reservoir. It can be removed for service (after draining the reservoir) by uncoupling the inlet line to the pump, removing the flanged cover where the line goes into the tank, and then withdrawing the strainer.

  Some maintainers are not aware of a strainer in the reservoir, or if they are, they do not clean it regularly. A dirty strainer restricts flow into the pump and may cause the pump to fail prematurely.

  The inlet strainer should be removed for inspection and should be cleaned before reinstallation. Wire mesh strainers can be cleaned with an air hose, blowing against the normal flow direction. They should also be washed in approved solvent, scrubbing with a bristle brush. The solvent should be compatible with the hydraulic fluid in the tank. For example, a lubricating solvent can be used on strainers operating in petroleum based oil. The strainer should then be blown out whether or not it appears to be dirty. Some clogging materials are hard to see. If there are any holes in the mesh, or if there is obvious physical damage, the strainer should be replaced.

When reinstalling the strainer, inspect all joints in the inlet plumbing for air leaks, particularly at union joints. There must be no air leaks in the inlet line fittings, or any other components, on the suction side of the pump. Check the tank hydraulic fluid level to be sure it covers the top of the strainer by at least 3 in. (76 mm) at minimum hydraulic fluid level, which is with cylinders extended. If it does not, there is danger of a vortex forming above the strainer, which may allow air to enter the system when the pump is running.

Notice the condition of the inlet hose (if one is used). A partially-collapsed hose, or one with internal swelling, has the same effect on cavitation probability as a clogged inlet strainer.

- **Step 2—Pump and relief valve:** If cleaning the pump strainer does not correct the problem, isolate the pump and relief valve from the rest of the system by disconnecting the plumbing (Figure 5.4.14-1) and capping both ends of the disconnected lines. This dead heads the pump into the relief valve. First, back off the relief valve. Then, start the pump and watch the gauge for a pressure buildup as the relief valve adjustment is tightened. If full pressure can be developed, obviously the pump and relief valve are operating correctly and the trouble is further down the line. If full pressure cannot be developed, or if the pressure is erratic, continue with step 3.
- **Step 3—Pump or relief valve:** Further testing must be done to determine whether the pump is worn out or if the relief valve is malfunctioning.

  Discharge from the relief valve tank port must be observed. If possible, disconnect the tank return line from the relief valve. Attach a short length of hose to the relief valve outlet. Hold the open end of the hose over the tank filler opening where the rate or flow can be observed. Start the pump and run the relief valve adjustment up and down while observing the relief valve discharge flow. If the pump is bad, a full stream of hydraulic fluid may possibly be observed when the relief valve is backed off, but this stream will greatly diminish, or stop, as the relief valve setting is increased. If a flowmeter is available, the flow rate can be measured and compared with the catalog flow rating of the pump.

  If a flowmeter is not available, the flow can be estimated by discharging the stream into a clean container over a measured time interval. However, even without any measurement of the flow volume, a bad pump is indicated if the discharge flow varies widely as the relief valve adjustment is run up and down. The discharge flow should be fairly constant at all pressure levels, dropping off slightly at higher pressures.

If the relief valve discharge line cannot be disconnected, the mechanic can place his/her hand near the discharge opening inside the tank and can detect a large change in the flow if the pressure is varied. If the flow decreases as the relief valve setting is raised and only moderate, but not full, pressure can be developed, this may also indicate pump trouble. Proceed to Step 4.

During this test, if gauge pressure does not rise above a low value, 100 psi to 200 psi (0.7 MPa to 1.4 MPa), and if the discharge flow remains constant as the relief valve adjustment is tightened, the relief valve may be at fault and should be cleaned or replaced as instructed in Step 5.

- **Step 4—Indicators of Pump Trouble:** If a full stream of hydraulic fluid is present as described in Step 3, or if the stream diminishes markedly as the relief valve setting is raised, the pump is probably worn out. Assuming that the inlet strainer has been cleaned, and the inlet plumbing has been inspected for air leaks and collapsed hoses, if the pumped hydraulic fluid is slipping inside the pump from the outlet back to the inlet, then the pump may be worn out, or the hydraulic fluid may be too thin. High temperature in the hydraulic fluid will cause it to become thin and slip excessively. High slippage within the pump will cause it to run much hotter than the hydraulic fluid in the tank. In normal operation, with a good pump, the pump case may run 20°F to 30°F (11°C to 17°C) higher than the temperature in the hydraulic fluid tank. If greater than this, excessive pump slippage may be the cause.

  Check also for a sheared shaft key, broken shaft, broken coupling, loosened set screw, and other possible mechanical causes.
- **Step 5—Relief valve:** If Step 3 has indicated the relief valve may be at fault, the quickest proof is to temporarily replace it with a new one that is known to be good. Valve replacement should only be attempted by qualified and trained personnel. The faulty valve may later be reconditioned by the manufacturer. Pilot operated relief valves have small internal orifices that may become blocked with dirt. Use an air hose to blow out all passages and pass a small wire through the orifices. Check also for free movement of the spool or poppet. Pipe thread connections in the body may distort the body and cause the spool to bind. If possible, check for spool binding before unscrewing the threaded connections, or, while testing on the bench, screw pipe fittings tightly into the port threads.
- **Step 6—Cylinder:** If the pump develops full pressure while dead heading into the relief valve as described in Step 2, then both of these components can be assumed to be good. Check the cylinder piston seals.
- **Step 7—Directional (four-way) valve:** If the cylinder has been tested for piston leakage and found to have reasonably

tight piston seals, the four-way control valve may be checked for excessive spool leakage. It is rare that a valve becomes so worn that the pump cannot build up full pressure, but it can happen. Symptoms of excess leakage in the valve spool are a loss of cylinder speed together with the relief valve adjusted to a high setting. This condition would be more likely to happen when using a pump with small displacement operating at very high pressure, and might have developed gradually over a long time. On solenoid type valves, it is also possible for the solenoid to malfunction and lead to leakage due to improper valve seating (when the solenoid is holding the spool open).

- **Step 8—Other components:** If the above procedure does not reveal the trouble, check other components individually. Usually the quickest and best troubleshooting procedure is to replace suspected components, one at a time, with similar ones known to be good. Pilot operated solenoid valves that will not shift out of the center position may have insufficient pilot pressure available.

CHAPTER 5.5—ELECTRICAL MAINTENANCE

5.5.1—GENERAL

The environment in which electrical equipment operates can significantly affect the service life of motors, control components, conductors, insulation, illumination, and grounding. Sudden breakdown of major electrical components and the frequently time-sensitive tasks of specifying and ordering replacements for items, such as electrical motors and controls, may cause substantial delays affecting navigational and vehicular traffic. These circumstances may be mitigated by the introduction of a systematic electrical maintenance program of inspection, testing, cleaning, adjustment, and remediation of motors, motor control components, transformers, power circuit and power control components, insulation, conductors, illumination, heating devices, ground systems, and auxiliary power systems.

C5.5.1

Electrical systems require that current flows as designed, when designed, and not flow through short circuits, arc across air gaps, or behave in any other unexpected manner. Excessive heat, deterioration or damage of wire or insulation, corrosion, or damage of conduits are all potential causes of unexpected current paths. Most of these causes and other likely causes of electrical failure, such as mechanical failure of moving parts, switches, or breakers, can be detected prior to failure by careful inspection and maintenance.

5.5.2—ELECTRIC MOTORS

The maintenance of electric motors should follow a specific program determined beforehand and influenced by the importance, cost, and the complexity of the motor. The motor manufacturer's recommended maintenance schedule should be followed. The inventory of spare parts and spare motors should permit immediate replacement of vital system motors. The inventory should be updated as needed to confirm that spares are available for critical systems and are added to the inventory if new structure or replacement systems are installed. The bridge owner's operating and maintenance manuals should be maintained in good and legible condition and should be updated, as necessary, to reflect changes in components, circuitry, or maintenance recommendations.

Lubricate motor bearings only when scheduled. Excessive grease from over-lubrication creates heat due to churning and can damage bearings. Prior to lubricating, thoroughly clean any excess lubricant from the bearings and fittings. Dirt introduced during lubrication causes more bearing failures than lack of lubrication.

Check the motor frame and bearings for excessive heat or vibration with suitable test equipment. Listen for abnormal noise.

For DC motors, observe the brushes while the motor is running. The brushes should ride on the commutator with little or no sparking and no brush noise. Stop the motor and observe if the brushes move freely and the spring tension is equal. Observe that the commutator is clean, smooth, and has a polished surface where the brushes ride. Clean any accumulated

C5.5.2

Internal parts of a motor may be at line voltage, even when it is not rotating. Before performing any maintenance, which could result in contacting any internal part, the power source should be disconnected from the motor.

foreign material between the commutator bars, and from the brush holders and posts using only clean, dry, compressed air.

Dirt, heat, moisture, debris accumulation, and vibration are enemies of electrical equipment and can damage insulation, bearings, contacts, and most moving parts. Visual inspection of these can be complemented by insulation resistance testing, which can be performed by battery powered instruments, when component performance indicates there may be current leakages. In addition, infrared thermography should be used to check for hot spots caused by resistance or over-current heating of components and wires (See Chapter 2.10).

5.5.3—MOTOR CONTROL COMPONENTS

Motor control components are located in the branch circuits. They are called power circuit components if their contacts operate in the power circuit, and are called control circuit components if their contacts operate in the logic or control circuit. Power circuit components can include molded case circuit breakers, disconnect switches, contactors, variable speed drives, motor starters, capacitor starting relays, and rheostats. Control circuit components include various types of operator interface devices; pushbuttons; numerous types of function switches such as pressure, temperature, limit, and proximity; and numerous relays such as control, overload, time-delay, voltage-sensing, phase-failure, phase-reversal, plugging, synchronizing, under-load and jam-detection, and auxiliary contacts.

Good conduction requires clean, tight joints that are free of contaminants. Good insulation requires the absence of carbon tracking and contaminants. During each scheduled maintenance, maintainers should:

- Vacuum or wipe clean all exposed surfaces of the component and the inside of its enclosure. Equipment may be blown clean with compressed air that is dry and free from oil.
- Tighten all electrical connections to proper torques.
- Look for signs of overheated joints, charred insulation, and discolored terminals.
- Wire and cables should be examined to eliminate any chafing against metal edges caused by vibration that could progress to an insulation failure.

Power circuit component contacts experience both mechanical and electrical wear during their operation. Generally, mechanical wear is insignificant and contact erosion is primarily due to electrical wear caused by arcing. Contact replacement should be done for the entire group of springs and contacts when measurements indicate that one or more components in the system are no longer usable. For power circuit components:

C5.5.3

Control component maintenance should be performed only by qualified personnel, who know how the equipment is intended to be used and who are capable of understanding the manufacturer's instructions and are experienced at the required tasks.

Maintenance of control components requires that all power to these components be turned off by opening, and locking open, the branch circuit disconnect device. If control power is used during maintenance, use caution to prevent feedback of a hazardous voltage through a control transformer. Discharge power factor correction capacitors before working on any part of the associated power circuit.

Inspections and tests should be made only on controllers and equipment that are de-energized, disconnected, and isolated by proper lock-out procedures, so that accidental contact cannot be made with live parts and so that federal, state, and local bridge maintenance safety procedures will be observed.

- The inspection of contacts should include checking for loose, missing, broken, or corroded hardware.
- The inspection of disconnect switches should be similar to that for contacts.

Circuit interrupters, circuit breakers, and motor circuit protectors are totally enclosed within their molded cases. However terminations for all contacts, switches, breakers, interrupters, and circuit protectors should be checked for loose connections and signs of vibrating, and the components can be checked with a remote read infrared thermometer for excessive heat during use.

Starting and speed regulating rheostat contacts should be periodically inspected, cleaned, and dressed smooth with a file.

Emery cloth, or other dressing abrasives that leave grit behind, should not be used, and any metal filings should be vacuumed out of the component and the housing panel.

Control circuit component contacts handle much smaller currents than do power circuit devices and they seldom need to be replaced because of wear. Typically, these contacts need to be replaced due to damage as a result of short circuit. These contacts are generally not replaceable, or are replaced as complete assemblies in the form of cartridges, contact blocks, or switches complete with their own housings.

Where a motor branch circuit has been in service prior to a fault, the opening of the short circuit protective device indicates a fault condition in excess of operating overload. This fault condition must be corrected and the necessary repairs made before reenergizing the branch circuit.

5.5.4—GROUNDING

Required grounding connections to earth are important to component life and necessary for safety. Undesirable or unintentional grounds can cause operating troubles and erratic and dangerous performance of vital circuits. Unintentional grounding sometimes occurs where stray strands of wire in an improperly fitted wire connection make contact at the wrong places. Improper grounds may also occur when insulation on wires is chafed because of vibration, such as at conduit entrances. Moisture is a possible cause of ground faults. If enough water collects in a conduit as a result of flooding or condensation, it may become necessary to remove the wires, clean the conduit, provide drain holes, and install new wiring. Maintenance activities should include cleaning and dressing connections for corrosion and maintaining tightness. Verify operation of ground fault interrupters.

C5.5.4

Make sure circuits are de-energized before working on any conduit, or part of a device suspected of containing water, as dangerous ground fault currents may be present.

5.5.5—LIGHTING, SIGNALS, AND WARNING DEVICES

Automatic roadway traffic gates and resistance gates are provided for public safety. Due to their frequency of usage, a monthly observation of operation should include checking for smoothness of operation, tightness of fasteners, adjustment to the counterweight and stop positions as required, burned out warning lights, broken or damaged receptacles, tight electrical connections, corrosion, impact damage, or other deterioration. Annual inspection should include close examination of limit switches; inspection of contacts; and checking for corrosion on fixtures, conduits, mounting brackets, or other metal parts. Fixtures that are inoperative, damaged, or display missing hardware should be brought to the attention of maintainers for repair or replacement.

Navigational lights serve as a safety warning to marine traffic. Aerial lighting, if present, serves as a safety warning to aviation. The scheduled maintenance inspection should include checking fixtures, conduits, mounting brackets, or other metal parts for corrosion; inspecting lenses, gaskets, and other hardware for missing, loose, or broken components; and making sure the conduits and fixtures are properly grounded. Inoperative navigational lights should be brought to the attention of maintainers for repair or replacement.

General lighting refers to lighting on the movable span not associated with the navigationa1 lights or the traffic warning lights. It includes lighting found in the control house, machinery spaces, and bridge roadway, as well as flood and spotlighting. Maintenance should be performed weekly or as required. Burnt out lamps should be replaced.

Traffic signals serve as a safety warning to motorists and, in some instances, to pedestrians. They are integrated with the bridge control system. Frequent checks by bridge operators for burnt out bulbs should be conducted, with more in-depth inspection occurring over periods of not greater than six months. During the scheduled maintenance inspections, electrical connections should be checked for tightness and corrosion. Wire conduits, light mounting brackets, and other metal parts should be checked for deterioration and corrosion. All wiring should be checked for frayed, cracked, or deteriorated insulation. Maintainers should be notified of any problems so that repairs or replacement of components can be implemented.

C5.5.5

Any malfunctioning or missing warning lights, signals, or navigation lights should be reported immediately and recommended for immediate repair.

5.5.6—AUXILIARY POWER

A standby generator, with a diesel or gasoline engine in a weatherproof enclosure, is preferred by the current AASHTO specifications (Reference 6) and is a vital system in the event of a power failure. The bridge owner should have complete operating and maintenance manuals on site for this equipment. Routine electrical maintenance should include inspection of the condition of the generator and determination that the battery is charged to a reasonable fraction of its rated capacity after cleaning terminals and performing a test discharge. If the battery does not deliver 80 percent of rated capacity, it should be replaced. The general condition of the generator should be checked monthly. This check should include a determination of satisfactory oil coolant, fuel, and battery fluid levels. The auxiliary power capability should be verified at a minimum of six month intervals at which time the bridge should go through an open/close bridge cycle with the generator furnishing the power. Engine performance should be observed and engine temperature, oil pressure, voltage, and current recorded. Dielectric strength should be measured and recorded annually.

C5.5.6

One generator exercising system that has functioned well for some owners is an automated generator start-up and power transfer mechanism that causes the bridge to either run on generator power periodically, or to at least run the generator until it reaches normal operating temperature and exercise the system periodically. The suggested frequency will vary with environmental conditions at the site, but some owners have set the system to run as frequently as once a week for up to one hour. Diesel generators are generally preferable to gasoline types, since the fuel is less prone to create a potential hazard, and because diesel fuel does not degrade as rapidly as gasoline when the fuel sits unused in the tank. Moisture can accumulate in the tank due to condensation and other environmental factors, so a water trap should be installed in the fuel line and collected water should be frequently removed.

5.5.7—OPERATOR'S (TENDER'S) HOUSE

The operator's (tender's) house electrical systems should be regularly maintained to provide a safe and comfortable environment for the bridge tender. Regular maintenance should include assurance of the presence of the following items:

- Clean consoles and monitoring screens that are free of dust.
- House lighting and electrical receptacles.
- Clean windows that are free from water intrusion.
- Emergency lighting and emergency exit signs.

CHAPTER 5.6—MAINTENANCE RECORDS AND REPORTING

5.6.1—GENERAL

Chronological records of scheduled preventive maintenance (parts replacement, lubrication, adjustment, cleaning) in addition to records of repairs are an essential part of the bridge file. A complete history of these records provides a useful source of information for future bridge maintenance management. Many movable bridges, particularly the older ones, do not have maintenance manuals, schedules, and forms for their components and assemblies. This chapter provides sample record forms and guidance for maintenance records and reporting methods. Many of the forms included in this chapter are adapted from the Florida Department of Transportation's *Bridge Operations and Maintenance Manual* (Reference 58).

5.6.2—PURPOSE OF MAINTENANCE RECORDS

A complete, accurate file of maintenance records for work performed under the in place routine maintenance program and work performed as a result of reported deficiencies provides data useful to:

- Record, monitor, and provide written documentation that the preventive maintenance schedule is kept.
- Record, monitor, and provide written documentation that deficiencies have been corrected.
- Predict the need for minor repairs before major operational difficulties and safety hazards occur.
- Identify recurring deficiencies and troubleshoot their cause.
- Evaluate the in place maintenance schedule and budget.
- Allow new personnel to become familiar with the status and maintenance requirements of the bridge.

5.6.3—CONTENT OF MAINTENANCE RECORDS

Keeping accurate records of all maintenance activities is crucial to a successful preventive maintenance program. Records should document the date of the maintenance inspection, the components inspected, the condition at the time of inspection, and any corrective measures taken. Maintenance inspection forms should take the form of checklists designed for specific structural, mechanical, and electrical components. However, sketches, diagrams, and photographs as required should be incorporated to adequately describe the conditions found. In doing so, a history of maintenance problems can be established for the bridge. This will show adverse condition progression over time by comparing past and present records.

The numbering and terminology used in completing the forms should be consistent with the bridge plans, inspection reports, and previous maintenance records.

Maintenance records should be concise while describing thoroughly the condition and work performed. When complex repairs or major rehabilitations are performed, the record plan set should be updated to reflect the repairs either by revision to the plan, including identifying the revision number and date in the title block and a brief note where the revision occurs in the plans, or by use of supplemental sheets.

5.6.4—SAMPLE FORMS AND THEIR USE

The sample forms presented herein are grouped into three classifications:

- Logs
- Reports of deficiencies or incidents
- Reports of maintenance/inspection

Logs are tallies of occurrences. Reports of deficiencies or incidents are accounts of unusual occurrences or observations such as equipment malfunction reports and accident reports. Reports of performed maintenance document routine and repair maintenance work performed on the bridge equipment.

5.6.4.1—Bridge Operator's (Tender's) Forms, Logs, and Checklists

The following sample forms, log sheets and checklists for use by bridge tenders are included:

- Bridge information form
- Bridge opening log
- Bridge maintenance log
- Shift change log/checklist
- Incident log
- Safety equipment checklist

5.6.4.2—Bridge Operator's (Tender's) Reports

The following sample report forms are included for use by the bridge operator:

- Drawbridge malfunction report
- Unsafe condition report
- Vehicle traffic accident report
- Waterborne traffic accident report
- Personnel injury report
- Bridge damage report
- Unnecessary bridge opening report
- Unauthorized approach of vessel report

5.6.4.3—Maintenance Reports

The following sample report forms can be completed by maintainers. They are used to record maintenance activities and document maintenance inspection findings.

- Bridge maintenance record (and component maintenance tag)
- Emergency generator maintenance checklist
- Machinery oil/grease maintenance checklist
- Brake maintenance checklist
- Mechanical components maintenance checklist
- Electrical components maintenance checklist
- Maintenance lubrication log (a sample maintenance lubrication log is provided in Table 5.3.19-1).

BRIDGE INFORMATION FORM

Name of Bridge ____________________

Bridge Number ____________________

Bridge Location ____________________

Telephone No. ____________ Office No. ____________

In Case of Emergency Call:

NAME	TITLE	PHONE #	BEEPER #	MOBILE PHONE #

Local Police Phone Number ____________________

Local Fire & Rescue Number ____________________

Date of Last Form Update ____________ Updated By ____________
Name

Coast Guard Number ____________________

SAMPLE BRIDGE OPENING DAILY LOG FORM

Bridge Tender Log Sheet No. ____ of ____	SHIFT INFORMATION				DESCRIBE WEATHER AT START OF SHIFT	Winds (MPH)		Weather Changed
Log Date :________________	Shift"	Operator	Maintainer	Gate Keeper		Steady	Gusts	Yes/No
Route No:________ Bridge No: ________	2300-0700							
Waterway: ________ Mile Marker: ________	0700-1500							
City/Town: ________ State: ________	1500-2300							

Opening Number	VESSEL INFORMATION					TIME							Total No. Vsl. Transit During Opening	Problems		Write Comments on Reverse Side
	Name / ID	Type	Direction U / D	Method Signal R / W / V	Height (optional)	Time of Opening Signal		Time Bridge Opened		Vessel Transit Duration	Bridge Closed Duration	Opening Duration		Bridge Ops.	Marine Ops.	

Vessel Key:
See Back of Form

SAMPLE BRIDGE OPENING DAILY LOG FORM (Reverse Side)

Note No.	COMMENTS:

Vessel Key

Symbol	Description of Craft	Symbol	Description of Craft	Symbol	Description of Craft	Symbol	Description of Craft
C	Cargo Ship	FD	Fire Department	P	Passenger Ship	T	Tug (light without scow or barge)
CB	Coal Barge	G	Government Vessel	PB	Power Boat	TC	Tanker - Chemical
CF	Commercial Fishing	L	Self-propelled Lighter	PF	Party Fishing Vessel	TD	Tug and Derrick
CFS	Commercial Shell fishing	MP	Marine Police - State	R/T	Repair/Test/Training	TOB	Tug and Oil Barge
CG	Coast Guard	OB	Oil Barge - Self-propelled	SB	Sailboat Under Sail	TS	Tug and Scow
D	Dredge	OT	Oil Tanker - Self-propelled Ocean Going	SBA	Sailboat Under Auxiliary Power	TT	Tug and Tanker(X) X= # Tugs
EX	Excursion						

BRIDGE MAINTENANCE LOG

Bridge No.: ____________________ **Month:** ____________________ **Year:** ______________

DATE	TYPE OF CREW	TIME IN	TIME OUT	OPERATOR'S SIGNATURE	CREW LEADER'S SIGNATURE
NOTES: MAINTENANCE REPORT NO. _____					
NOTES: MAINTENANCE REPORT NO. _____					
NOTES: MAINTENANCE REPORT NO. _____					
NOTES: MAINTENANCE REPORT NO. _____					
NOTES: MAINTENANCE REPORT NO. _____					
NOTES: MAINTENANCE REPORT NO. _____					
NOTES: MAINTENANCE REPORT NO. _____					
NOTES: MAINTENANCE REPORT NO. _____					

SHIFT CHANGE LOG/CHECKLIST

Date: ______________________________

Shift: __ 12:00 AM—8:00 AM __ 8:00 AM—4:00 PM __ 4:00 PM—12:00 AM

	YES	NO
Joint review of logs, noting any unresolved problems or unusual conditions:		
Bypass switches are properly sealed except as noted here:		
Comments/Explanations:		

Off. Operator ________________________ On. Operator ________________________

Shift: __ 12:00 AM—8:00 AM __ 8:00 AM—4:00 PM __ 4:00 PM—12:00 AM

	YES	NO
Joint review of logs, noting any unresolved problems or unusual conditions:		
Bypass switches are properly sealed except as noted here:		
Comments/Explanations:		

Off. Operator ________________________ On. Operator ________________________

Shift: __ 12:00 AM—8:00 AM __ 8:00 AM—4:00 PM __ 4:00 PM—12:00 AM

	YES	NO
Joint review of logs, noting any unresolved problems or unusual conditions:		
Bypass switches are properly sealed except as noted here:		
Comments/Explanations:		

Off. Operator ________________________ On. Operator ________________________

INCIDENT LOG

Bridge : ______________________________

DATE:	**TIME:**	**BRIDGE OPERATOR:**
REMARKS:		
NOTIFIED:		

DATE:	**TIME:**	**BRIDGE OPERATOR:**
REMARKS:		
NOTIFIED:		

DATE:	**TIME:**	**BRIDGE OPERATOR:**
REMARKS:		
NOTIFIED:		

SAFETY EQUIPMENT CHECKLIST

BRIDGE:	YES	NO
FIRST AID KIT		
Is it in a readily accessible location?		
LIFE JACKETS		
Are there a minimum of two (2) jackets?		
Are the jackets in good conditions?		
LIFE RING		
Are the life rings in good condition?		
Is it accessible?		
Is it in good condition?		
Is a 200-foot rope attached to the ring?		
Is the rope in good condition?		
FIRE EXTINGUISHERS		
Are there two fire extinguishers?		
What type: A. B. C. Halon		
Are they properly mounted and in good shape?		
Is the inspection current?		
FLASHLIGHTS		
Are there at least two available?		
Are they in working condition?		
OTHER ESSENTIALS		
Two reflectorized hand-held flags?		
Two reflectorized work vests?		
One electrically rated floor mat in good shape?		
Six traffic cones?		
COMMENTS:		
REPORT BY: **DATE:**		

MOVABLE BRIDGE MALFUNCTION REPORT

BRIDGE OPERATOR FILL OUT THIS PART OF REPORT

Bridge Name: ______________________________ Date:___/___/___

Bridge No.: ______________________________ Time:________ AM PM

Bridge Operator's Name: ______________________

Problem Reported By: ______________________

Problem Reported: ______________________

Circle the Kind of Failure:

1:	Gates	A: Won't Lower	B: Won't Raise	C: Lights	D: Other
2:	Locks	A: Won't Lower	B: Won't Drive	C: Other	
3:	Spans	A: Won't Lower	B: Won't Raise	C: Other	

4: Other (Explain any others in the space below)

____

____

____

____

Circle if Cars Delayed _____ Hours _____ Minutes

Circle if Boats Delayed _____ Hours _____ Minutes

ELECTRICIAN/MECHANIC FILL OUT THIS PART OF REPORT

Electrician/Mechanic's Name: ______________________________________

Specific Repairs Made: ______________________________________

____

____

____

____

____

Reason for the Repairs: ______________________________________

____

____

____

____

____

Real Cause of Failure: ______________________________________

____

____

____

____

____

Bridge Back in Full Service ____________________ AM PM

Bridge Back in Partial Service ____________________ AM PM

Elect./Mech. Signature ______________________

Supervisor's Signature ______________________

UNSAFE CONDITION REPORT

Bridge Name: ______________________________

Bridge Number: ______________________________

Bridge Location: ______________________________

Operator: ____________________ Date:__________ Time: __________

Describe Condition: ______________________________

What is the unsafe condition? ______________________________

How does/could the unsafe condition affect the operation of the bridge? ______________________________

Who/what could be injured/damaged? ______________________________

One copy to remain at the bridge.

Other copy to be sent to: ____________________

VEHICLE TRAFFIC ACCIDENT REPORT

(BRIDGE OPERATOR SHOULD FILL OUT AS MUCH OF THE INFORMATION AS SHE/HE CAN OBTAIN)

Location: ______________________________

Bridge No: Road No: County: Local: Bridge Name:

____

Time of Accident: Date:____________, 20___ Hour: __________ AM ___ PM ___

Weather Conditions: ______________________ (Clear, Raining, Fog)

VEH. NO. PER SKETCH	DRIVER'S NAME ADDRESS & PHONE NO.	TYPE OF VEHICLE & TAG NO.	DRIVER'S LICENSE NO.	INSURANCE COMPANY

DOT property damaged: ______________________________

____

____

____

____

Description of accident: ______________________________

____

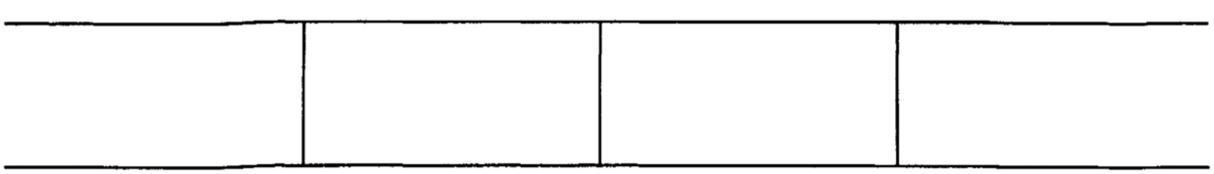
____

____

____

Police accident report no. (if available): ______________________________

Schematic Drawing of Vehicle Location



Plan View of Bridge

WATERBORNE TRAFFIC ACCIDENT REPORT

Page 1 of 2

Location: ______________________________

Bridge No.: ________ Road No.: ________ County: ________ Local: ________ Bridge Name: ________

Time of Accident: Date: ____________, 20____ Hour: ____________ AM _____ PM _____

Weather Conditions: ______________________________

Clear ________ Raining _______ Fog _______

Detailed Description of Accident:

Vessel No. 1	Vessel No. 2	Vessel No. 3
Type: Name: Owner: Address: Captain: Address: Employees: Speed: Direction: Loaded ______ Empty _____	Type: Name: Owner: Address: Captain: Address: Employees: Speed: Direction: Loaded ______ Empty _____	Type: Name: Owner: Address: Captain: Address: Employees: Speed: Direction: Loaded ______ Empty _____

WATERBORNE TRAFFIC ACCIDENT REPORT

Page 2 of 2

Signals Given by the Boat(s):

Signals Given by the Bridge:

Time Bridge was Clear for Marine Traffic:

Direction of Tide: Incoming: _________ Outgoing: ___________

Direction of the Wind: NW _____ N _____ NE _____ E _____ SE _____ S _____ SW _____ W _____

Type of Damage to Vessels:

Vessel No. 1	Vessel No. 2	Vessel No. 3

Operator's Signature: ______________________ Title: ______________________ Date: ________________

Detailed description of all damage to bridge or other state property (to be completed by Bridge Maintenance Foreman):

Statement of condition of damaged portion of bridge or other state property immediately before accident:

Survey Officer:
Name (Printed):
Signature:
Title:
Report Date:
Contact Phone No.:

PERSONNEL INJURY REPORT

Bridge Name: ____________________

Bridge Number: ____________________

Bridge Location: ____________________

Operator: ____________________

Injured Person's Name: ____________________

Address: ____________________ Age: ________

____

Check as Applicable: Employee ________ Contractor ______
General Public ______ Other (describe) ____________

Was the person on the job at the time of injury? Yes _____ No _____

Describe the Incident:

____

Describe the Injury:

____

Ambulance/Hospitalization Required? Yes _____ No _____

Ambulance Company and Name of Hospital:

____

Operator's Signature: ____________________ Date: ____________

BRIDGE DAMAGE REPORT

Bridge Name: ______________________________

Bridge Number: ______________________________

Bridge Location: ______________________________

Operator: ______________________________

Describe Incident:

____
____
____
____

Describe Damages:

____
____
____
____

Describe Unusual Occurances Prior to Incident:

____
____
____
____

Describe Affect on Bridge Operations:

____
____
____
____

Cause of Damage:

____
____
____
____

Describe Required Repairs:

____
____
____
____

Bridge Operator's Signature: ______________________ Date: __________

UNNECESSARY BRIDGE OPENING REPORT

Bridge Name: ____________________ Bridge No.: ____________________

Bridge Location: ____

*Number of Vessel (if numbered): ____

*Name of Vessel: ____

*Home Port (if shown): ____

*Name and Address of Owner: ____

____

Month __________ Day __________ Year ______ Time ______ AM ___ PM ___

Direction of Passage: North ______ South ______ East ______ West ______

Cause of Unnecessary Bridge Opening:

Appurtenances Unessential to Navigation:

Antenna ______ Outrigger ______ Decorative Mast ______

Flagpole ______ False Stack ______

Other ____

Other Cause: ____

____

Clearance Gauge: ______ Feet

Estimated Clearance for Vessel's Highest Fixed Point: ______ Feet

Remarks: ____

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Bridge Operator's Signature: ______________________________ Date: __________

*Violation cannot be processed without this information.

UNAUTHORIZED APPROACH OF VESSEL REPORT

Bridge Name: ______________________ Bridge No.: ______________________

Bridge Location: ____

*Number of Vessel (if numbered):______________________________________

*Name of Vessel:____

*Home Port (if shown):____

*Name and Address of Owner: ______________________________________

____

Month ________ Day ________ Year _______ Time ________ AM ____ PM ____

Direction of Passage: North _______ South _______ East ________ West ________

Details of Incident: ____

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Bridge Operator's Signature: ______________________________ Date: ______________

*Violation cannot be processed without this information.

BRIDGE MAINTENANCE RECORD

Bridge No.: ____

Component and Maintenance Task: ____

Location: ____

Maintenance Interval: ________________

MAINTENANCE		CREW LEADER'S SIGNATURE	MAINTENANCE TASK	COMMENTS
DUE DATE	DATE PERFORMED			

COMPONENT MAINTENANCE TAG

COMPONENT: ____________________

DATE INSTALLED __________ **MAINTENANCE FREQUENCY:** __________

MAINTENANCE/REPAIR		
DATE	**NAME**	**WORK DONE**

EMERGENCY GENERATOR MAINTENANCE CHECKLIST

Bridge No.: ______________________________

ITEM		COMMENTS
Spark Plugs		
Compression		
Points		
Radiator		Check before and after generator exercise.
	Hoses	
	Coolant Level	
Fuel System		
Change Fuel Filter		
Change Air Filter		
Air System		
Generator Brushes		
Engine Oil		
	Change Oil	
	Change Filter	
Engine Mounts		
Gauges		
Remarks		
Electrical Checks		
Remarks		
Date:		Signature:

MACHINERY OIL/GREASE MAINTENANCE CHECKLIST

Bridge No.: ______________________________

COMPONENT	LUBRICANT GRADE	NOTES
Generator Motor Oil		
Brake Fluid		
Gear Grease		
Speed Reducer Oil		
Bearing Grease		
Linkage/Pin Grease		
Hydraulic Fluid		
Coupling Grease		
Grid Coupling Grease		
Span Lock/Wedge Grease		
Buffer Cylinder Oil		
Cable/Chain Fluid		
Traffic Gate Reducer Oil		

Date: ______________ Signature: ______________________________

Commentary:

During maintenance inspection of machinery lubrication systems, evaluate the level and condition of lubricants. Note observations and work performed (such as inspection or cleaning, add or change lubricant, etc.).

BRAKE MAINTENANCE CHECKLIST

Bridge No.: ____________________

COMPONENT	COMMENTS
Pads	
Brake Fluid	
Push Rod Seals	
Springs	
Brake Wheel/Disc	
Manual Release Lever	
Linkage and Pins	
Brake Motor	

Date: ____________ Signature: ____________________

Commentary:

During scheduled brake maintenance activities, check and comment on the component condition. Note any adjustments or maintenance repairs performed.

MECHANICAL COMPONENTS MAINTENANCE CHECKLIST

Bridge No. ____________________ Bridge Name ________________________________

FREQUENCY (W, 1M, 6M, Y)*	LETTER	ITEM TO CHECK	SEE PAGE	COMMENTS
	A	Bearings		
	B	Pillow Blocks		
	C	Buffer Cylinders		
	D	Speed Reducer(s)		
	E	Couplings		
	F	Live load Shoes/Strike Plates		
	G	Span Locks		
		1) Cross Shaft		
		2) Independent		
		3) Hydraulics		
	H	Machinery Supports/Frames		
	I	Fasteners		
	J	Shafts		
	K	Gears/Pinions/Racks		
	L	Gear Motors (Auxiliary Drives)		
	M	Brakes		
	N	Traffic Gates		
	O	Hydraulic System		
		1) Drives		
		2) Motors		
		3) Hoses		
		4) Cylinders		
		5) Traffic Gates		
	P	Flat & Curved Tracks		
	Q	Steel		
	U	Tender's Facilities		
	R	Fender System		
	S	Bridge Wash Down		
	T	Other		

* W = Weekly 1M = Monthly 6M = Semiannual Y = Annual X = Deficiency = - Inspected N/A = Not Applicable

SUPERVISOR'S SIGNATURE: DATE:

CREW LEADER'S SIGNATURE: DATE:

ELECTRICAL COMPONENTS MAINTENANCE CHECKLIST

Bridge No. ____________________ Bridge Name ________________________________

FREQUENCY (2,1M,6M,Y)*	LETTER	ITEM TO CHECK	SEE PAGE	COMMENTS
	A	Brake Assemblies		
	B	Motors		
	C	Generators		
	D	Leaf Limit Switches		
	E	Bridge Submarine Cables		
	F	Panel(s) & Control Cabinets		
	G	Circuit Breakers		
	H	Manual Motor Starters		
	I	Magnetic Motor Starters		
	J	Contact Tips		
	K	Fuses		
	L	Relays		
	M	Mech. Operated Devices (Switches)		
	N	Meters & Instruments		
	O	Solenoids		
	P	Resistors		
	Q	Drum Controllers		
	R	Equipment Grounding		
	S	Control Console		
	T	Programmable Logic Controller(s)		
	U	Variable Speed Drives		
	V	Automatic Transfer		
	W	Conduit System		
	X	Span Locks		
	Y	Sump Pump(s)		
	Z	Traffic Gates		
	AA	Traffic Signals		
	BB	General Lighting		
	CC	Navigation Lights		
	DD	Marine Horn		
	EE	Marine Radio		
	FF	Telephone		

* W = Weekly 1M = Monthly 6M = Semiannual Y = Annual X = Deficiency = - Inspected N/A = Not Applicable

SUPERVISOR'S SIGNATURE: DATE:

CREW LEADER'S SIGNATURE: DATE:

BRIDGE MAINTENANCE LOG

Bridge No.: ____________________ **Month:** __________________ **Year:** ____________

DATE/TIME	NUMBER	PARTY/REASON CALLED	PERSON CALLING

APPENDIX A – GEAR MECHANICS

A.1—SPUR GEARS

Gears accomplish several basic purposes. One is to provide mechanically interlocked, positive connection between two shafts, which can transmit torque from the driving shaft to the driven shaft, while another is to provide mechanical advantage, or change rotational speed. One more specialized purpose is to change rotary motion into linear motion by means of a gear and a straight line of teeth machined into a rack.

A pair of friction wheels of the same diameter is illustrated in Figure A.1-1. If the wheels are held together and one is driven, it will drive the other at exactly the same speed. On a friction wheel system, the relationships between speed, torque, contact force, and frictional driving force are quite simple. Wheels of similar diameter have similar rotational speeds, shaft torques, and contact and friction forces. If the size of one wheel is doubled, as shown in Figure A.1-2, the contact and friction forces must be the same at the point of contact for the forces to be balanced. Since force *f* is the same and the distance (or torque arm) to the center of the drive shaft is doubled on wheel 1, the shaft torque, which is equal to the torque arm times the applied force *f*, is also doubled on wheel 1. It may also be seen that since the circumference of a wheel is proportional to its diameter (circumference = πd), the circumference change from wheel 2 to wheel 1 is also doubled. If wheel one is required to remain in contact with wheel 2, then for one revolution of wheel 2, wheel 1 will turn only half of one revolution.

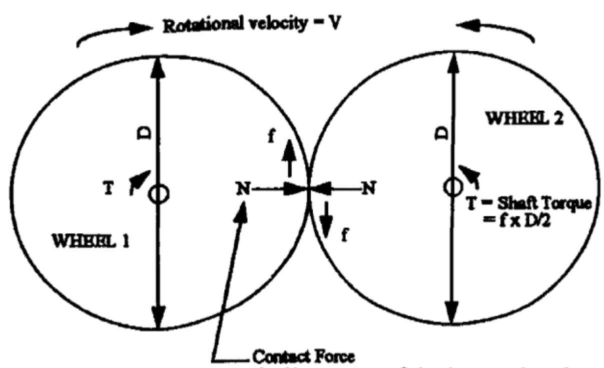

Figure A.1-1 – Equal diameter friction wheels

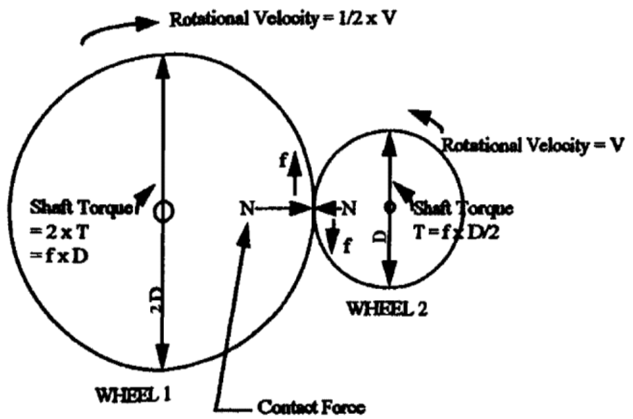

Figure A.1-2 – Unequal diameter friction wheels

Figure A.1-3 shows a simple friction wheel and rack system. If we assume wheel one is the tire on an automobile, then we can easily visualize this system's basic function. As wheel 1 turns through a 90 degree arc, the axle center moves forward so that R2 becomes a vertical line, and Point B comes into contact with the rack. If there is no slippage, the axle center will move horizontally through a distance equal to the arc length between points A and B. It may be readily seen that this distance is one quarter of the total circumference of the wheel. If we move through four such 90 degree arcs, we again have Point A in contact, having completed one revolution of wheel 1, and having moved a horizontal distance equal to the circumference of wheel 1.

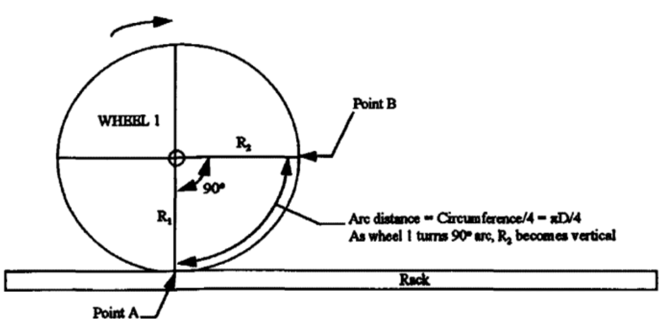

Figure A.1-3 – Friction wheel and rack

For movable bridges, the conditions are such that friction type systems as discussed above are impractical. Torques and loads are substantial, and a friction system might slip, leading to potentially disastrous results. Toothed gears function similarly to the above friction systems, except that the diameter used in the formulas would be the diameter (D_p) of the "pitch circle." The pitch circle is the theoretical circle that rolls tangent to the pitch circle of a matched gear. It is roughly located at the mid height of spur teeth as shown in Figure A.1-4.

Spur gears are cylinders with gear teeth cut into their circumference. The teeth are parallel to one another as well as to the axis of the cylinder. Two spur gears having the same size teeth will mesh together. The smaller of the two is usually called the pinion, and the larger one is called the gear. In most cases the pinion drives the gear; however, during braking, for instance, the gear drives the pinion. Sometimes, the pinion and the gear of the gear set are referred to as the "driver" and the "driven," respectively. Figure A.1-4 shows a gear and pinion in proper mesh. Notice that their pitch circles are tangent.

Pinions and gears are individual parts which are pressed or shrink fitted, and keyed onto separate shafts. However, sometimes for smaller diameter pinions, the teeth may have been cut directly into the shaft, so that the pinion is integral with the shaft.

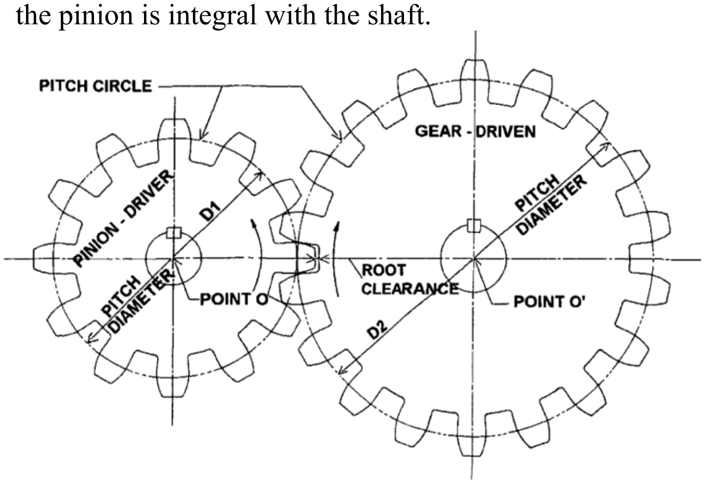

Figure A.1-**4** – Spur gears in correct mesh. The pitch circles are tangent

On small gears, the teeth appear to have a curved profile. On larger gears, the profile seems to flatten out and approach a straight line. The tooth profile of a gear is thus a function of its pitch circle diameter. On most spur gears, this function is an involute curve. An involute curve is the shape traced by a point on a string as the string is unwound from a fixed base circle as shown in Figure A.1-5. The profile of a complete tooth consists of two identical, opposed involutes cut before the point of intersection so that the top is flat, as shown in Figure A.1-6.

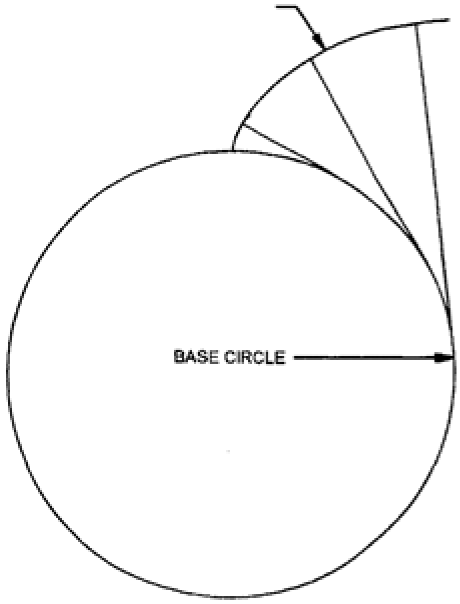

Figure A.1-5 - An involute curve

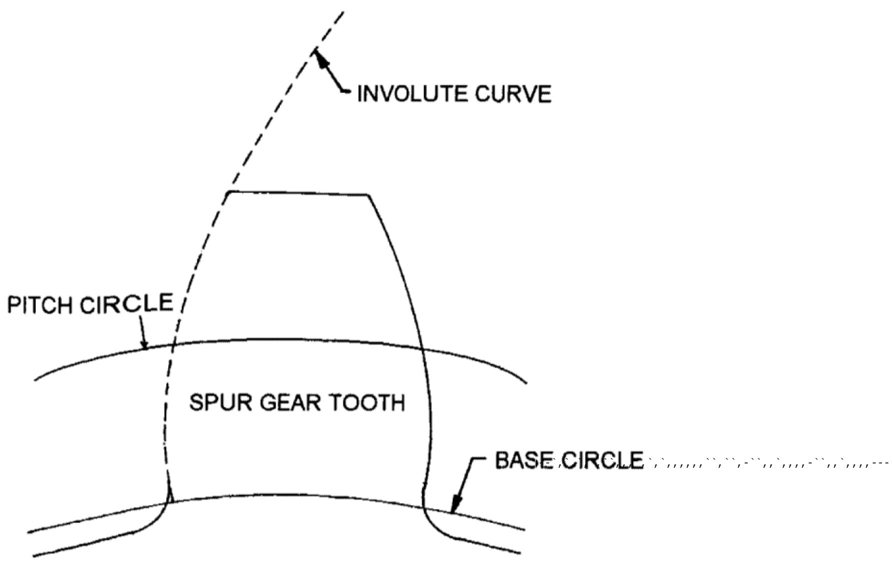

Figure A.1-6 – An involute profile

Spur gear teeth of two different standard depths have typically been used in bridge machinery. These are known as stub and full depth teeth. As their names imply, these teeth differ in tooth height, or the depth of tooth from the tip to root. In most cases, the gears from the motor pinion to the last reduction before the rack pinion have full depth teeth, which is the case with newer movable bridges. In older bridges, however, stub tooth forms have been used for the rack and pinion. Correct tooth shape is an exacting part of gearing design, and is necessary to achieve smooth translation of the rotary motion, which, in gear terminology, is known as conjugate action. The significance of the involute tooth profile is illustrated in Figure A.1-7.

Two spur gears running together will have their pitch circles in contact at the pitch point. A line through the pinion center (0) and the gear center (0′) will pass through this point. As long as the teeth are in mesh, the points of contact between them are always in a straight line. This line is called the line of action and is tangent to the base circles of both the gear and pinion. If teeth are not cut to the proper involute shape, they will bind as they rotate into and out of the mating gear teeth. The pressure angle is the included angle between the line of action and a line tangent to the pitch circles at the pitch point, as shown in Figure A.1-7.

Figure A.1-8 denotes the various parts of a spur gear tooth. It is recommended that inspectors use this identification terminology when reporting about gear teeth.

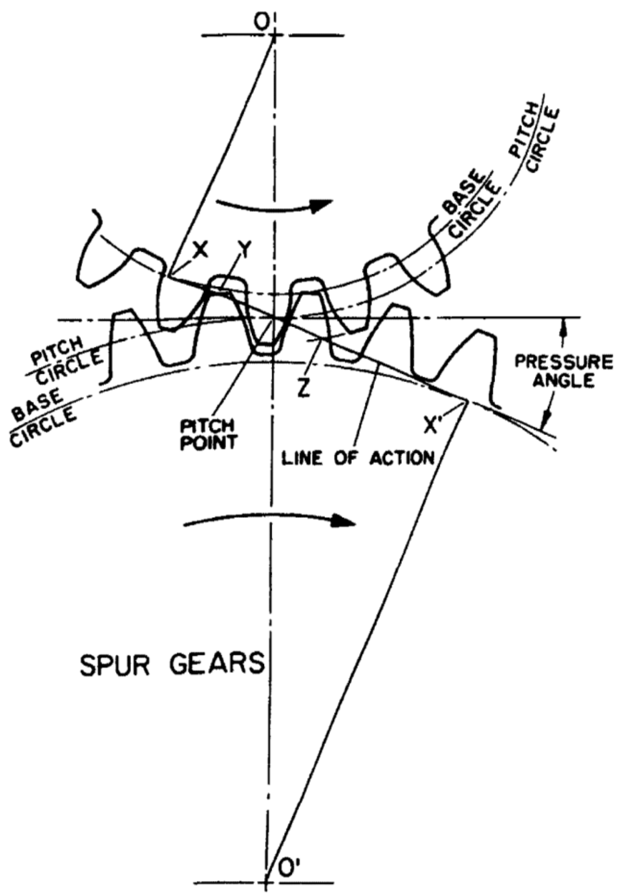

Figure A.1-7 – Two spur gears in proper mesh

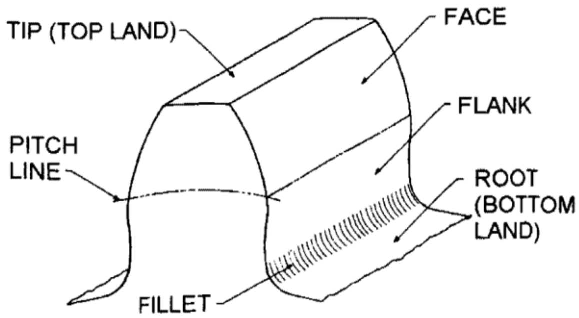

Figure A.1-**8** – Spur tooth nomenclature

A.2—SPUR RACKS

A spur rack is a flat, straight bar that has teeth machined into it, as seen in Figure A.2-1. It may be thought of as a gear segment having an infinite pitch radius. A section of such a gear would be perfectly straight; consequently, a rack tooth profile would be the involute of a base circle having an infinite radius. Since such an involute would be a straight line, racks have straight sided teeth. Many bridge applications require large radius gear segments. Swing span bridge racks and trunnion bascule bridge racks are examples. Any involute gear having a large pitch radius will have nearly straight sided teeth. Years ago, in order to simplify manufacturing, many large diameter gears were made with straight sided teeth and referred to as "curved racks." Today, however, even the largest diameter gears used in bridge machinery have accurately finished, involute tooth forms. The term "rack" continues to be used to identify such large diameter gears and gear segments, whether the teeth have curved or straight profiles.

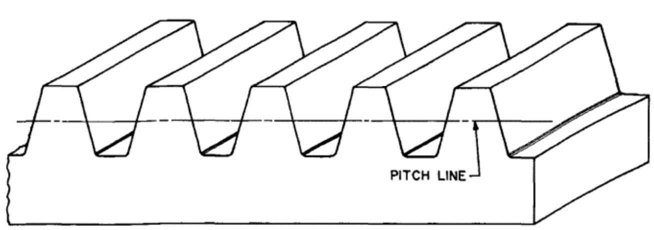

Figure A.2-**1** – A straight spur rack

A.3—BEVEL GEARS

Bevel gears are used to transmit rotation from one shaft to a nonparallel shaft; perpendicular shafts, or shafts at 90 degrees to each other, are most common. The basic shape of bevel gears is conical, rather than cylindrical, and the teeth are tapered with the large end being at the maximum diameter of the cone. Actually only a portion of the cone, called a frustum, is used since it would be difficult to cut teeth at the pointed end and those teeth would have little strength to transmit usable power. Bevel gear teeth have an involute profile similar to spur gears.

Figure A.3-l shows a pair of bevel gears in mesh. Notice that both members are the same size, having the same number of teeth. Speed reduction does not occurs with this gear set. Bevel gear sets such as this, having a ratio of 1:1, are commonly called miter gears. Most bevel gears in bridge machinery service have a ratio greater than 1:1.

Typical uses of bevel gears on movable bridges include driving the vertical rack pinion shafts on swing spans from the horizontal transverse shafts, driving the span position indicators from the trunnion end on bascules, and driving various rotary switches and other electrical devices on all types of movable bridges.

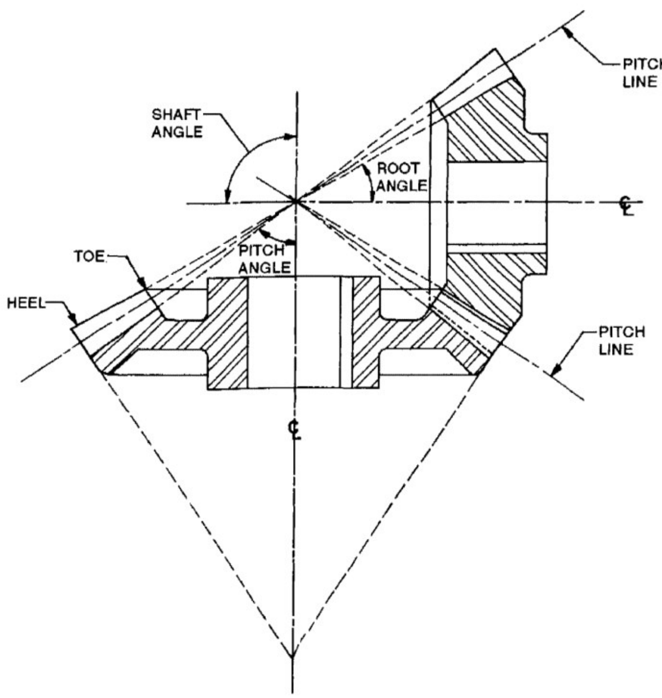

Figure A.3-1 - Sectional view of a bevel gear set.

A.4—FORMULAS AND SYMBOLS

Figure A.4-1 illustrates a spur gear and spur rack. This figure is the reference diagram for defining various tooth parts necessary for measuring and determining tooth wear.

Pitch: The standard measure of gear tooth size in the English system is diametral pitch (*P*), although another means is also used and is called circular pitch (*p*). Circular pitch is the distance along the pitch circle or pitch line between corresponding points on adjacent teeth. For instance, if the distance along the pitch circle

CA.4

In addition to thinning of gear teeth, or gear and pinion teeth, some gear sets had backlash provided by extending the center distance a sufficient amount, and neither the gear nor the pinion was thinned.

from the center of one tooth to the center of an adjacent tooth is 3 in., then the gear has a circular pitch of 3 in. Given the number of teeth (N) and the pitch diameter of a gear (D_p) or pinion (d_p), the circular pitch can be determined using the following formula:

$$p = \frac{D_p \pi}{N} \quad \text{(Equation A.4-1)}$$

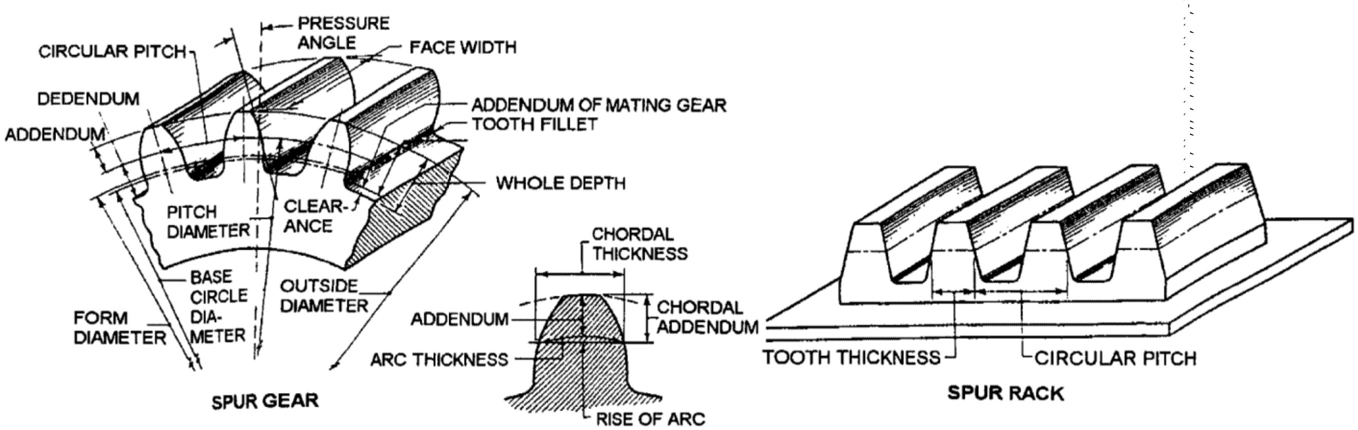

Figure A.4-1 – Spur gear and rack terminology

Diametral pitch is simply the number of teeth per inch of pitch diameter:

$$P = \frac{N}{D_p} \quad \text{(Equation A.4-2)}$$

From these two equations, it may be determined that circular pitch and diametral pitch have an inverse relationship:

$$P = \frac{\pi}{N} \quad \text{(Equation A.4-3)}$$

Note: All tables used in the following calculations are provided at the end of this Appendix (Pages A-17 to A-19). The tables used in this Manual are based on diametral pitch. Circular pitch dimensions must be converted to the diametral pitch system in order to use them. Table A.4-1 gives standard circular pitch dimensions for most gears used in bridge machinery. The equivalent diametral pitch is listed in column 2. Diametral pitch values for circular pitches not listed in Table A.4-1 may be calculated using Equation A.4-3.

Addendum (a): The height by which a tooth projects beyond the pitch circle or pitch line; also, the radial distance between pitch circle and the addendum circle,

The tables and examples provided in this appendix are in the customary U.S. units. Equivalent S.I. versions of the tables have been generated by AGMA and ANSI, and can be obtained from them.

or outside diameter.

Backlash (BL): The amount of space between meshing teeth. Backlash is an elusive and inconsistent entity as there is no standard for the amount of backlash required for a given size gear set.

A common way of providing backlash is to cut the gear teeth thinner than their calculated thickness. This is illustrated in Figure A.4-2. The gear teeth are selected since they are stronger than the pinion teeth. However, this practice is not followed by all manufacturers, and frequently both the pinion and gear teeth are thinned.

Table A.4-3 lists nominal backlash values for spur gears based upon center distance and diametral pitch. The center distance of a gear set may be calculated using the following formula:

$$CD = \frac{D_p + d_p}{2} \qquad \text{(Equation A.4-4)}$$

Without further data, the average value of the two amounts given should be used as the assumed original backlash. This will normally be sufficiently accurate for determination of gear tooth wear.

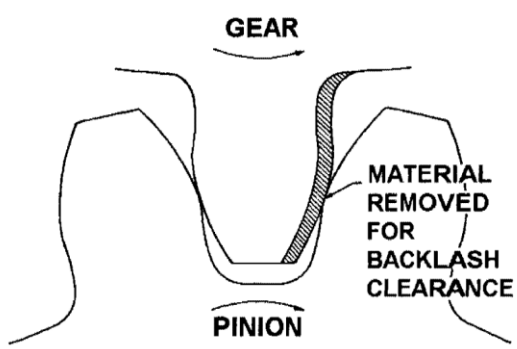

Figure A.4-2 – Providing for backlash

Dedendum (b): The depth of a tooth space below the pitch circle or pitch line; also, the radial distance between the pitch circle and the root circle.

Center distance (CD): The distance between parallel axes of spur gears; also, the distance between the centers of pitch circles.

Circular thickness (t_p for pinions, t_g for gears): The tooth thickness taken at the pitch circle.

Clearance (c): The amount by which the dedendum in a given gear exceeds the addendum of its mating gear; also, the radial distance from the root circle to the tip of the mating tooth.

Outside diameter (d_o for pinions, D_o for gears): The outside diameter of a pinion or gear, equal to the sum of the pitch diameter plus two times the addendum.

Pressure angle (PA): The slope of the tooth at the pitch circle position.

Working depth (h_k): The depth of engagement of mating teeth, that is, the sum of their operating addendums.

Whole depth (h_t): The total depth of a tooth space, equal to the addendum plus dedendum, also equal to the working depth plus the clearance.

It is impractical to measure the actual circular tooth thickness along the pitch circle. Therefore, straight line or chordal dimensions are used when measuring gear teeth. Figure A.4-3 shows the relationship between circular and chordal tooth parts.

Chordal thickness (t_c): The straight line distance taken between the points on the tooth faces intersected by the pitch circle.

Chordal addendum (a_c): The radial distance from the chordal thickness line to the tip.

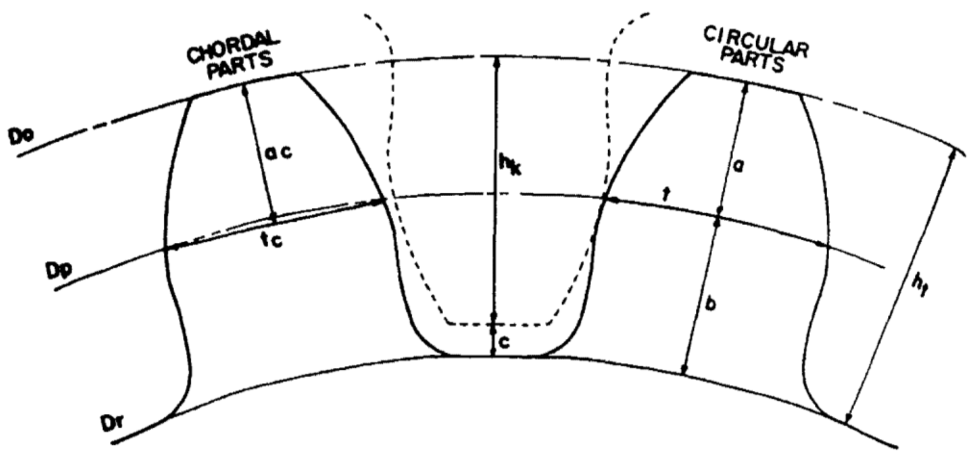

Figure A.4-3 – Circular and chordal tooth parts

EXAMPLES

The following examples illustrate how to calculate chordal tooth dimensions for gear teeth having standard full depth, stub, modified addendum, and bevel tooth forms, and include both vernier tooth caliper and span vernier tooth calculations.

Note: Since most of the existing gears are designed in the U.S. customary units, the calculations below are also presented in the same units. If needed, similar calculations can be performed in SI units.

Example 1. Determine the chordal addendum and chordal tooth thickness of the following full depth spur gear set.

Pinion: $N = 14$ teeth

$p = 2$ in. circular pitch

d_p = 8.913 in. pitch diameter

Gear: N = 69 teeth
p = 2 in. circular pitch
D_p = 43.9 in. pitch diameter

Convert the circular pitch to diametral pitch using Table A.4-1.

2 in. circular pitch (p) = 1.5708 in. diametral pitch (p)

Table A.4-2 gives the chordal thickness and addendum for a 1 P standard, full depth tooth. Locate the number of teeth (N) and read the t_c and a_c values. Now, since these values are for a 1 P tooth, they should be divided by the diametral pitch of the gear or pinion being calculated.

Pinion:

$$a_c = \frac{1.04401}{1.5708} = 0.665 \text{ in.} \quad t_c = \frac{1.56752}{1.5708} = 0.998 \text{ in.}$$

The procedure is the same for the mating gear, except that backlash should be taken into consideration. Calculate the center distance, using Equation A.4-4, and select the average backlash for the center distance and diametral pitch from Table A.4-3.

$$CD = \frac{8.913 + 43.9}{2} = 26.407 \text{ in.} \quad BL = 0.040 \text{ in.}$$

$$a_c = \frac{1.00893}{1.5708} = 0.642 \text{ in.}$$

$$t_c = \frac{1.57066}{1.5708} - BL = 1.000 - 0.040 = 0.960 \text{ in.}$$

Many bridges, particularly older ones, have 20 degree stub tooth pinions and gears. Since stub teeth are shorter than full depth teeth, they have shorter addendums (a). Addendum values for full depth, AGMA stub and Nuttal stub teeth are given in Table A.4-4. Although the addendums of stub teeth are less than those of corresponding pitch full depth teeth, the tooth thicknesses are the same at the pitch circles and other points along the tooth profile at similar distances from the pitch circles.

Example 2. Calculate the chordal dimensions for the following AGMA 20 degree stub tooth gear set.

Pinion: N = 18 teeth

p = 0.75 in.
d_p = 24 in.

Gear: N = 52 teeth
p = 0.75 in.
D_p = 69.3333 in.

Pinion:

First, find the difference between the true addendum of the stub tooth and the true addendum of the corresponding full depth gear using Table A.4-4.

$$a \text{ (full depth)} - a \text{ (stub)} = 1.3333 - 1.0667 = 0.267 \text{ in.}$$

Determine the chordal addendum of the full depth pinion tooth with the same pitch and number of teeth as the stub tooth, and subtract 0.267 in. from it.

$$a_c \text{ (stub)} = a_c \text{ (full depth)} - 0.267 = \frac{1.03425}{0.75} - 0.267 = 1.112 \text{ in.}$$

Since the chordal thickness of the stub tooth pinion is the same as that for the corresponding full depth pinion, the t_c calculation is the same as outlined in Example 1.

$$t_c = \frac{1.56880}{0.75} = 2.092 \text{ in.}$$

Calculations for the gear are the same as performed on the pinion, but should include adjustment for backlash by subtracting the *BL* from the calculated chordal tooth thickness, as shown in Example 1. If the gear set had Nuttal stub teeth, the same procedure would be followed using the addendum values for Nuttal teeth.

Note: It is not necessary to know the pressure angle to calculate the true and chordal addendum and tooth thickness, since those values are independent of the pressure angle.

Example 3. Determine the span dimensions for the following spur gear set.

Pinion: N = 17 teeth
P = 5 diametral pitch
d_p = 3.400 in.
PA = 14.5 degrees

Gear: N = 96 teeth
P = 5 diametral pitch
D_p = 19.200 in.
PA = 14.5 degrees

The number of teeth (k) over which the span measurement is to be taken depends upon the total number of teeth in the full pinion or gear. These values are given in Table A.4-5. Notice that the numbers may be different for

$14^1/_2$ degrees and 20 degrees *PA* teeth. Table A.4-6 lists the span dimensions (*M*) for a 1 *P* pinion or gear. To obtain the corresponding dimensions for other pitches, divide these values by the actual diametral pitch. Both Tables A.4-5 and A.4-6 may be used for full depth and stub teeth.

From Table A.4-5, obtain the number of teeth for the span measurement:

k (pinion) = 2 teeth $\qquad$ k (gear) = 8 teeth

From the span dimensions in Table A.4-6, calculate the required values:

$$M_p \text{ (pinion)} = \frac{4.6535}{5} = 0.931 \text{ in.}$$

$$M_g \text{ (gear)} = \frac{23.3268}{5} = BL = 4.665 - 0.025 = 4.640 \text{ in.}$$

The amount by which the gear tooth was thinned to provide for backlash, 0.025 in., was calculated the same way as in Example 1.

With the standard addendum gearing, the gear teeth are stronger than the pinion teeth. In order to attain a better strength balance between them, engineers frequently use modified addenda gearing: the pinion addenda is increased by a predetermined amount and the gear addenda is shortened by the same amount. This is illustrated in Figure A.4-4.

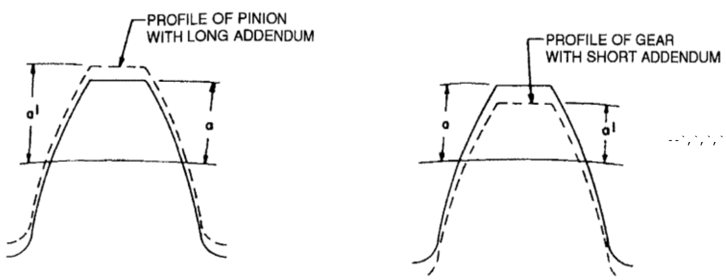

Figure A.4-4–Long and short addendum gearing

When modified addendum gearing is used, there are an infinite number of possible chordal and span dimensions and it is impractical to chart them. Therefore, dimensions should be calculated from the following formulas. All symbols with a prime (') designate dimensions modified by changing the addendum. Hence, D_o' is the outside diameter of a gear having a modified addendum.

$$a' = \frac{D_o' - D_p}{2}$$

$a' =$ modified addendum (Equation A.4-5)

$$t' = \frac{p}{2} + 2\ \tan(PA)\ (a' - a)$$

$$t' = \text{modified circular thickness} \qquad \text{(Equation A.4-6)}$$

$$t_c' = D_p\ \sin\left(\frac{180t'}{\pi D_p}\right)$$

$$t_c' = \text{modified chordal thickness} \qquad \text{(Equation A.4-7)}$$

$$a_c' = a' + \frac{D_p}{2}\left[1 - \cos\left(\frac{180t'}{\pi D_p}\right)\right]$$

$$a_c' = \text{modified chordal addendum} \qquad \text{(Equation A.4-8)}$$

Example 4. Find the chordal and span dimensions for the following 5 diametral pitch, 20 degree pressure angle full depth spur gear set having modified addenda.

Pinion: N = 14 teeth
d_o = 3.4 in.
d_p = 2.8 in.

Gear: N = 69 teeth
D_o = 14 in.
D_p = 13.8 in.

$$a' = \frac{d_o' - d_p}{2} = \frac{3.4 - 2.8}{2} = 0.3 \text{ in.}$$

$$\therefore a = 0.2 \text{ in. (from Table A.4-4)}$$

$$p = \frac{\pi}{P} = \frac{\pi}{5} = 0.6283$$

$$t' = \frac{p}{2} + 2\tan(PA)(a' - a) = \frac{0.628}{2} + 2\tan(20)(0.3 - 0.2) = 0.387 \text{ in.}$$

$$t_c' = d_p \sin\left(\frac{180t'}{\pi d_p}\right) = 2.8\sin\left(\frac{180 \times 0.387}{\pi \times 2.8}\right) = 0.386 \text{ in.}$$

$$a_c' = a' + \frac{d_p}{2}\left[1 - \cos\left(\frac{180t'}{\pi d_p}\right)\right] = 0.3 + \frac{2.8}{2}\left[1 - \cos\left(\frac{180 \times 0.387}{\pi \times 2.8}\right)\right] = 0.313 \text{ in.}$$

To calculate the span dimensions for modified addendum gears, find the value of k from Table A.4-5 and use one of the following formulas:

For 20 degrees *PA*:

$$M = \frac{(2.952k + 0.014N - 1.476)}{P} + 0.684(a - a')$$

(Equation A.4-9)

For 14-1/2 degrees *PA*:

$$M = \frac{\left(3.0428k + 0.053N - 1.521\right)}{P} + 0.501(a - a')$$

(Equation A.4-10)

Substitute values in Equation A.4-9:

$$M_p = \frac{\left(2.952 \times 2 + 0.014 \times 14 - 1.476\right)}{5} + 0.684(0.3 - 0.2) = 0.993 \text{ in.}$$

The procedure for calculating the chordal and span dimensions for the mating gear is identical, but remember to subtract the backlash from the chordal tooth thickness.

Example 5. Determine the chordal dimensions for the pinion of a 5 *P*, 20 degree PA bevel gear set having a 90 degree shaft angle:

Pinion: $N = 20$ teeth
$d_p = 4$ in.

Gear: $N = 40$ teeth
$D_p = 8$ in.

Except for the chordal addendum the formulas for calculating tooth proportions of standard addendum, 90 degree straight bevel gears are identical to those for spur gears.

Table A.4-2 may be used to determine the chordal tooth thickness (t_c) in the same way as in previous examples. Remember this is the thickness at the large end of the tooth.

The following formula is used to calculate the chordal addendum at the large end of 90 degrees straight bevel teeth; N_m is the number of teeth in the mating gear or pinion:

$$a_c = a + \frac{D_p N_m}{2\sqrt{N^2 + (N_m)^2}} \left[1 - \cos\left(\frac{90}{N}\right)\right]$$ (Equation A.4-11)

Span measurements are not used when measuring bevel gears since the teeth are cut into conical surfaces and the measurements would be inaccurate. Means of calculating tooth dimensions of bevel gears having modified addenda or shaft angles other than 90 degrees is beyond the scope of this Manual.

Using Table A.4-3 to calculate t_c:

$$t_c = \frac{1.56918}{5} = 0.314 \text{ in.}$$

Solve for a_c using Equation A.4-11:

$$a_c = 0.2 + \frac{4 \cdot 40}{2\sqrt{20^2 + 40^2}}\left[1 - \cos\left(\frac{90}{20}\right)\right] = 0.206 \text{ in.}$$

Table A.4-1 – Standard circular pitches and their equivalent diametral pitches

Circular Pitch	Equivalent Diametral Pitch	Circular Pitch	Equivalent Diametral Pitch
p	P	p	P
4	0.7854	1 1/4	2.5133
3 1/2	0.8976	1 3/16	2.6456
3	1.0472	1 1/8	2.7925
2 3/4	1.1424	1 1/16	2.9568
2 1/2	1.2566	1	3.1416
2 1/4	1.3963	15/16	3.3510
2	1.5708	7/8	3.5904
1 7/8	1.6755	13/16	3.8666
1 3/4	1.7952	3/4	4.1888
1 5/8	1.9333	11/16	4.5696
1 1/2	2.0944	2/3	4.7124
1 7/16	2.1855	5/8	5.0265
1 3/8	2.2848	9/16	5.5851
1 5/16	2.3936	1/2	6.2832

Table A.4-2 – Chordal dimensions for a 1 P standard, full-depth gear

No. of Teeth	Chordal Thickness	Chordal Addend.	No. of Teeth	Chordal Thickness	Chordal Addend.	No. of Teeth	Chordal Thickness	Chordal Addend.	No. of Teeth	Chordal Thickness	Chordal Addend.
10	1.56435	1.06156	47	1.57051	1.01311	84	1.57071	1.00743	121	1.57075	1.00511
11	1.56546	1.05598	48	1.57052	1.01285	85	1.57071	1.00725	122	1.57075	1.00507
12	1.56631	1.05133	49	1.57053	1.01258	86	1.57071	1.00716	123	1.57076	1.00503
13	1.56698	1.04739	50	1.57054	1.01233	87	1.57071	1.00708	124	1.57076	1.00499
14	1.56752	1.04401	51	1.57055	1.01209	88	1.75071	1.00700	125	1.57076	1.00495
15	1.56794	1.04109	52	1.57056	1.01187	89	1.57072	1.00693	126	1.57076	1.00491
16	1.56827	1.03852	53	1.57057	1.01165	90	1.57072	1.00686	127	1.57076	1.00487
17	1.5685	1.03625	54	1.57058	1.01143	91	1.57072	1.00679	128	1.57076	1.00483
18	1.56880	1.03425	55	1.57058	1.01121	92	1.57072	1.00672	129	1.57076	1.00479
19	1.56890	1.03244	56	1.57059	1.01102	93	1.57072	1.00665	130	1.57076	1.00475
20	1.56918	1.03083	57	1.57060	1.01083	94	1.57072	1.00658	131	1.57076	1.00472
21	1.56933	1.02936	58	1.57061	1.01064	95	1.57073	1.00651	132	1.57076	1.00469
22	1.56948	1.02803	59	1.57061	1.01046	96	1.57073	1.00644	133	1.57076	1.00466
23	1.56956	1.02681	60	1.57062	1.01026	97	1.57073	1.00637	134	1.57076	1.00462
24	1.56967	1.02569	61	1.57062	1.01011	98	1.57073	1.00630	135	1.57076	1.00457
25	1.56977	1.02466	62	1.57063	1.00991	99	1.57073	1.00623	136	1.57076	1.00454
26	1.56986	1.02371	63	1.57063	1.00978	100	1.57073	1.00617	137	1.57076	1.0045q
27	1.56991	1.02284	64	1.57064	1.00963	101	1.57074	1.00711	138	1.57076	1.00447
28	1.56998	1.02202	65	1.57064	1.00947	102	1.57074	1.00605	139	1.57076	1.00444
29	1.57003	1.02127	66	1.57065	1.00943	103	1.57074	1.00599	140	1.57076	1.00441
30	1.57008	1.02055	67	1.57065	1.00938	104	1.57074	1.00593	141	1.57076	1.00439
31	1.57012	1.01990	68	1.57066	1.00907	105	1.57074	1.00587	142	1.57076	1.00435
32	1.57016	1.01926	69	1.57066	1.00893	106	1.57074	1.00582	143	1.57076	1.00432
33	1.57019	1.01869	70	1.57067	1.00880	107	1.57074	1.00575	144	1.57076	1.00429
34	1.57021	1.01813	71	1.57067	1.00867	108	1.57074	1.0570	145	1.57077	1.00425
35	1.57025	1.01762	72	1.57067	1.00855	109	1.57075	1.00565	146	1.57077	1.00422
36	1.57028	1.01714	73	1.57068	1.00843	110	1.57075	1.00560	147	1.57077	1.00419
37	1.57032	1.01667	74	1.57068	1.00832	111	1.57075	1.00556	148	1.57077	1.00416
38	1.57035	1.01623	75	1.57068	1.00821	112	1.57075	1.00551	149	1.57077	1.00413
39	1.57037	1.01582	76	1.57069	1.00810	113	1.57075	1.00546	150	1.57077	1.00411
40	1.57039	1.01542	77	1.57069	1.00799	114	1.57075	1.00541	151	1.57077	1.00409
41	1.57041	1.01504	78	1.57069	1.00789	115	1.57075	1.00537	152	1.57077	1.00407
42	1.57043	1.01471	79	1.57069	1.00780	116	1.57075	1.00533	153	1.57077	1.00405
43	1.57045	1.01434	80	1.57070	1.00772	117	1.57075	1.00529	154	1.57077	1.00402
44	1.57047	1.01404	81	1.57070	1.00762	118	1.57075	1.00524	155	1.57077	1.00400
45	1.57048	1.01370	82	1.57070	1.00752	119	1.57075	1.00519	156	1.57077	1.00397
46	1.57050	1.01341	83	1.57070	1.00743	120	1.57075	1.00515			

Table A.4-3 – Nominal backlash values for spur gears

Center Distance (IN)	Normal Diametral Pitches				
	0.5-1.99	2-3.49	3.5-5.99	6-9.99	10-19.99
	Backlash, Normal Plane (IN)				
Up to 5					0.005-0.015
Over 5 to 10				0.010-0.020	0.010-0.020
Over 10 to 20			0.020-0.040	0.015-0.025	0.010-0.020
Over 20 to 30	0.030-0.050	0.030-0.040	0.025-0.035	0.020-0.030	
Over 30 to 40	0.040-0.060	0.035-0.045	0.030-0.040	0.025-0.035	
Over 40 to 50	0.050-0.070	0.040-0.065	0.035-0.050	0.030-0.040	
Over 50 to 80	0.060-0.080	0.045-0.055	0.040-0.060		
Over 80 to 100	0.070-0.095	0.50-0.080			
Over 100 to 120	0.080-0.110				

Table A.4-4 – True addendum values for standard full depth, AGMA stub, and Nuttal stub-toothed gears and pinions

Diametral Pitch	a (full-depth)	Diametral Pitch	a (Nuttal)
1/2	2.000	0.7854	1.000
3/4	1.333	0.8976	0.875
1	1.000	1.0472	0.750
1 1/4	0.8000	1.1424	0.6875
1 1/2	0.666	1.2566	0.625
1 3/4	0.5714	1.3963	0.5625
2	0.5000	1.5708	0.5000
2 1/4	0.4444	1.6755	0.4687
2 1/2	0.4000	1.7952	0.4375
2 3/4	0.3636	1.9333	0.4062
3	0.3333	2.0944	0.3750
3 1/2	0.2857	2.1855	0.3593
4	0.2500	2.2848	0.3437
5	0.2000	2.3562	0.3333
6	0.1666	2.3936	0.3281
Diametral Pitch	**a (stub)**	2.5133	0.3125
		2.6158	0.2968
1/2	1.6000	2.7925	0.2812
3/4	1.0667	2.9568	0.2656
1	0.8000	3.1416	0.2500
1 1/4	0.6400	3.3510	0.2343
1 1/2	0.5333	3.5904	0.2187
1 3/4	0.4571	3.8666	0.2031
2	0.4000	4.1888	0.1875
2 1/4	0.3556	4.5696	0.1718
2 1/2	0.3200	4.7124	0.1666
2 3/4	0.2909	5.0265	0.1562
3	0.2667	5.5851	0.1406
3 1/2	0.2286	6.2832	0.1250
4	0.2000		
5	0.1600		
6	0.1333		

Table A.4-5 – Number of teeth included in span measurement, k, for 14 1/2° and 20° gears

Number of Teeth in Gear		k
$Ø_2$ = 14 1/2 DEG	$Ø_2$ = 20 DEG	
9 to 22	7 to 16	2
23 to 34	17 to 25	3
35 to 47	26 to 34	4
48 to 59	35 to 43	5
60 to 72	44 to 52	6
73 to 84	53 to 61	7
85 to 97	62 to 70	8
98 to 109	71 to 79	9
110 to 121	80 to 88	10
122 to 134	89 to 97	11
. . .	98 to 106	12
. . .	107 to 115	13
. . .	116 to 124	14
. . .	125 to 133	15

Table A.4-6 – Span dimensions for a 1 P gear. Backlash not included

Number of Teeth in Gear	Span Dimension IN	Number of Teeth in Gear	Span Dimension IN	Number of Teeth in Gear	Span Dimension IN	Number of Teeth in Gear	Span Dimension IN	Number of Teeth in Gear	Span Dimension IN
14-1/2 DEG PRESSURE ANGLE									
9	4.6106	27	7.7488	45	10.8869	63	17.0666	81	20.2047
10	4.6160	28	7.7541	46	10.8923	64	17.0720	82	20.2101
11	4.6213	29	7.7595	47	10.8976	65	17.0773	83	20.2155
12	4.6267	30	7.7649	48	13.9445	66	17.0827	84	20.2208
13	4.6321	31	7.7702	49	13.9499	67	17.0881	85	23.2677
14	4.6374	32	7.7756	50	13.9553	68	17.0934	86	23.2731
15	4.6428	33	7.7810	51	13.9606	69	17.0988	87	23.2785
16	4.6482	34	7.7863	52	13.9660	70	17.1042	88	23.2838
17	4.6535	35	10.8332	53	13.9714	71	17.1095	89	23.2892
18	4.6589	36	10.8386	54	13.9767	72	17.1149	90	23.2956
19	4.6643	37	10.8440	55	13.9821	73	20.1618	91	23.2999
20	4.6697	38	10.8493	56	13.9875	74	20.1672	92	23.3053
21	4.6750	39	10.8547	57	13.9929	75	20.1725	93	23.33107
22	4.6804	40	10.8601	58	13.9982	76	20.1779	94	23.3161
23	7.7273	41	10.8654	59	14.0036	77	20.1833	95	23.3214
24	7.7327	42	10.8708	60	17.0505	78	20.1886	96	23.3268
25	7.7380	43	10.8762	61	17.0558	79	20.1940	97	23.3322
26	7.7434	44	10.8815	62	17.0612	80	20.1994		
20 DEGREE PRESSURE ANGLE									
7	4.5262	20	7.6604	33	10.7946	46	16.8810	59	20.0152
8	4.5402	21	7.6744	34	10.8086	47	16.8950	60	20.0292
9	4.5542	22	7.6885	35	13.7748	48	16.9090	61	20.0432
10	4.5683	23	7.7025	36	13.7888	49	16.9230	62	23.0093
11	4.5823	24	7.7165	37	13.8026	50	16.9370	63	23.0233
12	4.5963	25	7.7305	38	13.8168	51	16.9510	64	23.0373
13	4.6103	26	10.6966	39	13.8303	52	16.9650	65	23.0513
14	4.6243	27	10.7106	40	13.8448	53	19.9311	66	23.0654
15	4.6383	28	10.7246	41	13.8588	54	19.9452	67	23.0794
16	4.6523	29	10.7386	42	13.8728	55	19.9592	68	23.0934
17	7.6184	30	10.7526	43	13.8868	56	19.9732	69	23.1074
18	7.6324	31	10.7666	44	16.8530	57	19.9872	70	23.1214
19	7.6464	32	10.7806	45	16.8670	58	20.0012		

APPENDIX B—REFERENCES

*Note: References are by author alphabetically, accurate to the first letter

SELECTED REFERENCE LIST

1. 23 CFR 650.

2. 29 CFR 1900–1910 (OSHA).

3. 33 CFR 1–118.

4. 46 CFR 1–599.

5. AASHTO, *Guide Specifications for Bridges Vulnerable to Coastal Storms*, Washington, D.C.: American Association of State Highway and Transportation Officials, 2008.

6. AASHTO, *LRFD Movable Highway Bridge Design Specifications*, Washington, D.C.: American Association of State Highway and Transportation Officials, 2014.

   a. AASHTO, *Guide Specifications for LRFD Seismic Bridge Design*, 2nd Edition, with 2012, 2014, and 2015 Interim Revisions, Washington, D.C.: American Association of State Highway and Transportation Officials, 2011.

7. AASHTO, *Maintenance Manual for Roadways and Bridges*, Washington, D.C.: American Association of State Highway and Transportation Officials, 2007.

   a. AASHTO, *Guide for Bridge Maintenance Management*, Washington, D.C.: American Association of State Highway and Transportation Officials, 1980.

   b. AASHTO, *LRFD Bridge Design Specifications*, Customary U.S. Units, Washington, D.C.: American Association of State Highway and Transportation Officials, 1994.

   c. AASHTO, *LRFD Bridge Design Specifications*, SI Units, Washington, D.C.: American Association of State Highway and Transportation Officials, 1994.

   d. AASHTO, *LRFD Bridge Design Specifications*, Customary U.S. Units, Washington, D.C.: American Association of State Highway and Transportation Officials, 2014.

   e. AASHTO, *Standard Specifications for Movable Highway Bridges*, Washington, D.C.: American Association of State Highway and Transportation Officials, 1938.

   f. AASHTO, *Standard Specifications for Movable Highway Bridges*, Washington, D.C.: American Association of State Highway and Transportation Officials, 1953.

   g. AASHTO, *Standard Specifications for Movable Highway Bridges*, Washington, D.C.: American Association of State Highway and Transportation Officials, 1970.

   h. AASHTO, *Standard Specifications for Movable Highway Bridges*, Washington, D.C.: American Association of State Highway and Transportation Officials, 1988.

8. AASHTO, *Manual for Bridge Evaluation* (MBE), Washington, D.C.: American Association of State Highway and Transportation Officials, 2014.

9. AASHTO, *Roadside Design Guide*, Washington, D.C.: American Association of State Highway and Transportation Officials, 2011.

10. AASHTO, *AASHTOWare Bridge Management Software (BrM)* http://aashtowarebridge.com. Washington, D.C.: American Association of State Highway and Transportation Officials, 2013.

11. AASHTO, *Manual for Bridge Element Inspection* (MBEI). Washington, D.C.: American Association of State Highway and Transportation Officials, 2015.

12. Abrahams, M., *Seismic Performance of Movable Bridges*, HMS 7th Biennial Symposium, November 1998.

13. AGMA, *Geometry Factors for Determining the Pitting Resistance and Bending Strength of Spur and Helical Herringbone Gear Teeth*, Alexandria, VA: American Gear Manufacturers Association, 1989.

14. Allen, J.M., "Ailing Hydraulic Systems Have Three Common Symptoms," *Rock Products*, March, 1979.

15. American Red Cross, *American Red Cross Standard First Aid Workbook,* 1991.

16. ANSI/ASME, *Dimensioning and Tolerancing*, ANSI YI4.5, American National Standards Institute/American Society of Mechanical Engineers, 2009.

17. ANSI/AGMA, *Appearance of Gear Teeth—Terminology of Wear and Failure.* ANSI/AGMA 1010-E95. Alexandria, VA: American National Standards Institute/American Gear Manufacturers Association, 2007.

18. ANSI/AGMA, *Design and Selection of Components for Enclosed Gear Drives*, American National Standards Institute/American Gear Manufacturers Association 6001-E08.

19. ANSI/AGMA, *Fundamental Rating Factors and Calculation Methods for Involute Spur and Helical Gear Teeth*, American National Standards Institute/American Gear Manufacturers Association 2001-D04.

20. ANSI/AGMA, American National Standards Institute/American Gear Manufacturers Association

    a. Inspection Practices – Part 1: Cylindrical Gears – Tangential Measurements 915-1-A02

    b. Inspection Practices – Part 2: Cylindrical Gears – Radial Measurements 915-2-A05

    c. Accuracy Classification System – Tangential Measurements for Cylindrical Gears 2015-1-A01

    d. Accuracy Classification System – Radial Measurements for Cylindrical Gears 2015-2-A06

21. ANSI/AGMA, *Gear Nomenclature, Definitions of Terms with Symbols*, American National Standards Institute/American Gear Manufacturers Association 1012-G05.

22. ANSI/AGMA*, Industrial Gear Lubrication*, American National Standards Institute/American Gear Manufacturers Association 9005-E02.

23. ANSI/AGMA, *Information Sheet—Geometry Factors for Determining the Pitting Resistance and Bending Strength of Spur, Helical. and Herringbone Gear Teeth*, American National Standards Institute/American Gear Manufacturers Association 908-B89.

24. ANSI/AGMA, *Flexible Couplings—Lubrication*, American National Standards Institute/American Gear Manufacturers Association 9001-B97.

25. ANSI/AGMA, *Flexible Couplings—Nomenclature for Flexible Coupling*, American National Standards Institute/American Gear Manufacturers Association 9009-D02.

26. ANSI/AGMA*, Standard for Industrial Enclosed Gear Drives*, American National Standards Institute/American Gear Manufacturers Association 6013-A06.

27. ANSI/AGMA

    a. ANSI/AGMA, *Cylindrical Wormgearing Tolerance and Inspection Methods*, American National Standards Institute/American Gear Manufacturers Association.

    b. ANSI/AGMA, *Code of Inspection Practice – Part 6: Bevel Gear Measurement Methods*, American National Standards Institute/American Gear Manufacturers Association.

    c. ANSI/AGMA, *Bevel Gears – ISO System of Accuracy*, American National Standards Institute/American Gear Manufacturers Association.

28. ANSI/NETA. *Maintenance Testing Specifications for Electrical Power Distribution Equipment and Systems*. Portage, MI: American National Standards Institute/InterNational Electrical Testing Association, 2011.

29. *ANSI/NFP/JIC – T2.24.1. Hydraulic Fluid Power – Systems Standard for Stationary Industrial Machinery – Supplement to ISA 4414:1998 – Hydraulic Fluid Power – General Rules Relating to Systems*, Milwaukee, WI: National Fluid Power Association. 2007

30. AREMA. *Bridge Inspection Handbook*. Lanham, MD: American Railway Engineering and Maintenance of Way Association, 2008.

31. AREMA, *Manual for Railway Engineering*, Lanham, MD: American Railway Engineering and Maintenance of Way Association, 2014.

32. ASCE, *Quality in the Constructed Project: A Guide for Owners, Designers and Constructors*, Manuals and Reports on Engineering Practice No. 73, Reston, VA,: American Society of Civil Engineers, 2000.

33. ASME*, Risk-Based Inspection—Development of Guidelines*, American Society of Mechanical Engineers, 1991.

34. AWS, *Welding Inspection Handbook*, American Welding Society, 2000.

35. Baranowski, L.B., "Maintenance & Cleanliness of Hydraulic Fluids & Systems," *ASTM Spec. Tech. Pub. 491,* 1972.

36. Barsom, John M. and Rolfe, Stanley T., *Fracture and Fatigue Control in Structures*, Third Edition, Prentice-Hall, 1999.

37. Birnstiel, *A Proposed Scope for Movable Highway Bridge Machinery Inspection*, St. Petersburg, FL: Heavy Movable Structures, 3rd Biennial Symposium, 1990.

38. Birnstiel, *ICE Manual of Bridge Engineering, Chapter Movable Bridges*, London, England: Institution of Civil Engineers, 2008.

39. Bohle, F., "Functional Gear Checking," *Machinery (NY)*, April, 1952.

40. Brown, Christensen, Heavner, Landy, Vasu, "Floating Bridge Drawspan Maintenance," *ASCE Journal of Structural Division*, November, 1981.

41. CAN/CSA-S6-06. *Canadian Highway Bridge Design Code, including Supplement Nos. 1, 2 and 3*. Toronto, Ontario, Canada: Canadian Standards Association, 2013.

42. Cartlidge, C.H., "Design of Swing Bridges from a Maintenance Standpoint," *Journal of Western Society of Engineers*, February, 1907.

43. Castellani, G. and Parenti-Castellani, V., "Rating Gear Strength," *ASME Journal of Mechanical Design*, April, 1981.

44. Castellani, G., "Rating Gear Life," *International Symposium on Gearing & Power Transmissions*, Tokyo, 1981.

45. Catbas, F.N., Gul, M., Gokce, H.B., Frangopol, D. and Grimmelsman, K.A. *Critical Issues, Condition Assessment and Monitoring of Heavy Movable Structures: Emphasis on Movable Bridges*. Structure and Infrastructure Engineering Journal, 2013.

46. Catbas, F.N., Malekzadeh, M. and Khuc, T. *Movable Bridge Maintenance Monitoring*. Orlando, FL: Florida Department of Transportation, 2013.

47. CCAA. *Overhead Crane Inspection and Preventative Maintenance Checklist*. Novi, MI: Crane Certification Association of America, 2013.

48. Chang, F. F. M., *A Statistical Summary of the Cause and Cost of Bridge Failures*, FHWA, U.S. Department of Transportation, 1973.

49. Chen, Wai-Fah and Duan, Lian, "Chapter 13: Movable Bridges." *Bridge Engineering Handbook*, Second Edition, Superstructure Design. Boca Raton, FL: CRC Press, 2014.

50. Committee on Ship-Bridge Collisions, *Ship Collisions with Bridges; The Nature of the Accidents, Their Prevention and Mitigation,* Marine Board of the Commission of Engineering and Technical Systems, National Research Council, National Academy Press, 1983.

51. De Ries, J., "Development of Electromechanical Equipment of Movable Bridges," *Annates des Trauaux Publics de Belgique*, No.6, 1958-59.

52. Department of Transport, U.K. *The Assessment of Highway Bridges and Structures, Design Manual for Roads and Bridges*, Volume 3, Section 3, Part 4. London, England, 2001.

53. Ecale, H., Brown, G., Kocsis, P., "Chicago Type Bascule Balancing: A New Technique," *ASCE Journal of Structural Division*, November, 1977.

54. EPA, *PCBs: Marking and Disposal*, Environmental Protection Agency, 1978.

55. EPA, *PCB Use in Electrical Equipment*, Environmental Protection Agency 1982.

56. Eurocode 3, Part 2-1 BS EN 1993-2, Design of Steel Bridges, 2008.

57. FDOT, *Bridge Inspector's Field Guide of Structural Elements*. Tallahassee, FL.: Florida Department of Transportation, 2008.

58. FDOT, *Bridge Operations and Maintenance Manual*, Tallahassee, FL: Florida Department of Transportation, 1991.

59. FDOT, *Movable Bridge Inspection Training Course Student Workbook*, Tallahassee, FL: Florida Department of Transportation, 1990.

60. Feuer, Norman J., "Abnormal Movement of Bascule Bridges," ASME, Second Movable Bridge Symposium, November, 1987.

61. FHWA, *Bridge Inspector's Manual for Movable Bridges*, Federal Highway Administration, 1977.

62. FHWA, *Bridge Inspector's Reference Manual* (BIRM), Federal Highway Administration, 2002, Revised 2012.

63. FHWA, *Evaluating Scour at Bridges,* Fourth Edition, FHWA-NHI-01-001, Federal Highway Administration, May 2001.

64. FHWA, *Inspection of Fracture Critical Bridge Members*, FHWA-IP-86-26, Federal Highway Administration, September, 1986.

65. FHWA, *Manual on Uniform Traffic Control Devices for Streets and Highways* (MUTCD). Washington, D.C.: Federal Highway Administration, 2009, (R2012).

66. FHWA. *Recording and Coding Guide for the Structure Inventory and Appraisal of the Nation's Bridges*, Report No. FHWA-PD-96-001. Washington D.C.: Office of Engineering, Bridge Division, Bridge Management Branch. December 1995 (R2000).

67. FHWA, *Seismic Retrofitting Manual for Highway Structures: Part 1 – Bridges*, FHWA-HRT-06-032, Federal Highway Administration, January, 2006.

68. Fisher, John W., *Fatigue and Fracture in Steel Bridges*, Wiley-Interscience, 1984.

69. Fisher, John W., *Inspecting Steel Bridges for Fatigue Damage*, Fritz Engineering Laboratory Report No. 386-1S(81), March, 1981.

70. General Electric Co., *Electrical Equipment for Movable Bridges*, 1955.

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

72. Hamilton, C.P. & Hewmann, G.W., "Controls for Movable Bridges," *ENR*, May 4, 1944.

73. Hamilton, C.P., "Operating Movable Bridges," *ENR*, November 18, 1937.

74. Hardesty, Fischer & Christie, "Fifty-Year History of Movable Bridge Construction: Part I," *ASCE Journal of Construction Division*, pp. 511–527, September, 1975.

75. Hardesty, Fischer & Christie, "Fifty-Year History of Movable Bridge Construction: Part II," *ASCE Journal of Construction Division*, Vol. 101, No.3, pp. 529–543, September, 1975.

76. Henke, R.W., "Why Doesn't Everyone Use Electronic Controls?" *Hydraulics & Pneumatics*, June, 1985.

77. Higgins, L.R., *Handbook of Construction Equipment Maintenance*, McGraw Hill Book Co., 1979.

78. Higgins, Lindley R., *Maintenance Engineering Handbook*, 5th ed., McGraw-Hill Book Co., 1994.

79. Hirano, F. & Veno, T., "Lubrication and Failure of Gears," *JSME Journal*, Vol. 79, 1976.

80. HMI. *Hoist Inspection and Hoist Maintenance Personnel Manual*. Charlotte, NC: Hoist Manufacturers Institute, 2002.

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

    a. HMS. *Archive of Technical Papers*, Heavy Movables Structures, 2014.

82. Hool, G.A. & Kinne, W.S., *Movable and Long Span Steel Bridges*, 2nd ed., McGraw-Hill Book Co., 1943.

83. Hovey, "Movable Bridges," *Civil Engineering*, Vol. 1, No.7, April, 1931.

84. Hovey, *Movable Bridges, Vol. I: Superstructure*, John Wiley & Sons, 1926.

85. Hovey, *Movable Bridges. Vol. II: Machinery*, John Wiley & Sons, 1927.

86. Hunt, R.E., "Hydraulic Cylinder Maintenance," *Hydraulic Pneumatic Mechanical Power*, October, 1978.

87. Hyman, W.A., Hom, A.D, Jennings, O., Hejl, F., Alexander, T., "Improvements in Data Acquisition Technology for Maintenance Management Systems," NCHRP Report No. 334, Transportation Research Board, 1990.

88. IDOT, *Investigation of Trunnion Failures Involving Movable Vertical Lift Bridges*, Physical Research Report No. 87, Springfield, IL: Illinois Department of Transportation, June, 1980.

89. IEEE

    a. IEEE, *Guide for Field Testing Power Apparatus Insulation*, Standard 62, Institute of Electrical and Electronics Engineers, 1995.

    b. IEEE, *National Electrical Safety Code*, C2, Institute of Electrical and Electronics Engineers, 2012.

    c. IEEE, *Recommended Practice for the Design of Reliable Industrial and Commercial Power Systems*, 493–1980, Institute of Electrical and Electronics Engineers, January 2013.

90. IEEE Power Engineering Society. *Standard Test Procedure for Polyphase Induction Motors and Generators*, ANSI C50.21 IEEE 112, 1992.

91. IFI, *Fastener Standards*, Ninth Edition, Industrial Fasteners Institute, 2014.

92. INDOT. *Bridge Inspection Manual*. Indianapolis, IN.: Indiana Department of Transportation, 2010 (Rev 2013).

93. Jackson, Lowell B. and Barnow, Barbara A., *Quality Improvement Resource Guide: Engineering a Quality Future in Transportation*, Publication No. FHWA SA-94-002, October, 1993.

94. Johnson, R. Jr., Craine, S.D., "Causes and Prevention of Premature Gear Failures," *Iron and Steel Engineer*, September, 1953.

95. Juran, J.M., Gryna, Frank M., eds. *Juran's Quality Control Handbook*, McGraw-Hill Book Co., The University of Michigan, 1988.

96. Keep, P., "Condition Monitoring in Hydraulic Systems," *Power International*, September, 1988.

97. Knott, I., Wood, D., and Bonyun, D., *Risk Analysis for Ship-Bridge Collisions*, ASCE Coastal Zone 1985, Fourth Symposium on Coastal and Ocean Management, Baltimore, July 30–August 2, 1985.

98. Koglin, Terry L. *Movable Bridge Engineering*. New York: John Wiley & Sons, 2003.

99. LA-DOT, *Movable Bridge Inspector's Program Lesson Plan*, Baton Rouge, LA: Louisiana Department of Transportation, 1978.

100. LA-DOTD. *Pontis Inspection Manual*. Baton Rouge, LA: Louisiana Department of Transportation and Development, 2009.

101. Lamberger, E.H., and McCullough, W.W., "Maintaining Electric Motors and Generators," *The Petroleum Engineer*, May, 1943.

102. Larsen, D.O., *Ship Collision Risk Assessment for Bridges*, IABSE Colloquium, Introductory Report, pp. 113–128., 1983.

103. Lawrie, R.J., "How to Maintain Motor Controls," *Electrical Construction and Maintenance*, April, 1964.

104. Lawrie, Robert J., ed. *Electric Motor Manual: Application. Installation, Maintenance, Troubleshooting*. McGraw-Hill, Inc., 1987.

105. Lipanye, L.L., "Better Motor Maintenance and Field Testing," *Coal Age*. March, 1960.

106. Mazurek, David F. & DeWolf, John T., "Experimental Study of Bridge Monitoring Technique," *ASCE Journal of Structural Engineering*, September, 1990.

107. McCullough, W.W., *Electric Motor Maintenance*, John Wiley & Sons, NY; Chapman & Hall, 1947.

108. MD-SHA, *Pontis Element Data Collection Manual*. Andover, MD: Maryland State Highway Administration, 2003.

109. Miller, Robert W., *Lubricants and Their Applications*, McGraw-Hill, Inc., 1993.

110. Minervino, *Development of a Manual for Inspection, Evaluation and Maintenance of Movable Bridges*, St. Petersburg, FL: Heavy Movable Structures, 6th Biennial Symposium, 1996.

111. National Research Council, *Minding the Helm*. National Academy Press, Washington, D.C., 1994.

112. NCHRP. *Bridge Inspection Practices*. Synthesis 375. Washington, D.C.: Transportation Research Board, 2007.

113. NEMA*, Motors and Generators*, National Electrical Manufacturers Association, 1987.

114. NEMA. *Safety Standard for Construction and Guide for Selection, Installation and Use of Electric Motors and Generators*, NEMA MG2, 2014.

115. NFPA, *Encyclopedia of Fluid Power Standards*, National Fluid Power Association.

116. NFPA, *National Electrical Code*, National Fire Protection Association, 2014.

117. NLGI, *Lubricating Grease Guide*, National Lubricating Grease Institute, 2006.

118. NYSDOT, *Collision Vulnerability Manual*. Albany, NY: New York State Department of Transportation, June 1995 (Rev. 1996).

119. NYSDOT, *Concrete Details Vulnerability Manual*, Albany, NY: New York State Department of Transportation, September 1995 (Rev. 1997).

120. NYSDOT. *Crane Preventative Maintenance Checklist*. Albany, NY: New York State Department of Transportation, accessed 2013.

121. NYSDOT, *Hydraulic Vulnerability Manual*, Albany, NY: New York State Department of Transportation, December 1991 (Rev. 1996).

122. NYSDOT, *Overload Vulnerability Manual*, Albany, NY: New York State Department of Transportation, August 1995.

123. NYSDOT, *Seismic Vulnerability Manual*, Albany, NY: New York State Department of Transportation, October 1995 (Rev. 2004).

124. NYSDOT, *Steel Detail Vulnerability Manual*, Albany, NY: New York State Department of Transportation, May 2000.

125. O'Connor, Patrick D.T., *Practical Reliability Engineering*, 3rd ed., John Wiley & Sons, 1991.

126. ODOT. *Bridge Inspection Program Manual*. Oregon Department of Transportation, 2013.

127. Parsons Brinckerhoff, *Bridge Inspection and Rehabilitation – A Practical Guide*, New York, NY: John Wiley & Sons, Inc., 1993.

128. Pingree, C.H., "Comparing Electromechanical & Hydraulic Direct Drives," *Plant Engineering*, April 16, 1981.

129. *Practical Strain Gauge Measurements*, Hewlett-Packard Co. Application Note 290-1.

130. Rehm, Kelley C. *Bridge Inspection: Primary Element*, Arlington Heights, IL: Roads and Bridges. 2013.

131. Ressler, S. J., and Daniels, 1. Hartley, *Vulnerability Assessment of Steel Highway Bridges: A Probabilistic Model*, Advanced Technology for Large Structural Systems (ATLSS) Report No. 90-01, Lehigh University, January, 1990.

132. Rich, B., "Keeping Hydraulic Cylinders Healthy," *Machine Design*, December 7, 1978.

133. Rosaler, R.C. & Rice, James O., *Industrial Maintenance Reference Guide*, McGraw-Hill Co., 1987.

134. Sexsmith, R. G., *Bridge Risk Assessment and Protective Design for Ship Collision*, IABSE Colloquium, Preliminary Report, pp. 424–433, 1983.

135. Shanafelt, G., *Bridge Designs to Reduce and Facilitate Maintenance and Repair*, NCHRP Report No. 123, 1985.

136. Shaw, E.T., "Inspecting & Testing Electrical Equipment: Part 2," *Actual Specifying Engineer*, May, 1971.

137. SKF. *Bearing Failures and their Causes PI-401*. Goteborg, Sweden: SKF Group, 1999.

138. Teker, J.W., "Inspection and Tests—Gear and Pinions," *Railway, Mechanical & Electrical Engineer*, May, 1952.

139. The Crosby Group, Inc., *Blocks and Fittings for Wire Ropes and Chains*. 1994.

140. Townsend, Dennis, P., *Dudley's Gear Handbook*, 2nd ed., McGraw Hill Book Co., 1991.

141. United Kingdom Defense Standard, 00-40, *Reliability and Maintainability Part 1 Management Responsibilities and Requirements for Programmes and Plans*, 2012.

142. United States Steel, *Tiger Brand Wire Rope Engineering Handbook*, 1946.

143. USCG, *Bridge Permit Application Guide*, U.S. Coast Guard, U.S. Department of Transportation.

144. U.S. Department of Commerce, *Analysis of Bridge Collision Incidents*, Vols. 1 and 2, Operations Research, Inc., May, 1976.

    a. TRB, *Vulnerability Assessment and Ranking of Steel Bridges*, Transportation Research Record 1290, March, 1991.

145. U.S. Department of Transportation/FHWA. *Stream Stability at Highway Structures*, FHWA, U.S. Department of Transportation, FHWA-HIF-12-004, 2012.

146. U.S. Government. *Moving Ahead for Progress in the 21st Century Act (MAP-21), Section 1111, National Bridge and Tunnel Inventory and Inspection Standards Program*. U.S. Government Printing Office, Washington, DC, January, 2012.

147. U.S. MIL-STD-785B *Reliability Programs for Systems and Equipment*, 1980.

148. U.S. MIL-HDBK-781A *Reliability Test Methods, Plans, and Environments for Engineering, Development Qualification, and Production*, 1996.

149. U.S. MIL-HDBK-217F *Reliability Prediction of Electronic Equipment*, 1995.

150. Vernon, H.H., "Control Equipment for Movable Highway Bridges," *General Electric Review*, November, 1926.

151. Vernon, H.H., "Electrical Equipment for Bascule, Lift and Swing Bridges," *General Electric Review*, October, 1933.

152. W. E. Rossnagel, Lindley R. Higgins, Joseph A. MacDonald, *Handbook of Rigging for Construction and Industrial Operations*, 4th ed., McGraw-Hill Book Co., 1988.

153. Waddell, W. A. L., *Bridge Engineering: Vol. I*, John Wiley and Sons, 1916.

154. Waddell, W. A. L., *Bridge Engineering: Vol. II*, John Wiley and Sons, 1916.

155. Wengenroth, Reese H. & Mix, Howard A., “Fifty-Year History of Movable Bridge Construction-Part III,” *ASCE Journal of Construction Division*, Vol. 101, No.3, pp. 545-557, September, 1975.

156. Westinghouse Electric Co., *Westinghouse Maintenance Hints*, 1974.

157. Whitmer, E.W., “Analysis of Failures Clue to Trouble Control,” *Electrical World*, September 18, 1943.

158. WI-DOT. *Structure Inspection Manual*. Madison, WI: Wisconsin Department of Transportation, 2011.

159. Wild, Philip, *Industrial Sensors & Applications for Condition Monitoring*, Mechanical Engineering Publication Limited, London, 1994.

160. Witherell, Charles E., *Mechanical Failure Avoidance: Strategies and Techniques*, McGraw-Hill, Inc., 1994.

161. Wright, H.A., “Don’t Forget Your Control Equipment,” *Mill and Factory*, March, 1951.

162. WRTB. *Wire Rope User’s Manual*. 4th Ed. Alexandria, VA: Wire Rope Technical Board, 2005.

163. WSDOT. *BridgeWorks Movable Elements*. Olympia, WA: Washington State DOT, 2006.

APPENDIX C – GLOSSARY

A

Abrasion: A wearing, grinding, or rubbing away of material. The products of abrasion will be introduced into the system as generated particulate contamination.

Accumulator: A container in which liquid is stored under pressure as a source of fluid power.

Acme Thread: A single, double, or triple lead thread often used for converting rotary motion to linear motion, as in an electric lock bar operator.

Addendum: Height of tooth above pitch circle or the radial distance between the pitch circle and the top of the tooth.

Adjustable Coupling: A coupling in which both flanges have a large number of holes around the perimeter, but one coupling has three more holes than the other, and the number of holes in each flange is evenly divisible by 3 (i.e., 54 and 57 holes respectively).

ADT: The average daily traffic.

ADTT: The average daily truck traffic.

Alternating Current (AC): In power applications, alternating current is the continuously reversing direction of current flow in a conductor. Current flows away from and then toward the power source once during each cycle in a sinusoidal manner. Thus the term alternating refers to the reversals in direction of electrical current flow in each cycle.

Alternator: A device for converting mechanical energy into electrical energy in the form of alternating current. It may be called an AC generator.

Ammeter: An instrument designed to measure electric current flow.

Ampere: The unit of electric current flow. One ampere will flow when one volt is applied across a resistance of one ohm.

Anti-friction Bearing: A ball or roller-type bearing.

Approach Ratio: The ratio of the arc of approach to the arc of action.

Arc of Action: Arc of the pitch circle through which a tooth travels from the first point of contact with the mating tooth to the point where contact ceases.

Arc Chute: A device used to contain and help extinguish the electrical arc caused by the interruption of electrical current.

Arc of Approach: Arc of the pitch circle through which a tooth travels from the first point of contact with the mating tooth to the pitch point.

Arc of Recess: Arc of the pitch circle through which a tooth travels from its contact with the mating tooth at the pitch point to the point where its contact ceases.

Armature: The term applied to the rotating components on the shaft of a DC motor or generator.

Auto Transformer: Any transformer that changes the supply voltage between the input and output terminals by using the same windings. No isolation is possible between incoming and load side terminals.

Axial Misalignment: Misalignment resulting in the gear and pinion teeth not meshing along the entire length of the teeth. In effect, the gear and pinion longitudinal shaft axis are offset (not parallel) axially.

Axial Load: A force or thrust acting parallel to the centerline of a shaft, bearing, or gear.

Axial Plane: In a pair of gears it is the plane that contains the two axes. In a single gear, it maybe any plane containing the axis and a given point.

B

Backlash (BL): The amount by which the width of a tooth space exceeds the thickness of the engaging tooth on the pitch circles. As actually indicated by measuring devices, backlash may be determined variously in the transverse, normal or axial planes, and either in the direction of the pitch circles or on the line of action. Such measurements should be converted to corresponding values on transverse pitch circles for general comparison.

Balance Chain: A heavy chain used to counteract the weight of ropes as they pass from one side of a sheave to the other.

Bascule Bridge: A bridge on which one or two leaves rotate from a horizontal to a near-vertical position to open the channel.

Base Helix Angle: The angle at the base cylinder of an involute gear that the tooth makes with the gear axis.

Base Pitch: In an involute gear it is the pitch on the base circle or along the line of action. Corresponding sides of involute teeth are parallel curves, and the base pitch is the constant and fundamental distance between them along a common normal in a plane of rotation. The Normal Base Pitch is the base pitch in the normal plane, and the Axial Base Pitch is the base pitch in the axial plane.

Base Circle: The circle from which an involute tooth curve is generated or developed.

Bevel Gears: Conical gears that operate on intersecting axes that are usually at right angles.

Breather: A device which permits air to move in and out of a container or component to maintain atmospheric pressure.

Bridge Engineer: That person who is designated by the bridge owner to be responsible for the inspection/maintenance of all the highway bridges within the owner's jurisdiction.

Bridge Inspector: That person who, through specialized training and experience, is charged with performing a thorough inspection of every aspect of the bridge and presenting a clear, comprehensive report of the conditions found with sound recommendations based on the conditions observed, to guarantee public safety or investment.

Bridge Maintainer: That person charged with performing, based on recommendations made by the Bridge Engineer from review of a comprehensive inspection report, maintenance repairs to the respective structures to ensure public safety and investment.

Brushes: Usually rectangular, spring loaded carbon conductors that contact a commutator or slip ring and carry current from the brush terminal to the rotating conductor.

Buffer Cylinder: A device comprised of a rod and piston in an enclosed cylinder that cushions shock loads and permits gradual closing of a span.

Bus: Usually a large conductor with multiple connection points of one voltage or phase of power used to carry large electrical currents.

Bushing (mechanical): A soft metal sleeve that resists radial and axial loads on rotating members.

Bushing (electrical): A strong insulating material used to support the metal conductor passing through the center. Materials such as porcelain, Micarata, epoxy, and others are used as the insulator. Copper or aluminum is the conduction metal. Normally used in high voltage circuits to conduct current through a metal bank.

C

Cavitation: A local gaseous condition in a liquid stream such as the inlet of a hydraulic pump.

Center Distance (CD): The distance between the parallel axes of spur gears and parallel helical gears, or between the crossed axes of crossed helical gears and worm gears. Also, it is the distance between the centers of the pitch circles.

Center of Gravity: The point at which the entire mass of a body acts; the balancing point of an object.

Central Plane: In a worm gear this is the plane perpendicular to the gear axis and contains the common perpendicular of the gear and worm axes. In the usual case with the axes at right angles, it contains the worm axis.

Central Processing Unit (CPU): That part of the Programmable Logic Controller that governs activities. All logic solving and decision making is performed by the CPU. The CPU monitors the status of the inputs and outputs in response to the programmed instruction in memory, and energizes or de-energizes outputs as a result of the logical comparisons made through these instructions.

Chordal Addendum: The height from the top of the tooth to the chord subtending the circular-thickness arc.

Chordal Thickness: Length of the chord subtended by the circular thickness arc (the dimension obtained when a gear-tooth caliper is used to measure the thickness at the pitch circle).

Circular Thickness: The length of arc between the two sides of a gear tooth, on the pitch circle unless otherwise specified. Normal Circular Thickness is the circular thickness in the normal plane.

Circular Pitch: Length of the arc of the pitch circle between the centers or other corresponding points of adjacent teeth. Normal Circular pitch is the circular pitch in the normal plane. See Figure A4-1.

Clearance: The amount by which the dedendum in a given gear exceeds the addendum of its mating gear. It is also the radial distance between the top of a tooth and the bottom of the mating tooth space.

Clevis: A V-shaped, pinned connector that permits rotational or linear movement between two components (i.e. a crank and connecting rod).

Closed Position: Open to allow passage of vehicular traffic. Closed to navigational traffic.

Commutator: On a DC motor or generator, the rotating assembly of copper conducting bars that conduct current from the brushes into the armature.

Component: A general term used to define a distinct part or small subassembly of a member of system.

Conductor: A metal with low resistance to current flow, usually copper or aluminum, but may be any material with low impedance.

Constant Potential: A direct current supply voltage maintained at a constant value, such as 125 volts DC.

Contact: One of the conducting parts of a relay, switch, or connector that are engaged or disengaged to open or close the associated electrical circuits.

Contact Diameter: The smallest diameter on a gear tooth with which the mating gear makes contact.

Contact Ratio: The ratio of the arc of action to the circular pitch. It is sometimes thought of as the average number of teeth in contact. For involute gears, the contact ratio is obtained most directly as the ratio of the length of action to the base pitch.

Contact Stress: The maximum compressive stress within the contact area between mating gear tooth profiles. It is also called Hertz stress.

Contaminant: Any material or substance that is unwanted or adversely affects the fluid power system or components, or both.

Continuity: The state of being continuous. Electrically, it is a continuous circuit from one point to a second point. A continuity check of a conductor determines if the circuit is open and will not conduct current.

Conventional Drive: A bridge main drive assembly, characterized by exposed gears mounted on individual pillow blocks.

Control: A device used to regulate the function of a component or system.

Corrosion: The chemical change in bridge elements caused by the interaction of fluid or contaminants, or both. More specifically related to the chemical changes in metals. The products of change may be introduced into closed systems by intrusion of contaminants.

Counterweight Ropes: Wire ropes that connect the span and counterweights. On tower-drive and tower-span vertical lifts, the counterweight ropes are driven to operate the span. On span drive bridges, counterweight ropes are not driven.

Counterweight: A weight that is used to balance the weight of a movable member. In bridge applications, counterweights are used to balance a leaf or span so that it rotates or lifts with minimum resistance.

Crank: A rigid arm that, when used in conjunction with a connecting rod, translates rotary motion to linear motion.

Cross-bearing: A misalignment condition in which gear teeth are out of parallel lengthwise.

Current: A measure of the amount of electricity flowing in a conductor.

Curved Rack: A large-radius gear segment. Technically the term is contradictory, because by definition racks are flat, but since large-radius gear segments have only slight curvature and straight teeth, the term “curved rack” is commonly used to describe them.

Cycloid: The curve formed by the path of a point on a circle as it rolls along a straight line. When this circle rolls along the outer side of another circle, the curve is called an Epicycloid; when it rolls along the inner side of another circle it is called a Hypocycloid. These curves are used in defining the former American Standard composite tooth form.

D

Damper Winding: A special winding in a synchronous motor used to start the motor. It reduces hunting by damping action and increases starting torque of the motor.

Dead Load: The total weight of all components of a given structure. The “dead weight” of a bridge is merely the weight of the span itself, without cars, snow loading, etc.

Dedendum: The depth of tooth space below the pitch circle or the radial dimension between the pitch circle and the bottom of the tooth space.

Defects: Specific deficiencies assigned to bridge rlements during inspection and reporting.

Destructive Pitting: A stress related phenomena similar to spalling, except that the craters are approximately hemispherical.

Diametral Pitch: The ratio of the number of teeth to the number of inches of pitch diameter—equals number of gear teeth to each inch of pitch diameter. Normal Diametral Pitch is the diametral pitch as calculated in the normal plane and is equal to the diametral pitch divided by the cosine of the helix angle.

Dielectric: The ability of an insulating material to withstand breakdown under applied voltage.

Diode: A solid state device that restricts the flow of AC power to one direction only.

Direct Current (DC): The unidirectional flow of power (current) from a DC voltage source to a second DC voltage point.

Down-haul Ropes: On span-drive vertical lift bridges, the set of operating ropes connected at the bottom of the towers. The drums reel in the down-haul ropes to lower the span.

Drum Switch: A group of switch contacts mounted on a rotating drum where the contact point is a function of rotation of the operating handle.

Dryseal Pipe Thread: Taper pipe threads in which sealing is a function of root and crest interference.

E

Eccentric: A radially offset bushing mounted on a frame or fixed structural member that permits radial alignment of a shaft. Bascule bridge trunnion shaft eccentrics have two offset bushings, one inside the other.

Effective Face Width: That portion of the face width that actually comes into contact with mating teeth. If one member of a pair of gears has a greater face width than the other, or if the teeth are not in full face contact due to misalignment, then the effective face width is less than the available width on one or both elements.

Efficiency: The actual torque ratio of a gear set divided by its gear ratio.

Elements: System of classification of bridge components for inspection.

Elevating Bar: A mechanically actuated jack, several of which raise the ends of a swing span to permit insertion and withdrawal of live-load shoes.

Enclosed Drive: A bridge drive system in which the gears are enclosed in sealed housing(s), and no gears (except the rack and pinion) are exposed to the environment.

Enclosure: The housing providing environmental protection and protection against physical damage to electrical apparatus and motors.

End Bearing: Gear misalignment in which the entire load is carried by a small end portion of the tooth surface.

Evaluation: The examination of pertinent available data relative to a structure, component, or system for the purpose of determining the item's ability to perform its intended function.

Excitation: The production of a magnetic field by the circulation of current through a conductor. The term is normally applied to the production of magnetic fields in the motor windings.

External Gear: A gear with teeth on the outer cylindrical surface.

F

Face: The portion of curved tooth surface between the pitch circle and the top land.

Face of Tooth: That surface of the tooth that is between the pitch circle and the top of the tooth.

Fatigue Resistance: The ability of a structural component to withstand cyclical tension stress without onset of fatigue cracking.

Fillet: The rounded area at the root of a tooth. More generally, any inside corner that has been rounded to relive stress concentrations.

Fillet Curve: The concave portion of the tooth profile where it joins the bottom of the tooth space. The approximate radius of this curve is called the Fillet Radius.

Fillet Stress: The maximum tensile stress in the gear tooth fillet.

Filter: A device through which fluid is passed to separate matter held in suspension.

Flange: A mounting device usually consisting of a plate or collar.

Flank of tooth: That surface that is between the pitch circle and the bottom land. The flank includes the fillet.

Flashover: The jumping of fault current (arcing) from one point to a second point. On the DC commutator, it means the jumping of current from bar to bar, usually one quarter of the distance around the commutator.

Flexible Coupling: A coupling that accommodates slight angular and offset misalignment between two connected shafts.

Fretting: A type of wear resulting from minute reciprocal sliding motion that produces fine particulate contamination without chemical change.

Fretting Corrosion: Oxidation of fretting wear debris.

FRP: Fiber reinforced plastic. It consists of fiberglass, carbon, aramid, hybrid, or other fabric reinforced plastic.

G

Gating Control: The electronic equipment used to generate a suitable signal from the gate lead to turn on the thyristor.

Generator: A general name for a device for converting mechanical energy into electrical energy. An AC generator may be called an alternator.

Gland: The packing material used to fill the cavity of a stuffing box.

Ground: Any point that is at earth potential. Usually refers to a terminal or conductor that is connected to earth.

H

HDPE: High-density polyethylene, typically used in fender systems.

Helical Overlap: The effective face width of a helical gear divided by the gear axial pitch; also called the Face Overlap.

Helical Gear: A gear cylindrical in form that has helical teeth; that is, teeth parallel to each other but at an angle to the gear axis.

Helix Angle: The angle that a helical gear tooth makes with the gear axis at the pitch circle unless otherwise specified.

Herringbone Gear: A gear with both right-hand and left-hand helical teeth.

Hertz: The standardized electrical term meaning cycles per second.

Hertz Stress: See Contact Stress.

High Potential (High Pot): A very high voltage supply. In testing, it is a high voltage testing source used to measure insulation values.

Highest Point of Single Tooth Contact: The largest diameter on a spur gear at which a single tooth is in contact with the mating gear. Often referred to as HPSTC.

Horsepower: A measure of work for rotating equipment.

$$1\ \text{HP} = \frac{\textit{Torque (lb-ft) x RPM}}{5250}$$

Hunt: The action of a voltage regulator oscillating about a specified point while trying to regulate for a stable output.

Hydraulic Power Unit: A combination of components to facilitate fluid storage and conditioning, and delivery of the fluid under conditions of controlled pressure and flow to the discharge port of the pump, including maximum pressure controls and sensing devices when applicable. Circuitry components, although sometimes mounted on the reservoir, are not considered a part of the power unit.

Hydraulics: The engineering science pertaining to liquid pressure and flow.

I

Impedance: The characteristics of resisting the flow of electric current through a device. It consists of the resistance and reactance of an electrical component.

Induction: A condition where electrical voltage in one component is produced by the applied current in another component. The electric voltage will produce a current in a conductor that acts with the magnetic field produced by the current to produce a force.

Induction Motor: An AC electric motor in which the rotor has a current induced into it by the alternating electric field of the stator.

Inspection: The act of performing a comprehensive critical assessment of highway bridge components as a means to recognize, record, evaluate, and report bridge conditions that may presently impair, or may potentially impair, either public safety or investment.

Insulation: Any material that will not conduct electricity.

Interfacial Tension: The chemical force between liquid molecules that pulls them together.

Internal Redundancy: The ability of a structural member to distribute force using multiple load paths through more than one mechanically fastened component.

Internal Gear: A gear with teeth on the inner cylindrical surface.

Internal Diameter: The diameter of a circle coinciding with the tops of the teeth of an internal gear.

Involute: The curve formed by the path of a point on a straight line, called the generatrix, as it rolls along a convex base curve. (The base curve is usually a circle.) This curve is generally used as the profile of gear teeth.

J

Journal: The portion of a shaft that is enclosed by a bearing.

K

Keyway: A slot cut in a shaft and bore that permits insertion of a bar or key to prevent rational slippage.

Knee Of A Curve: The area of a curve where the slope of the curve changes substantially to a horizontal slope.

L

Laminar Flow: A flow situation in which motion occurs as a movement of one layer of fluid on another.

Land: The Top Land is the top surface of a tooth, and the Bottom Land is the surface of the gear between the fillets of adjacent teeth.

Laser: A device that emits a narrow beam of light through a process of optical amplification based on the stimulated emission of electromagnetic radiation.

Lead: The distance a helical gear or worm would thread along its axis in one revolution if it were free to move axially.

Leaf: The movable span of a bascule bridge.

Length of Action: The distance on an involute line of action through which the point of contact moves during the action of the tooth profile.

Line of Action: The path of contact in involute gears. It is the straight line passing through the pitch point and tangent to the base circles.

Live Load: Any weight or load on a structure that is not an integral part of the structure (i.e. on a bridge, vehicular traffic, pedestrians, and wind are live loads).

Live-load Shoe: Transmits live loads from the span to a pier-mounted strike plate.

Lock Bar: A bar that engages a socket to prevent span movement in either the closed or open position.

Lock-bar Operator: A device, often having an electric motor driving an acme threaded plunger, which inserts and withdraws a lock bar.

Locked Rotor Current: The steady state current drawn by a motor under locked rotor (stalled) conditions—commonly, but inappropriately, also referred to as starting current. Starting current comprises locked rotor current plus the transient inrush current that flows until the motor magnetic circuit stabilizes.

Log-log Scale: The ordinate and abscissa scales used to shorten the length of a graph.

Long-addendum Tooth: A pinion tooth whose addendum is longer than that of engaging gear tooth.

Longitudinal Shaft: A drive shaft that is mounted along the length of a span.

Lowest Point of Single Tooth Contact: The smallest diameter on a spur gear at which a single tooth of one gear is in contact with its mating gear. Often referred to as LPSTC. Gear set contact stress is determined with a load placed at this point on the pinion.

Lubricator: A device that adds controlled or metered amounts of lubricant into a system.

M

Magnetic Coupling: The interacting forces between two or more components caused by their magnetic fields.

Maintenance: The preservation and upkeep of a structure, component, or system to its as-installed, or subsequently rehabilitated condition.

Manifold: A hydraulic component which provides multiple connection ports from or to one hydraulic fluid source.

Megger: A small DC supply used for testing insulation. The meter scale is usually calibrated to read in megohms directly.

Member: A structural element requiring individual structural design (i.e., beam, column, truss member)

Module: Ratio of the pitch diameter to the number of teeth. Ordinarily, module is understood to mean ratio of pitch diameter in millimeters to the number of teeth. The English Module is a ratio of the pitch diameter in inches to the number of teeth. Electrical components may also sometimes be referred to as "modules."

Motor Control Center (MCC): Electrical switchgear used to start and control electric motor operation.

Movable Bridge: A bridge having one or more spans capable of being raised, turned, lifted, or slid from its normal service location to provide for the passage of navigation.

Multi-speed Motor: A motor capable of running at two or more speeds; the term is applied only to AC motors.

Multimeter: A test meter that can be used for measuring current or voltage, AC or DC, or resistance. Usually has several scale ranges.

N

Normal Plane: A plane normal to the tooth surfaces at a point of contact, and perpendicular to the pitch plane.

O

Ohm: A unit of electrical resistance. One volt will cause a current of one ampere to flow through a resistance of one ohm.

Open Position: Open to allow passage of marine traffic. Closed to vehicles and pedestrians.

Orifice: A restricted passageway in a fluid power system, usually a small hole drilled for the purpose of metering a flow.

Overload: A condition wherein a member experiences loading greater than its original design capacity.

Owner: An organization or agency responsible for the inspection, maintenance, and load rating of bridges, generally the legal owner of the structure.

Oxidation: The chemical breakdown of a substance due to reaction with oxygen.

P

Particle: A minute piece of matter with observable length, width, and thickness; usually measured in micrometers.

Permissive Circuit: Electrical controls inserted into a circuit to insure specific conditions are satisfied before the operation circuit can be operated.

Phase: One member or conductor of an AC circuit used to deliver power.

Pier: A structure, usually concrete, stone, or wood, that supports the ends of a movable span. A pivot pier, or center pier, bears the span dead load when a swing-span bridge is opened. Rest piers support spans in the closed positions.

Pillow Block: A bearing housing, usually of cast steel, that contains either a sleeve bearing or an anti-friction bearing.

Pinion: In an engaged gear set, the smaller gear. The pinion is usually the driver.

Pitch Circle: The curve of intersection of a pitch surface of revolution and a plane of rotation. According to theory, it is the imaginary circle that rolls without slipping with the pitch circle of a mating gear.

Pitch: The distance between similar, equally-spaced tooth surfaces, in a given direction and along a given curve or line. The single word "pitch" without qualification has been used to designate circular pitch, axial pitch, and diametral pitch, but such confusing usage should be avoided.

Pitch Diameter: The diameter of the pitch circle. In parallel shaft gears the pitch diameters can be determined directly from the center distance and the numbers of teeth by proportionality. *Operating Pitch Diameter* is the pitch diameter at which the gears operate. *Generating Pitch Diameter* is the pitch diameter at which the gear is generated. In a bevel gear, the pitch diameter is understood to be at the outer ends of the teeth unless otherwise specified. (See also reference to standard pitch diameter under Pressure Angle.)

Pitch Plane: In a pair of gears, it is the plane perpendicular to the axial plane and tangent to the pitch surfaces. In a single gear, it may be any plane tangent to its pitch surface.

Pitch Point: This is the point of tangency of two pitch circles (or of a pitch circle and a pitch line) and is on the line of centers. The pitch point of a tooth profile is at its intersection with the pitch circle.

Pitting: Selective localized formation of rounded cavities in a metal surface due to corrosion or to nonuniform electroplating.

Plane of Rotation: Any plane perpendicular to a gear axis.

Plastic Flow: Deformation of metal beyond the elastic limit.

Poly-Phase: Having more than one phase. Usually used on equipment using more than three phase supply voltages.

Pot Head: A high voltage insulating support used at terminal points to relieve mechanical and electrical stresses.

Pour Point: The lowest temperature at which oil will pour under prescribed test conditions.

Power Factor: A measure of the relation of power to current times voltage within a piece of electrical equipment, particularly motors.

Pressure: Force per unit area, usually expressed in pounds per square inch (psi) in the US system of units.

Pressure Angle (PA): The angle between a tooth profile and a radial line at its pitch point. In involute teeth, pressure angle is often described as the angle between the line of action and the line tangent to the pitch circle. Standard Pressure Angles are established in connection with standard gear-tooth proportions. In oblique teeth—that is, helical, spiral, etc.—the pressure angle may be specified in the transverse, normal, or axial plane. For a spur gear or a straight bevel gear, in which only one direction of cross-section needs to be considered, the general term pressure angle may be used without qualification to indicate transverse pressure angle. In spiral bevel gears, unless otherwise specified, pressure angle means normal pressure angle at the mean cone distance.

Principal Reference Planes: These are a pitch plane, axial plane, and transverse plane, all intersecting at a point and mutually perpendicular.

Programmable Logic Controller (PLC): An electronic device based on a microprocessor that uses pre-programmed logic to control the operation of a device, system, or the entire movable span. A PLC is an alternative to relays.

Pump: A device that causes liquid to flow against a pressure. It converts mechanical energy into fluid energy.

Q

Quick Disconnect: A coupling that can quickly join or separate an electrical conductor or a hydraulic line without the use of tools or special devices.

R

Rack: A gear with teeth spaced along a straight line, and suitable for straight-line motion. A Basic Rack is one that is adopted as the basis of a system of interchangeable gears. Standard gear-tooth proportions are often illustrated on an outline of the basic rack. A Generating Rack is a rack outline used to indicate tooth details and dimensions for the design of a required generating tool, such as a hob or gear-shaper cutler.

Radial Load: A force that acts perpendicular to an axis of rotation.

Ratio of Gearing: Ratio of the numbers of teeth on mating gears. Ordinarily the ratio is found by dividing the number of teeth on the larger gear by the number of teeth on the smaller gear or pinion. For example, if the ratio is "2" or "2 to 1," this usually means that the smaller gear or pinion makes two revolutions to one revolution of the larger mating gear.

Reactance: The electrical properly describing the non-resistive opposition to the flow of electricity through a component.

Reactor: An electrical device that reduces the voltage between input and output terminals by impeding the flow of current through it.

Rehabilitation: The restoration of bridge components (and subcomponents) to their original capacity (or that capacity determined by the owner).

Relay: An electrically operated switch usually used in control circuits and whose contacts are considered low amperage, compared to a contactor.

Reservoir: A container for storage of liquid in a fluid power system.

Resistance: An opposition to the flow of electrical current or hydraulic fluid.

Rheostat: A resistor with three connections points; one at each end of the resistance and third (called a wiper) that can be moved from one end to the other of the resistance.

Rigid Coupling: Usually, two flanged hubs bolted together to joint two shafts. Rigid couplings do not accommodate radial or axial displacement.

Roll Angle: The angle subtended at the center of a base circle from the origin of an involute to the point of tangency of the generatrix from any point on the same involute. The radian measure of this angle is the tangent of the pressure angle of the point on the involute.

Rolling and Peening: A type of plastic flow in which metal on the face and flank: of the gear is pushed toward the pitch lines and the face and flank of the pinion are pulled away from the pitch lines.

Root (bottom land): The surface at the bottom of the tooth space adjoining the fillet.

Root Circle: A circle coinciding with or tangent to the bottoms of the tooth spaces.

Root Diameter: Diameter of the root circle.

Rotor: The rotating windings on a motor or generator that is assembled on the rotating shaft.

S

SAE Port: A straight thread port used to attach tube and hose fittings. It employs an "O"-ring compressed in a wedge shaped cavity. A standard of the Society of Automotive Engineers J514 and ANSII B116.1.

Saturation: The point where increasing the current through a coil wrapped around an iron core will not substantially increase the magnetic field around the iron.

Scoring: Scratches in the direction of motion of mechanical parts caused by abrasive contaminants.

Scour: The erosive action of flowing water on soil or other material of the waterway bed.

Scouring: The rapid removal of metal from tooth surfaces caused by the tearing-out of small contacting particles that have welded together as a result of metal-to-metal contact.

Sensor: A device used to detect conditions and transform this information into an electrical signal for control purposes.

Service Life: The expected duration of satisfactory operation of a structure, component, or system under routine operating and maintenance conditions.

Series Field: In a DC motor, a heavy winding assembly mounted on the frame and connected in series with the armature. The current flowing through the armature must flow through this series field.

Sheave: On vertical-lift bridges, a large diameter pulley with annular grooves, over which the counterweight ropes pass.

Shock Load: Any sudden, high-impact force imparted to a superstructure or machine component.

Short Addendum: The smaller addendum on two engaging gears with unequal addendums.

Short Circuit: An unintentional electrical contact between current carrying parts resulting in the passage of current through an undesirable path.

Shunt Field: In a DC motor, the motor field is connected in parallel with the armature, or separately excited to produce the magnetic field in which the armature rotates.

Shunt Connector: A flexible wire on a brush used to connect the brush to the brush holder.

Single Phase: AC supply having two conductors and a single alternating voltage between them.

Sinusoidal: The property of alternating uniformly in polarity. Usually applied to sine wave functions.

Sleeve Bearing: A hollow, cylindrical, soft-metal bearing that is mounted in a housing.

Slip: Used to describe a decrease in speed of a motor under load. It means the difference between the power supply frequency and the motor frequency (speed of the motor in RPM). Usually slip motor speed is expressed as a percentage of the full motor speed.

Sludge: Particulate contaminant or a mixture of particulate and liquid contaminant separated from a fluid in an unconsolidated state.

Solenoid: A transducer that converts current into linear motion. Consists of one or more electromagnets that move a metal plunger. The plunger is usually returned to its original position by a spring or permanent magnet when the electromagnet(s) is (are) de-energized.

Spalling: Spalling is the chipping or crumbling off of flakes of gear tooth material due to high contact stress. This condition is usually characterized by an irregular cratered pattern caused by material progressively fatiguing and flaking off.

Speed Reducer: Usually a self-contained arrangement of gears that step down the speed and increase the torque of a drive motor.

Spiral Bevel: Gears with teeth that are curved and oblique.

Split Bearing: A two-piece, cylindrical, soft-metal bearing, sometimes with flanges at each end. Shims placed between the bearing halves can be removed as wear occurs, increasing bearing life.

Spur Gear: A gear with straight teeth that are perpendicular to the direction of motion.

Square-jaw Clutch: Two hubs, one with pockets and the other with corresponding lugs, which can engage or disengage two shafts; often used to engage emergency drive machinery.

Squirrel Cage: Refers to one type of AC induction motor. The name is derived from the resemblance of the stator to a squirrel cage.

Star Connection: A terminal point where three or more winding leads are connected at a common point. Frequently, this connection is solidly tied to a grounding point.

Stator: The outer frame and stationary windings, without rotating parts; it usually does not include the bearings of the motor.

Strainer: A device through which a fluid is passed to separate solids in suspension. A strainer is usually 40 micrometers or coarser while a filter is usually finer than 40 micrometers.

Structural Redundancy: The ability of a structural system to distribute force using multiple load paths through more than two main members.

Stub-tooth Gear: A gear whose teeth have working depth less than 2.000 divided by normal diametrical pitch.

Suction Line: A supply line at sub-atmospheric (vacuum) pressure to a pump, compressor, or other component.

Surface Fatigue: The failure of surface metal stressed repeatedly beyond the endurance limit of the metal.

Swing Bridge: A movable bridge in which the span rotates on a pivot pier to permit passage of marine traffic.

Synchronous: The term used when two or more components are in step with each other, and synchronized in time.

T

Tail Lock (shear lock): A lock-bar, located at the counterweight end of a bascule span, that engages with the pier.

Tail Stop: A device used on rolling bascules to prevent the spans from opening under heavy live loads on the counterweights.

Tangent Plane: A plane tangent to the tooth surfaces at a point or line of contact.

Tap Changer: A mechanism that enables the variation of input to output (ratio) voltages on a transformer by means of taps to adjust for changes in supply voltage.

Tapered Pipe Thread: Pipe threads in which the pitch diameter follows a helical cone to provide interference in tightening.

Three Phase: The AC circuit having 3 conductors (phases) to supply power. The three distinct alternating voltages are obtained between any two of the conductors at a time.

Thrust Bearing: A cylindrical, soft-metal bearing with flanges on each end to resist axial movement and bear axial loads.

Thyristor: A silicon controlled rectifier (SCR) used as a solid state switching device for power control.

Tip Relief: An arbitrary modification of a tooth profile whereby a small amount of material is removed near the tip of the gear tooth.

Top Land: The surface of the top of a tooth.

Torque: The angular force causing rotation. The unit dimension is the product of the force multiplied by the length of the arm between point of application and connection. For example, a one pound force on the end of a lever arm one foot long would be a pound-foot (lb-ft) of torque.

Total Face Width: The actual width dimension of a gear blank. It may exceed the effective face width, as in the case of double-helical gears where the total face width includes any distance separating the right-hand and left-hand helical teeth.

Transients: Instantaneous voltage peaks that vary substantially and suddenly from normal voltage levels.

Transverse Plane: A plane perpendicular to the axial plane and to the pitch plane. In gears with parallel axes, the transverse plane and the plane of rotation coincide.

Transverse Shaft: Any shaft positioned across the width of a span.

Trochoid: The curve formed by the path of a point on the extension of a radius of a circle as it rolls along a curve or line. It is also the curve formed by the path of a point on a perpendicular to a straight line as the straight line rolls along the convex side of a base curve. By the first definition, the trochoid is derived from the cycloid; by the second definition it is derived from the involute.

True Involute Form Diameter: The smallest diameter on the tooth at which the involute exists. Usually this is the point of tangency of the involute tooth profile and the fillet curve. This is usually referred to as the TIF diameter.

Trunnion: A large diameter shaft, pin, or gudgeon. Also may be used interchangeably to describe the journal for such shafts, pins, or gudgeons. The term was originally used to describe pin mounts used on early portable artillery pieces.

Tube: A hydraulic conductor whose size is its outside diameter. Tube is available in varied wall thicknesses. Hollow tubular structural members may also sometimes be referred to as tubes.

Turbulent Flow: A flow situation in which the fluid particles move in a random manner.

Turn-to-turn: On electrical coil conduits, it is the dimension between adjacent coils or conductor windings. For example, the insulation between two adjacent conductors is called the turn-to-turn insulation.

U

Undercut: A condition in generated gear teeth when any part of the fillet curve lies inside of a line drawn tangent to the working profile at its lowest point. Undercut may be deliberately introduced to facilitate finishing operations, as in preshaving.

Up-haul Ropes: On a span-drive vertical-lift, the set of operating ropes attached at the top of the towers. The drums reel in the up-haul ropes to raise the span.

V

Valve Actuator: The valve part(s) through which force is applied to move or position flow-directing elements.

Vertical-lift Bridge: A bridge in which the span moves up and down while remaining parallel to the roadway.

Viscosity: A measure of the internal friction or the resistance to fluid flow.

Viscosity Index (VI): A measure of the viscosity change as the temperature changes as compared to other fluids.

Viscosity, SSU or SUS: Viscosity expressed in Saybolt Universal Seconds, which is time, in seconds, for 60 cubic centimeters of oil to flow through a standard orifice at a given temperature.

Volt: The unit of electromotive force. That electromotive force that, when steadily applied to a conductor whose resistance is one ohm, will produce a current flow of one ampere.

Vulnerability Assessment: The process of analyzing a bridge's risk of failure for all known potential failure modes.

Vulnerability: The relative probability within a given period of time that a bridge will suddenly experience either a partial or complete collapse; major deformations within a span; or localized structural, mechanical, electrical, or other operational failures.

W

Wedge: On a swing-span bridge, a tapered shoe that bears live loads on the closed span.

Whole Depth: The total depth of a tooth space, equal to addendum plus dedendum; also equal to working depth plus clearance.

Windings: The electrical conductors in a motor or a generator that carry the current and create the magnetic fields required to produce rotation.

Working Depth: The depth of engagement of two gears; that is, the sum of their addendums. The standard working distance is the depth to which a tooth extends into the tooth space of a mating gear when the center distance is standard.

Worm: A worm has one or more threads in the form of screw threads on a cylinder.

Wormgear: The mate to a worm.

Wound Rotor Induction Motor: An induction motor whose rotor is wound with coils, as opposed to the solid bar conductors in a squirrel cage motor. By connection through slip rings to an external resistance, the resistance of the rotor circuit can be varied, thereby varying motor torque and speed.

NOTE: Definitions of gear terms are given in AGMA Standards 112.05, 115.01, and 116.01, entitled "Terms, Definitions, Symbols, and Abbreviations," "Reference Information—Basic Gear Geometry," and "Glossary—Terms Used in Gearing," respectively; obtained from American Gear Manufacturers Association, www.agma.org.