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Chapter 17 - Movable Bridges

A movable bridge is a bridge across a navigable waterway, or other travel way, that has at least one span which can be temporarily moved to increase the vertical clearance for objects passing underneath. An example of a bascule bridge is shown in Figure 17.1. Bridges with a movable span are a design option when it is not feasible to obtain the necessary vertical clearance for objects passing beneath the structure.

Figure 17.1 Bicentennial Bascule Bridge over the St. Joseph River

Each movable bridge has specialized features and unique mechanisms for movement. The following sections cover common types of movable bridges, including information on the operation and maintenance of the structure and the movement mechanisms. The maintenance of these specialized bridges requires a diverse team collectively capable of operating the structure as well maintaining the mechanical, electrical, pneumatic or other movement mechanisms. The duties, skills, and responsibilities of the bridge maintenance crews are defined by the bridge owner and are not uniform. Some crews are capable of performing maintenance on these structures, while other owners may elect to contract the work.

Movable bridges are unique structures as they integrate conventional structural components with mechanical systems and electrical power and control systems. These structures are also different from most highway bridges in that they actively facilitate the flow of both vehicular and waterborne (typically) traffic.

Movable bridges may be located in marine environments, snow and ice zones, and carry heavy traffic loads. Section loss due to corrosion in the structural components of the bridge can lead to misalignment, bending, or deformation in lock switches, open gears, and the electrical systems found on movable bridges. Heavy loads and thermal expansion effects can cause misalignment of the structures and lead to malfunctions in the operation of the bridge.

Maintenance and performance monitoring of movable bridges is often more critical than for fixed bridges given the dual service role and the potential for deterioration and other problems with the integrated systems that are essential for ensuring their operation and safety.

Recommendation

Movable bridge maintenance workers need to be constantly monitoring and inspecting structural, mechanical, and electrical elements.

17.1 Common Types of Movable Bridges

Three categories of movable bridges comprise over 95 percent of the total number of movable bridges within the United States. There are three basic types of movable bridges; (1) bascule, (2) lift, and (3) swing. A fourth, less common type, is a retractile bridge. Each type of movable bridge has variations in the design and machinery for opening and closing of the structure. For instance, bascule bridges can be further subdivided as rolling type (also call a Scherzer), a simple trunnion type (commonly referred to the Chicago style), and a modification of the trunnion (referred to as a Strauss). Each type of movable bridge has their own unique problems associated with each depending on their particular opening mechanism. Types of Movable Bridges and their associated displacement are shown in Table 17.1:

Table 17.1 Movable Bridge Types and Corresponding Displacement

Movable Bridge Type	Displacement Type
Bascule (Trunnion)	Rotation about a fixed horizontal axis
Rolling Lift Bascule (Rolling Lift)	Rotation about a fixed horizontal axis that simultaneously translates
Swing	Rotation about a fixed vertical axis
Retractile	Translation along a fixed horizontal axis
Vertical Lift	Translation along a fixed vertical axis

17.1.1 Terminology

Terms commonly used regarding movable bridges are defined below.

Auxiliary Counterweight: Secondary weights that offset the shifting weight of main counterweight ropes as they travel from one side of the sheave to the other during operation.

Bascule Pier: A pier designed to house the machinery and counterweight of a bascule bridge.

Counterweights: Weights fixed to the bascule girders to minimize the force required to move the leaf.

End Locks (also called *tail locks* or *heel locks*): Locks which prevent uplift at the long end of a bascule leaf by preventing the short end from deflecting under live loads. End locks are retracted prior to the start of the opening of the bridge.

Flanking Span Trusses: The trusses at either end of a lift span truss; they do not move.

Leaf: The movable span of a bascule bridge.

Lift Span Truss: The structural span designed to move up and down, parallel to the roadway.

Live Load Bearing: Support blocks that the span rests on while in the closed position for trunnion bascule, rolling lift bascule, and vertical lift bridges

Lockbar: A bar which engages a socket to prevent span movement in either the open or closed position.

Lockbar Actuator: A control system for a motor to the engage or retract a lock bar.

Lockbar Socket: The female end that typically contains bushings to guide the lockbar into a locked position.

Pinion: Any toothed gear of small size as compared with the gear which it engages. The pinion is usually the driver.

Pivot Pier: The pier on which the center bearing swing bridge rotates

Rack: A gear with teeth spaced along a straight line and suitable for straight-line motion.

Rest Pier: Piers designed to carry the load of the swing span of a swing span bridge in the closed position.

Segmental Girder: The arc shape end of rolling lift bascule bridge leaf.

Sheave: On vertical-lift bridges, a large diameter pulley with annular grooves, over which the counterweight ropes pass.

Span Brakes: Brakes which hold the movable span and stop it during emergency conditions.

Span Guides: Guides which are used to restrict the lateral and longitudinal movement of the span during operation.

Span Lock: The lock used to transfer vehicular live load between the leaves of a double-leaf bascule bridge and to ensure the span is in the closed position for single-leaf bascule and vertical lift bridges.

Stabilizing Machinery: Components that support the span when it is in motion.

Toe and Heel: Terms used to represent the long and short ends of a movable bridge. For example, a bascule bridge lifts up and rotates around what is called a trunnion. The long end (toe) usually spans over the water and the short end (heel) connects to the abutment. A counterweight makes up for the weight difference between the toe and heel.

Track Segment: A part or unit of a circular track used to carry the rollers of a rim bearing draw-span.

Track Girder: A beam or girder carrying a track.

Trunnion Bearing: A bearing which allows rotation of the trunnion shaft and supports the weight of the span when in a raised position.

Trunnion Shaft: A short axle that allows the rotation of bascule leaf typically about a common center line and mounted in the trunnion bearings.

17.1.2 Bascule Bridges

Bascule bridges are the most common movable bridges in operation today. They originated with medieval draw bridges with no counterweights. They have evolved to include counterweights, which has permitted increased size and utility. The counterbalances on modern bascules act to balance the weight of the leaf about its support.

Bascule bridges can be constructed with one or two leaves spanning the channel. A single-leaf bascule is supported by an abutment or pier and the single leaf spans the entire navigation channel. Only a single set of span drive and stabilizing machinery is required. However, the machinery may be significantly larger than that found on a double-leaf bascule spanning a channel of similar width. A schematic example of a single leaf simple trunnion bascule bridge is shown in Figure 17.2.

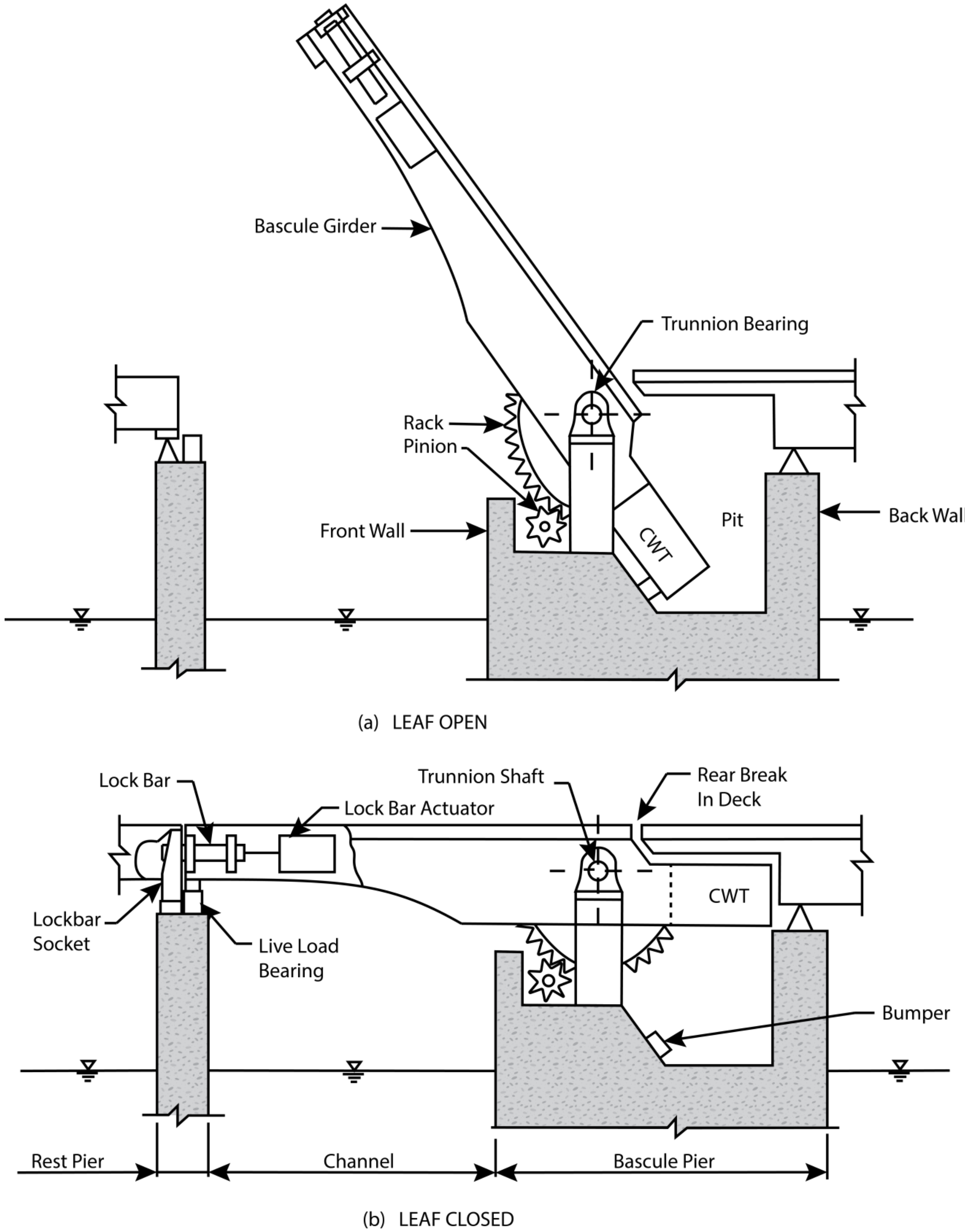


Figure 17.2 Single Leaf Simple Trunnion Bascule

A bridge with two leaves is called a double-leaf bascule, an example of which is shown in Figure 17.3. The two leaves usually meet at the center of the navigation channel. In double leaf bascule bridges, span locks are used to connect the tip ends of two cantilever bascule leaves; therefore, both leaves are forced to deflect equally. This ensures compatibility of the deck deflections from the opposing span leaves under traffic loads. The span locks typically consist of two main components: the receiver (lock bar socket) and the rectangular lock bar. The leaves would only need to be one-half the length of a single-leaf bascule leaf to span the same channel. However, double-leaf bascules require span drives and stabilizing machinery for both leaves, as the two leaves are independent of each other and, therefore, require independent machinery systems for operation.

The raised leaf of a bascule bridge opens the waterway for the passage of vessels and also provides a barrier to roadway traffic the moment it begins to open and remains a barrier throughout the cycle. An example is shown in Figure 17.3.

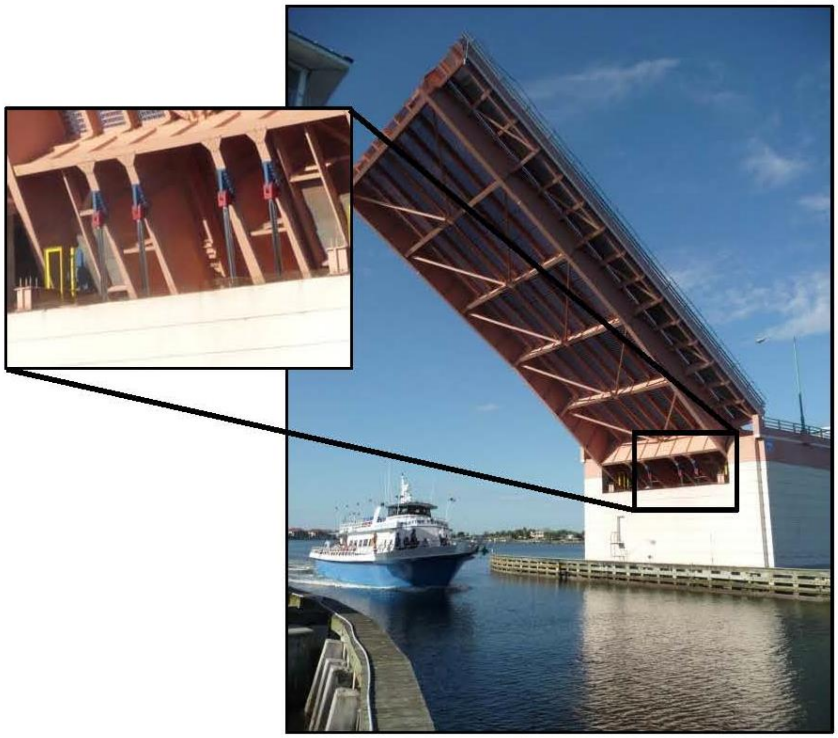


Figure 17.3 Cylinder Driven Simple Trunnion Bascule

A variety of bascule bridges exist, but the two most common types are the rolling bascule and the trunnion type bascule. See Figure 17.4 left for a simple trunnion bascule. The rolling bascule utilizes tread and track plates and the straight rack (shown in Figure 17.4 right). The trunnion type utilizes a curved segmental rack which is bolted or fabricated to a structural steel support and connected to the bascule girder.

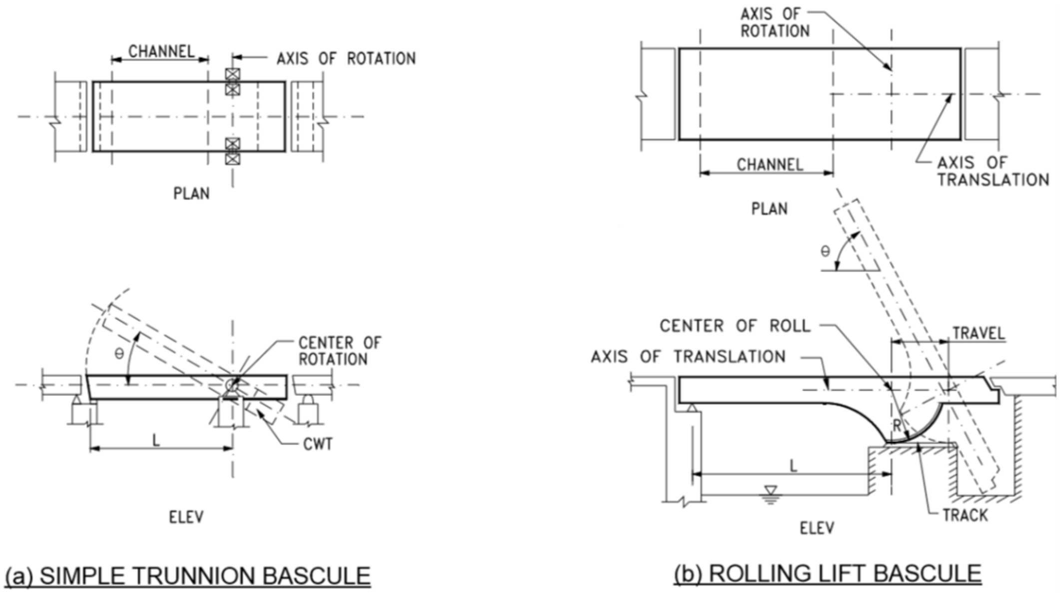


Figure 17.4 Types of Bascule Bridges (a) Simple Trunnion (b) Rolling Lift Bascule (Courtesy of Wisconsin DOT)

The pinion is the smallest gear in a gear set. The pinion is driven by the span drive machinery and engages the rack to move the span (see Figure 17.5). Simple trunnion bascules can also be operated by hydraulic cylinders. The cylinders are typically mounted on the bascule piers and the piston rods are connected to the leaves in a manner such that extending or retracting the rods rotates the leaf. See Figure 17.6 for an example of a hydraulic cylinder on a trunnion bascule bridge.

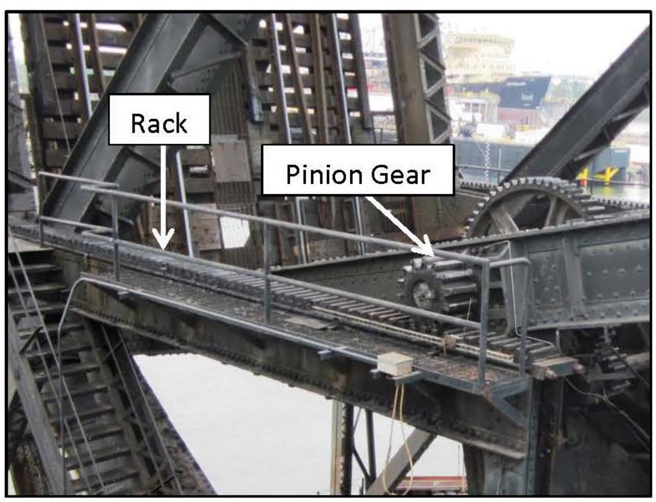


Figure 17.5 Rack and Pinion Gear

Figure 17.6 Hydraulic Cylinder on Trunnion Bascule Bridge

Counterweights are typically fixed to the bascule girders to minimize the force required to move the leaf. To achieve this, the trunnion axes are located at or near the center of gravity of the leaf including the counterweight.

For most bascule bridges, the ideal balance condition is slight toe, or span, heaviness, and it is the condition for which the bridge and mechanical components were designed. Operation during unbalanced conditions will place excessive wear on the bridge's structural and mechanical components, leading to costly repairs or possible safety concerns. During opening and closing, even a perfectly tuned and maintained leaf is expected to exhibit some friction, however, disruption to the alignment of leaves or any part of the mechanical system increases the friction. A balance test can be performed to determine the balance of the leaf and the friction present in the mechanical system. More details on balance testing are provided in Section 17.3.21.2.

Rolling lift bridges (also called Scherzer type) are characterized by a curved end section (or a "fish belly") of the girders or trusses. During bridge operation, the machinery creates a rotation about an axis that translates to movement in the horizontal direction. As the tread rolls along the tracks, the bascule leaf rotates open or closed.

Figure 17.7 depicts a single-leaf deck type Scherzer bascule. As the leaf tilts open to clear the channel the curved ends of the girders roll away from the channel. Slippage between the segmental girder treads and the tracks on which they ride is prevented by lugs or teeth that mechanically engage sockets. The protruding lugs are typically located on the track and the receiving holes or notches are in the segmental girder treads. Figure 17.7 shows the rack is located below the pinion, which is common on older Scherzer-type bridges. Some newer bridges have the rack located above the pinion.

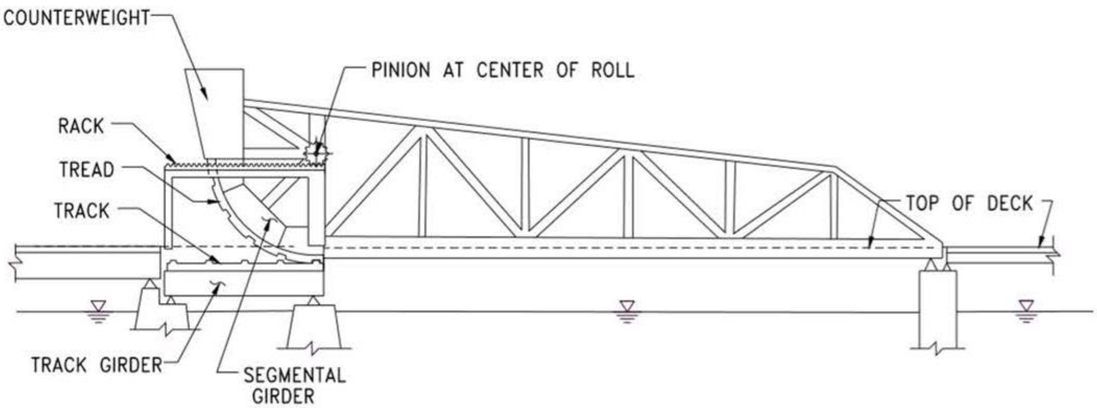


Figure 17.7 Through Single-Leaf Scherzer Rolling Lift Bascule

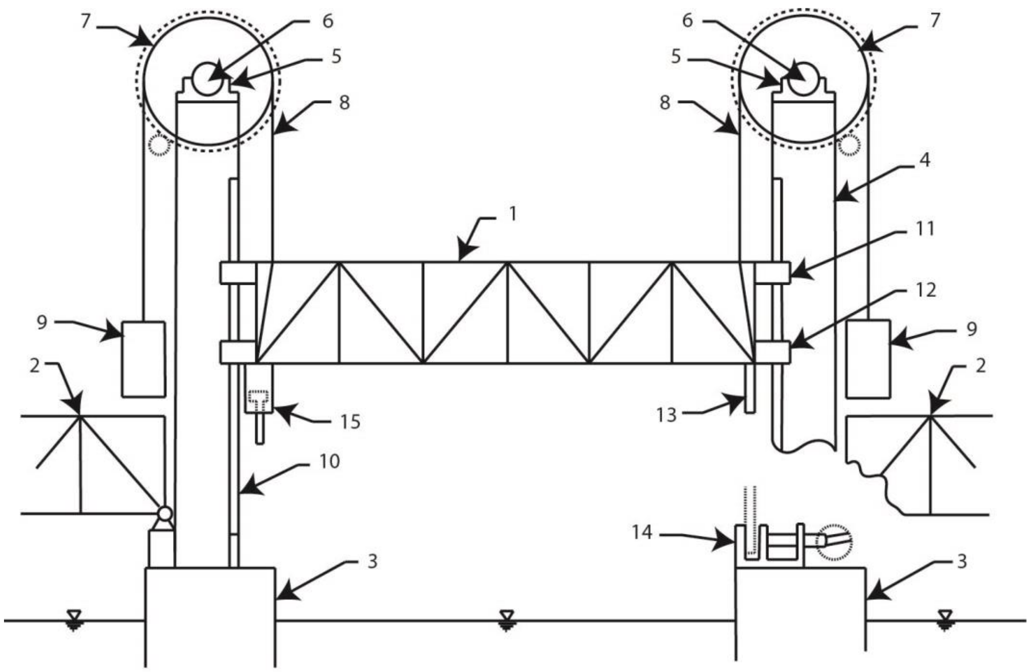
17.1.3 Vertical Lift Bridges

The spans on vertical lift bridges are lifted up and down just like an elevator. These bridges have a tower on each end, each of which encloses counterweights that offset the weight of the lift span. There are two main types of vertical lift bridges: Span Driven vertical lift bridges and Tower Driven vertical lift bridges. On Span Driven vertical lift bridges, the operating machinery is located on the lift span. Operating ropes, which are connected to the ends of the lift span and the counterweights, are draped over sheaves located at the top of the towers. An example of a Span Driven vertical lift bridge is shown in Figure 17.8.

Figure 17.8 Span Driven Vertical Lift Bridge

For Tower Driven vertical lift bridges, the operating machinery is located at the tops of each tower, with the lift span and counterweights located on either side of the operating drums. An example of a tower driven vertical lift bridge is shown in Figure 17.9. A schematic of a vertical lift bridge and its components is presented in Figure 17.10. Examples of vertical lift bridges include the Roosevelt Island Bridge between Queens, New York, and Roosevelt Island in the East River, and the Commodore Schuyler Heim Bridge at the Port of Los Angeles. The longest vertical lift bridge in service in the world is the Arthur Kill lift bridge between Staten Island, NY and Elizabeth, NJ with a span of 559 feet.

Figure 17.9 Tower Driven Vertical Lift Bridge



1. Lift Span Truss
2. Flanking Span Truss
3. Pier
4. Tower
5. CWT Trunion Bearing
6. CWT Trunion
7. CWT Sheave
8. Main CWT Ropes
9. Main CWT
10. Span Guide
11. Upper Span Guide
12. Lower Span Guide
13. Centering Bar & Span Lock Socket
14. Span Lock Actuator & Lockbar (Retracted)
15. Air Buffer

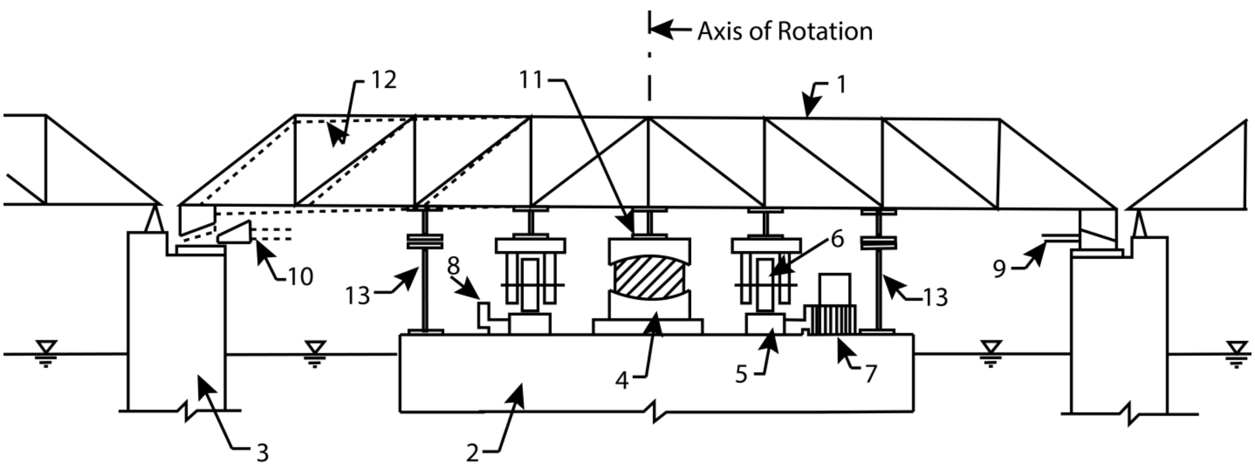
Figure 17.10 Vertical Lift Bridge Schematic

17.1.4 Swing Bridges

Swing bridges have an axis at their center and move by spinning horizontally until the bridge is perpendicular to its previous position, therefore creating two channels through which boats can run, as shown in the photographic example in Figure 17.11.

Figure 17.11 Center Bearing Swing Span Bridge

Swing bridges are also occasionally cantilevered out from one side of the channel when there is not space for the axis to be located right at the bridge's center. Swing bridges are rarely built today, due to slow operation of the movable span and the space needed for movement. A schematic of a center-bearing swing bridge is shown in Figure 17.12.



1. Swing Span (Draw)
2. Pivot Pier
3. Rest Pier
4. Center Bearing
5. Track
6. Balance Wheel
7. Pinion
8. Rack
9. End Wedges (Extended)
10. End Wedges (Withdrawn)
11. Distribution Framing
12. Deflected Position (Wedges Withdrawn)
13. Live Load Wedges

Figure 17.12 Center-Bearing Swing Bridge Schematic

The entire main span weight of a center pivot swing bridge rotates about and is supported by the center pivot bearing. Bronze disc type or an anti-friction type spherical thrust bearings may be used for center pivot bearings. Balance wheels help stabilize the span from any lateral forces on the span while the span is in motion. The wheels are set to a small clearance (approximately 0.1 inch) with tapered track, and only make light contact due to imbalance and/or wind loads.

A rim bearing swing span has an upper and lower track with large tapered rollers that rotate between the tracks. This tracks and rollers support the entire weight of the span during operation. Radial tension rods connected to a central hub hold the tapered rollers in alignment as the span rotates. This hub rotates about a vertical pin mounted to the pier. The rollers should rotate with no sliding or abnormal noises.

The ends of a swing bridge deflect during operation, and must be raised to meet the approach roadway level. This acts to stabilize the span under vehicular traffic. Several types of end lift machinery are used including: end wedges, end toggles, and eccentric cams. Most systems utilize crank mechanisms to lock the devices in place. The mechanisms are usually driven by a system of gears and a motor. During operation of a swing bridge, the ends of the swing span will deflect downward. In order to provide a smooth transition to the approach spans, and stabilize the bridge under load, end lift mechanisms are used to secure the swing span into place.

17.2 Operation of Movable Bridges

When a movable bridge is to be opened, a series of steps take place. The traffic lights turn to red, the alarm bell rings, and the gates are lowered. Next, the bridge lock is released allowing the bridge to move. When the span is fully opened, sensors automatically stop the machinery. The operator can override the system at any time during the movement.

While all movable bridges follow the same general procedure for operation, each bridge will have unique operating procedures which will be detailed in the Operations and Maintenance Manual for the bridge. To properly maintain the movable bridge, a maintenance worker must familiarize himself with the Operations and Maintenance Manual of the bridge, as well as the design plans for the structure (if available). Figure 17.13 provides an example of a table of contents for a movable bridge maintenance manual.

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OPERATION, MAINTENANCE, AND LUBRICATION MANUAL

JOB NO.: 10314-G

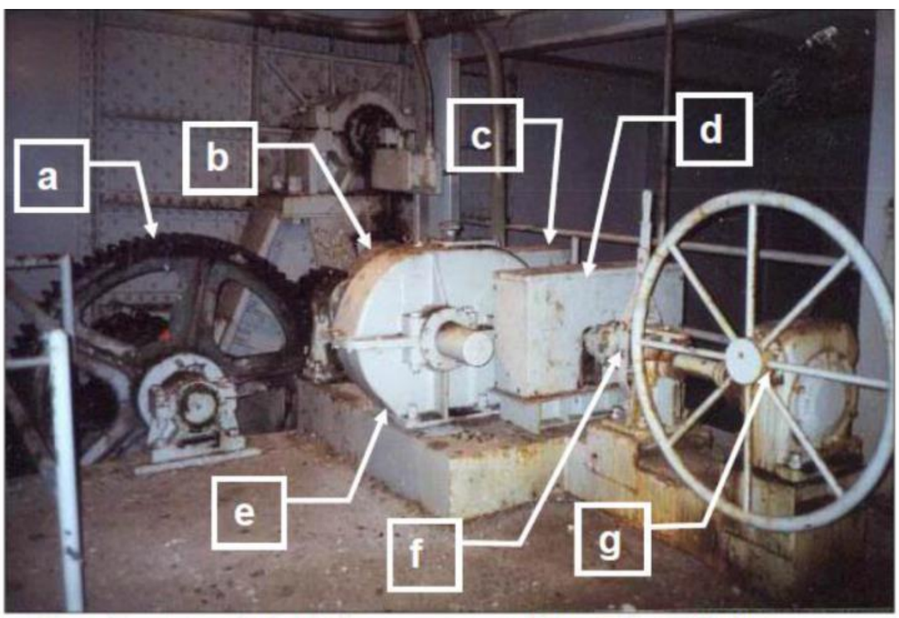
Figure 17.13 Example of a Table of Contents of a Bridge Specific Movable Bridge

Live load bearings are found on trunnion bascule, rolling lift bascule, vertical lift bridges and swing spans. Live load bearings are support blocks on which the span rests while in the closed position. On bascule bridges, the live load bearings are located forward of the trunnion and hold the main girder up. Live load bearing assemblies transfer vehicular live load from the movable span to the adjacent spans and piers when the bridge is in the closed position. An example of a live load bearing assembly is shown in Figure 17.14. The closed position is shown in Figure 17.14 (left), and the shoe (bearing) is shown in the open position in Figure 17.14 (right). Live load bearings are typically located at the four corners of a lift span, and in front of or behind the center of rotation for bascule bridges. The wedges located on the enter pivot pier of a swing span also serve as liveload bearings. Load bearing assemblies are comprised of an upper casting with a rounded surface (mounted to the span) and a flat strike plate mounted to the pier (or other fixed structure). The bearing and the strike plate are attached to the span and pier respectively, using bolts (and shims if necessary for adjustment purposes).

Figure 17.14 Live Load Wedges and Shoes
Closed Position with Wedge (left). Live Load Shoe (right).

Movable bridge machinery may be classified as either span drive or span stabilizing machinery. Span drive machinery are the components that move the span. Stabilizing machinery supports and restrains the span when it is at rest and when in motion.

Span drive machinery is similar across movable bridge types because the machinery converts the low-torque rotation of a motor (electric or internal combustion) to the high torque force required to move the span. In electro-mechanical drives, for instance, gearing is used to convert the low-torque, high-speed rotation of the motor to high-torque, low-speed rotation for moving the span. Various combinations of electrical, mechanical, and hydraulic components have been assembled to form span drives. An example of a span drive and its components is shown in Figure 17.15.



a Secondary gear reduction train
b Motor (behind speed reducer)
c Motor Brake
d Machinery Brake
e Primary Speed Reduce
f Clutch (behind manual drive wheel)
g Manual Drive (with right angle reducer)

Figure 17.15 Components of a Span Drive

Stabilizing machinery comprises electro-mechanical and/or hydraulic components that support the span when it is in motion and when it is at rest. The machinery components and assemblies are usually mechanical but fluid power (air and liquid) components are also utilized. General examples of stabilizing components for bascule bridges are the trunnion shafts and trunnion bearings (see Figure 17.16), span locks, centering devices, and buffers. On vertical lift bridges, stabilizing machinery includes the counterweight sheaves with trunnions and bearings, the main counterweight and auxiliary counterweight ropes, centering devices, span locks and guides, and buffers. Swing bridges are stabilized using center pivot bearings and balance wheels, rim girders, rollers and spider assemblies, center wedges; end lifts; centering latches or centering mechanisms, buffers, bumpers, and rigid stops.

Figure 17.16 Trunnion Bearing

The span motor and motor controller are used to slow the span during operation. Span brakes are not typically utilized for that function, but are used for holding the movable span and stopping it during emergency conditions.

The electrical, mechanical, and structural components of a movable bridge function as a system, which means that failures or deficiencies in one component will probably result in other components being affected. This means that a deficiency found at one item would most likely affect other elements.

17.2.1 Counterweights

Large blocks of concrete, called counterweights, are used to off-set the weight of the leaves on bascule spans or the lift spans on vertical lift spans. The weight of counterweight is designed to "balance" the system so the size of the mechanical systems and motors required to lift and close the leaf is minimized. A movable span operating in an unbalanced condition may cause overstress or failure of the mechanical or structural elements.

For lift bridges, auxiliary counterweight are secondary weights that are used to offset the shifting weight of main counterweight ropes as they travel from one side of the sheave to the opposite side during operation. The counterweights are made up of concrete and steel. The wire ropes holding the counterweight are guided by rails, sheaves, and termination points. Balance chains are used to help maintain span balance as they offset the weight of the wire rope as it spools during operation. An example of a counterweight assembly with auxiliary counterweights attached is shown in Figure 17.17.

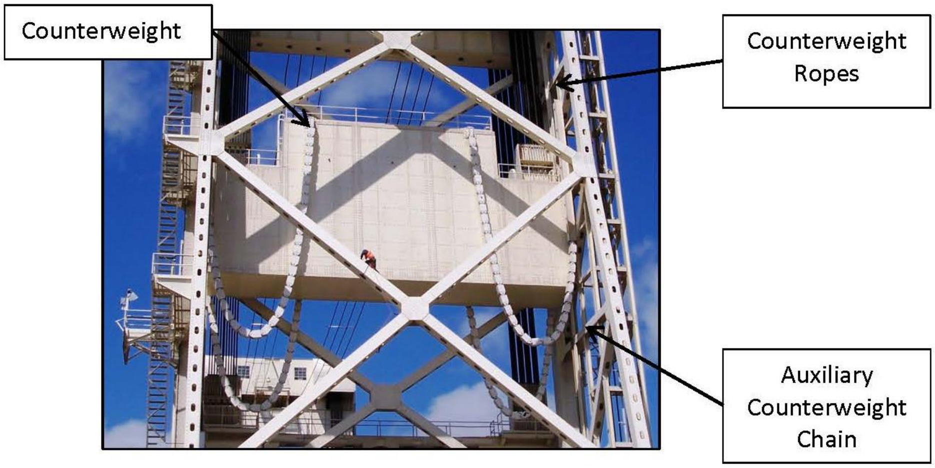


Figure 17.17 Counterweight Assembly

Throughout the lifetime of the bridge, counterweight adjustments are necessary. Short term adjustments compensate for ice or snow accumulations, for example. Adjustments to balance leaf weight changes due to activities such as repaving or painting are commonly performed. When the 250-foot long High Street Bridge in Alameda County, California was refurbished in 1996, 25,000 pounds of paint and primer were removed from its two bascule leaves. The counterweights had to be adjusted before and after repainting the span.

When to Call the Engineer

Whenever work is being performed on the bridge that will add or remove weight to either the movable span or the counter weight, the Engineer should be consulted to determine what steps, if any, will be required to keep the bridge in balance.

A dramatic example of the need to maintain proper counterbalance was shown by an accident on Chicago's Michigan Avenue Bridge on September 20, 1992. The two-level, double-leaf Bascule Bridge was undergoing repairs, and the concrete paving had been stripped off both the upper and lower decks. A large crane was parked behind the trunnion of one leaf, just above a counterweight that had not been lightened to compensate for the paving removal. Safety (span) locks may also have been improperly engaged or defective. The opposite side of the bridge was opened to allow a boat to pass. When it closed and mated with the side that had remained down, the static half was jarred enough to release its unbalanced energy. According to the Chicago Tribune, the leaf "shot up in the air”. According to an analysis in the Journal of the American Society of Mechanical Engineers, "The rapid rotation of the bridge ripped it from its trunnion bearings and the entire span slammed to the bottom of the counterweight pit." Six people were injured as they scrambled out of a bus struck by flying debris, and the rear window of an occupied car was smashed by the wrecking ball attached to the crane as it fell from the bridge.

17.2.2 Mechanical Systems

Most movable bridges are powered by either electric-mechanical or hydraulic-mechanical drives with power driven pinions operating against racks or by hydraulic cylinders. A schematic of typical mechanical components is shown in Figure 17.18. A small number are hand powered for normal operation. Some smaller bridges use hand power for standby operation. An example of a brake and hydraulic span drive system is shown in Figure 17.19.

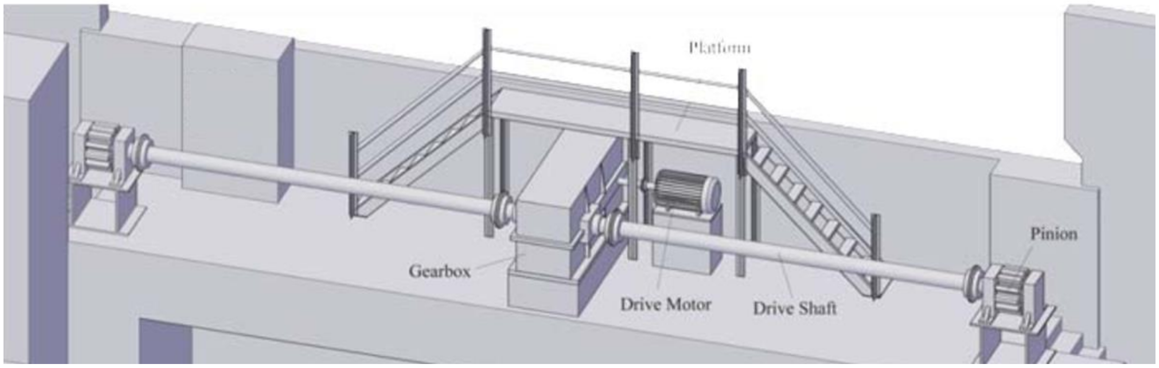


Figure 17.18 Mechanical/Electrical System of Representative Movable Bridge

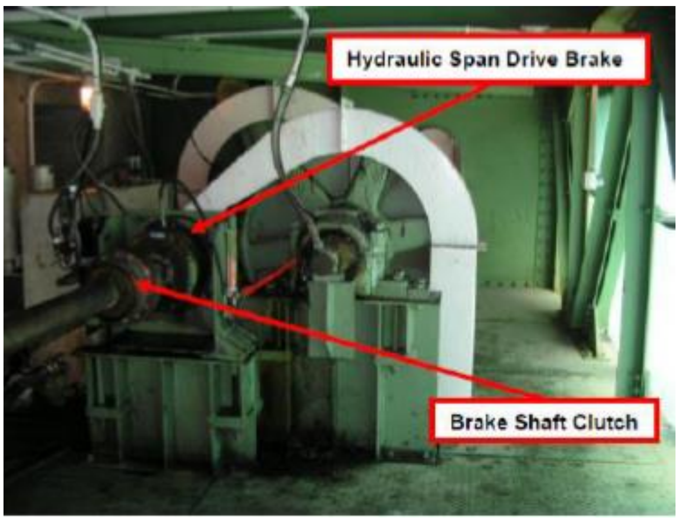


Figure 17.19 Brake and Hydraulic Span Drive System

The following components are often found on various types of movable bridges:

- Open Gearing: Open gearing transmits power from one shaft to another and alters the speed and torque output of the machinery. An example of open gearing is shown in Figure 17.20. Beveled gears change the direction of rotation.

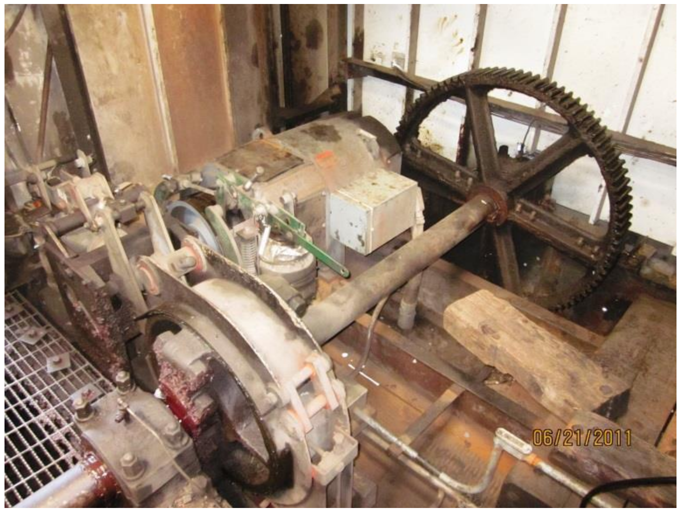


Figure 17.20 Open Gearing Operating Machinery

- Speed Reducers Including Differentials (Closed Gearing): Speed reducers including differentials serve the same function as open gearing. Differentials and speed reducers are typically compact packaged units which protect the gears and shafts and lubrication inside an enclosed housing (See Figure 17.21). In addition, the closed gearing is used as a torque equalizer, to match operating speeds and torques on various portions of the mechanical system.

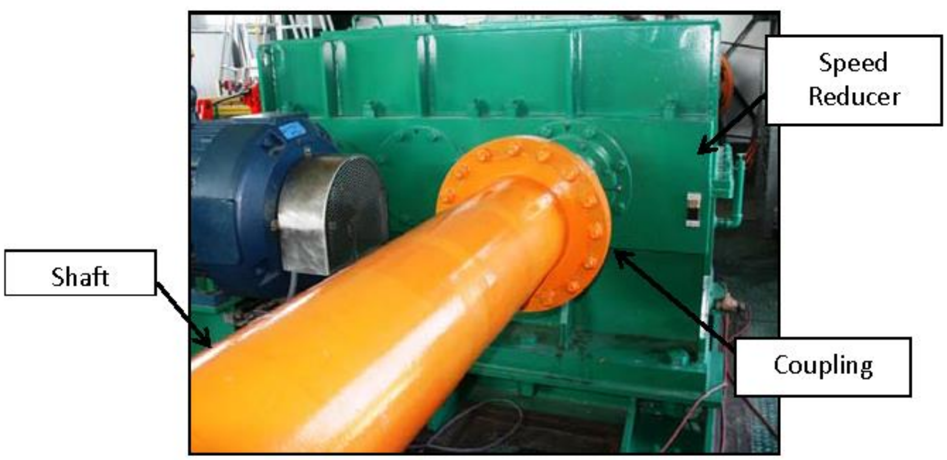


Figure 17.21 Speed Reducer (Closed Gearing), Shaft, and Coupling

- Shafts: Shafts transmit all the required mechanical power from one part of the machinery system to another for opening and closing operations. Figure 17.21 shows a shaft and coupling at the connection to the speed reducer on a vertical lift bridge. Shaft condition is directly related to the structural integrity and proper functioning of the movable bridge. Unanticipated distress on the shaft may indicate either degradation of the shaft, motor, gears, rack, or overloading of the bridge during operation. Shafts ends are usually connected by couplings, which are secured to the shaft by an interface fit.

- Couplings: Couplings transmit power between the ends of shafts in line with one another (See Figure 17.21). Some types of couplings can be used to compensate for slight imperfections in alignment between the shafts. Couplings are manufactured in large variety, but can be categorized into three general groups: rigid, flexible, and adjustable. Rigid couplings are commonly found on older bridges and basically clamp shaft ends together. Flexible type couplings are designed with internal elements that allow for misalignment during operation due to distortion of the bridge structure to avoid bending the shafts. They also simplify shaft installation by allowing slight misalignment at the joints. Adjustable couplings are in span drives of connected tower lift bridges and other drives that require angular adjustment with time because of wire rope stretch, etc. They are also used to precisely rotate electrical control devices such as limit switches to prevent damage.

- Bearings: Bearings provide support and help to maintain alignment of rotating shafts, trunnions, and pins. An example of a bearing which is supporting a span drive shaft is shown in Figure 17.22.

Figure 17.22 Bearings Supporting Span Drive Shaft

- Brakes: Brakes on movable bridges are generally used as a "parking brake". In other words, they are engaged when the span has stopped moving (much like the parking brake in your car). Brakes can be of either the drum type or disc type, and can be released manually, electrically, or hydraulically. An example of a drum type brake assembly is shown in Figure 17.23. They are generally spring applied for fail safe operation. Motor brakes are located close to the drive to provide dynamic braking capacity, except that brakes are to stop the movable portion of the bridge and to hold it in place. The manual, mechanical and electrically actuated brakes may be the drum or disk type. If they are used as machinery brakes, they are typically located close to where the fixed and moving parts of the bridge meet. Dynamic brakes typically serve as motor brakes, and are located close to the motor unless the motor is equipped with internal dynamic braking.

Figure 17.23 Typical Brake Assembly

- Air Buffers and Shock Absorbers: Air buffers and shock absorbers are located between the span and the pier at points where impact may occur between the two that mechanically control the deceleration of the span at the fully closes and/ or fully open positions. Typically the buffers are large pneumatic cylinders, or hydraulic energy absorbers. Major components of air buffer cylinders are the cylinder housing, the piston, the piston rod, inlet and outlet piping, and the strike plate. Gravity (or spring pressure for horizontally mounted buffers) extends the piston rod, which fills the void in the cylinder with air. As the span lowers, the rod is pushed in, causing the air inside to be compressed. A pressure relief valve allows the air to escape beyond the pressure setting. Forces are required to build-up and keep the pressure of the air at the movement of the span for a “soft” touchdown on the bearings. Shock absorbers achieve the same purpose as the air buffers. However, they are self-contained and, therefore, require little maintenance. An example schematic and photos of air buffers are shown in Figure 17.24 and Figure 17.25, respectively.

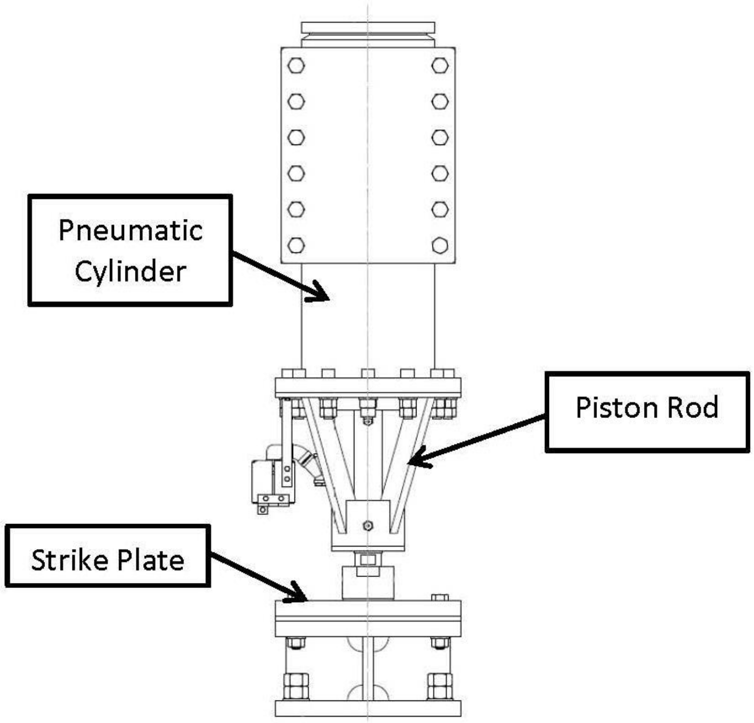


Figure 17.24 Air Buffer Schematic

Figure 17.25 Air Buffers in the Retracted (left) and Not Retracted (right) Positions (right - Courtesy of MaineDOT)

Span Locks: Span lock bars at the end of the span are engaged when the span is fully closed to prevent movement under live load. Span locks may also be provided at other locations on the span to hold the span in an open position against strong winds or to prevent movement from an intermediate position. They can be engaged either mechanically or hydraulically and typically consist of a forged steel lock bar that engages a receiving socket. Sockets on the drive end of the lock bar serve as guides and supports to the lock bar while in operation, and when engaged. The sockets are typically welded or cast housings equipped with adjustable wear shoes. Adjustment of the spacing is made by adjusting the shims and wear shoes. The lock bar operates within the sockets by a motor and gear driven crank mechanism. Linear lock bar operators are also common. Photo examples showing span lock bars and shims are shown in Figure 17.26 and Figure 17.27. The housings are usually mounted to the side of the bascule girders, or in the webs of the floor beams. Span lock couplings need to be loose enough to allow a proper opening operation, but at the same time, the gap between the bar and the receiver has to be small enough to ensure the adequate connection with minimal bouncing, under live load, from one leaf to the other. Deterioration or incorrect operation can cause a failure of the lock to retract or engage, triggering sensors and disruption of the operation of the bridge.

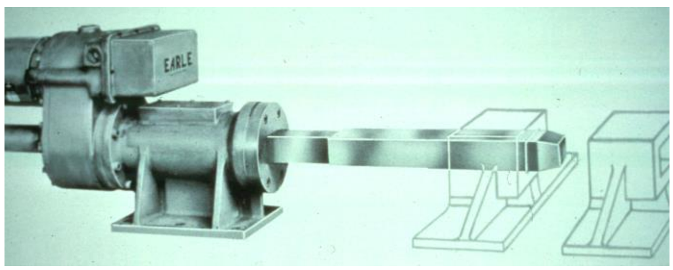


Figure 17.26 Mechanically Driven Span Lock

Figure 17.27 Span Lock Bars and Shim Removal (Courtesy of FDOT)

And example of a disengaged span lock with labelled components is shown in Figure 17.28.

Figure 17.28 Disengaged Span Lock (Courtesy of Indiana DOT)

An example of an engaged tail lock is shown in Figure 17.29.

Figure 17.29 Engaged Tail Lock

Additional examples of a tail lock in fully engaged and disengaged positions are shown in Figure 17.30 (left) and Figure 17.30 (right), respectively.

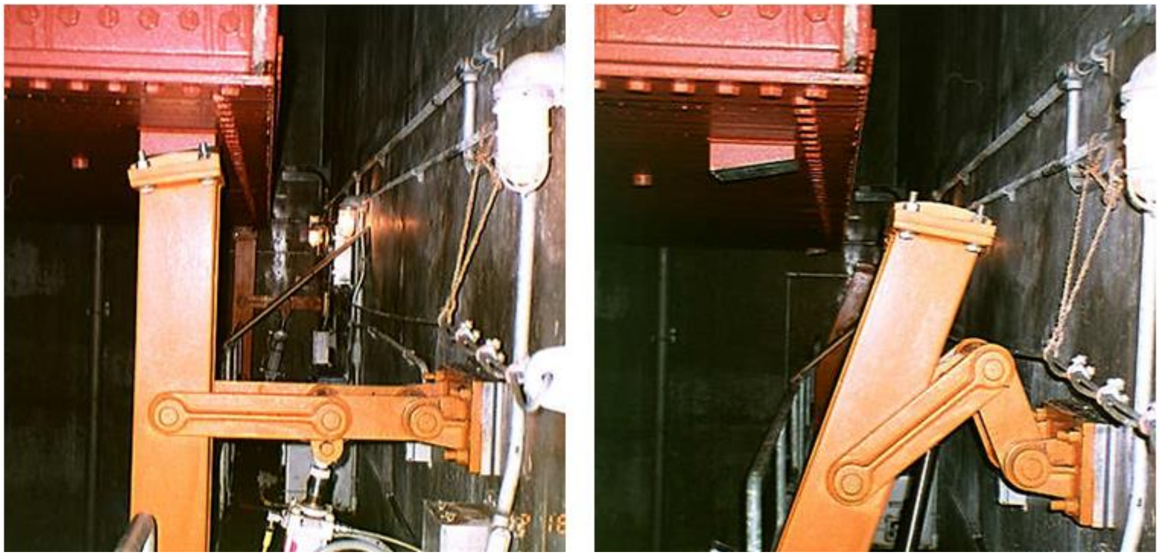


Figure 17.30 Tail Lock in Fully Engaged Position (left) and Disengaged Position (right) (Courtesy of MaineDOT)

Toe Locks: Toe locks transfer vehicular live load between the leaves of double-leaf bascule bridges when the structure is in the closed position. Unlike tail locks where the bridge can still carry vehicular traffic without the span engaged in the seated position, double bascules cannot carry traffic if the toe locks are not engaged, as the continuity of the two bascule cantilevers is required. A toe lock typically consists of a forged steel lock bar that engages a receiving socket. An example of a toe lock that is still not fully engaged is shown in Figure 17.31.

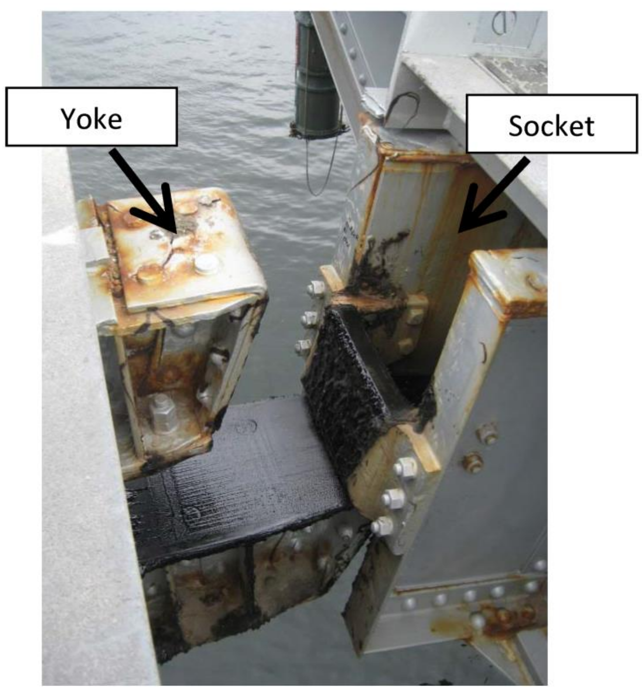


Figure 17.31 Toe Lock on Double Bascule Bridge

- Live Load Bearings and Strike Plates: Live load bearings and strike plates between the movable and fixed portions of the bridge are designed to bear most or all of the live load when the bridge is carrying traffic. Live load bearings are provided at the end of the moving leaf truss/girder at the approach end. An example for a lift bridge is shown in Figure 17.32.

Figure 17.32 Fixed Live Load Bearing

- Wire ropes: These ropes are typically used to connect the vertical lift span to the counterweights located in the towers for operation on vertical lift bridges and are comprised of individual wire strands that are tightly wound together. The wire rope is terminated at the lifting girder and counterweight using open spelter sockets affixed to each end (see Figure 17.33). Rope clips and wedge sockets are often used for terminations at the operating drums. An example of a drum and wire rope on a vertical lift bridge is presented in Figure 17.34.

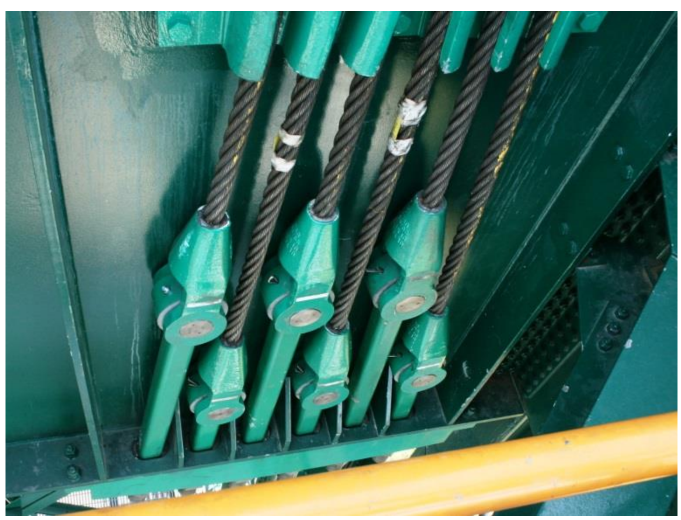


Figure 17.33 Wire Rope Socket Terminations

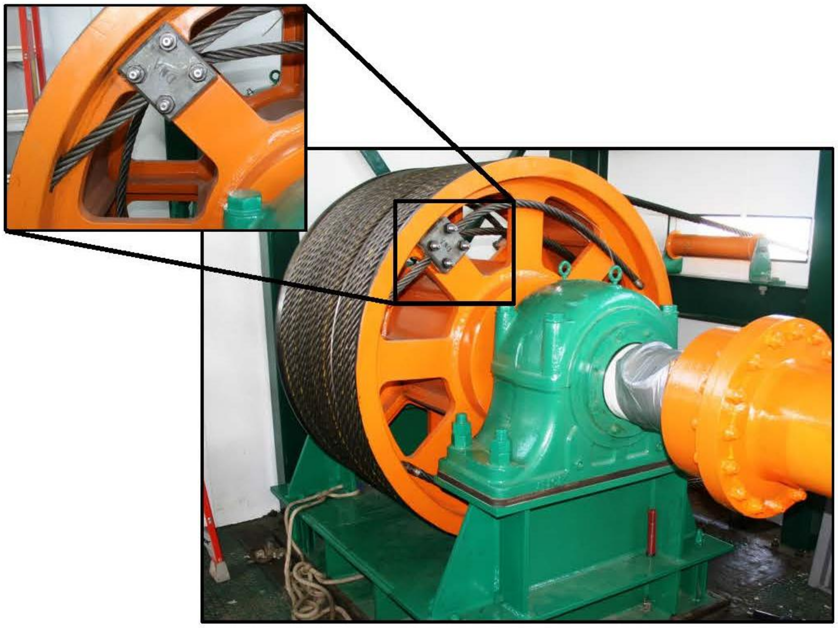


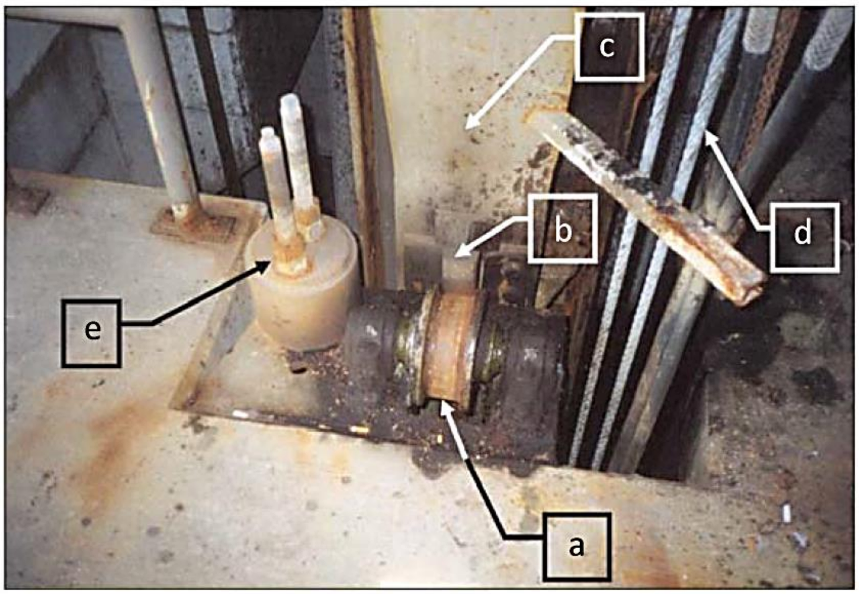
Figure 17.34 Operating Drum and Wire Rope with Rope Clip on Vertical Lift Bridge

- Counterweight Sheaves: These are large diameter, angular-grooved wheels located at the top of the towers, over which the counterweight ropes are draped, supporting the entire weight of the span and counterweight during operation. These sheaves are supported by shafts and bearings. An example of a counterweight sheave is shown in Figure 17.35.

Figure 17.35 Counterweight Sheave

- Operating Drums: Operating drums are large diameter, grooved drums to which the operating ropes are attached and are paid-out and taken-in during operation of the lift span. These drums are supported by shafts and bearings that are turned by the operating machinery. For Span Driven vertical lift bridges, these operating drums are located on the lift span. Drums are located at the tops of the towers on Tower Driven vertical lift bridges. The drums are grooved in a spiral fashion in order to store several wraps of wire rope. The grooves are cut to a specific dimension to properly space adjacent ropes and support the rope without crushing it.

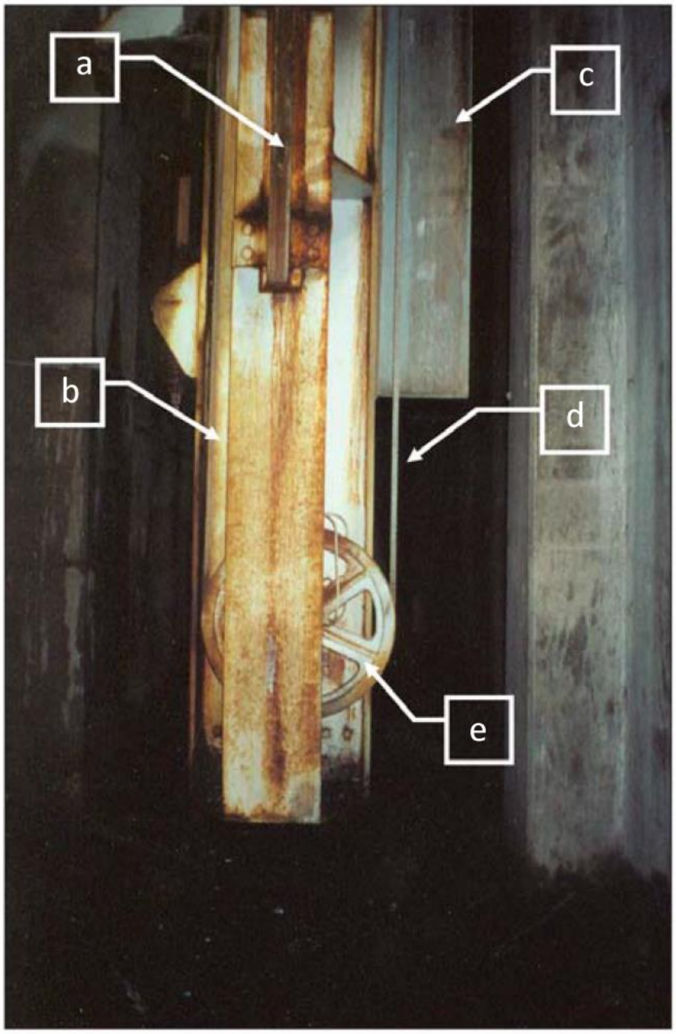
- Span Guides: Span guides restrict lateral and longitudinal movement of the span during operation. Roller guides are commonly used as span guides. Guide rails located along the tower legs are for contact with the guides against any side wind loads. An example of the guide rail detail is shown Figure 17.36.



a Guide roller
b Guide rail
c Lifting post
d Equalizer ropes
e Rope take-up

Figure 17.36 Span Guide Rail Detail (Courtesy of Wisconsin DOT)

- Counterweight Guides: Counterweight guides are used to limit lateral and longitudinal movement of the counterweights as they move within the towers. Sliding guides are frequently used as counterweight guides.
- Lifting Posts: The spans are guided vertically at each corner of the span by lifting posts, as shown in Figure 17.37. Typically, lifting posts are rigidly connected to the end floorbeams and fascia girders.



a Plate clamp rail
b Lifting post
c Guide rail
d Equalizer rope for longitudinal system
e Lower sheave

Figure 17.37 Components of a Lifting Post (Courtesy of Wisconsin DOT)

- Equalizing Systems: Skewing of the lift span during raising and lowering is restrained (in both the longitudinal and transverse directions) by wire rope stabilizing systems. The stabilizing system is separate from the counterbalancing systems described earlier. Figure 17.38 shows a moving drum stabilizing system. One rope is fastened to the pier wall and passes through sheaves then wrapped around a drum and anchored on the fixed portion of the structure. A second rope provides the same from the opposite pier wall. The drum is mounted on the movable span. An stabilizing system is necessary because center of gravities could be different between the span and lift cylinders, and there could be different degrees of friction in the listing posts.

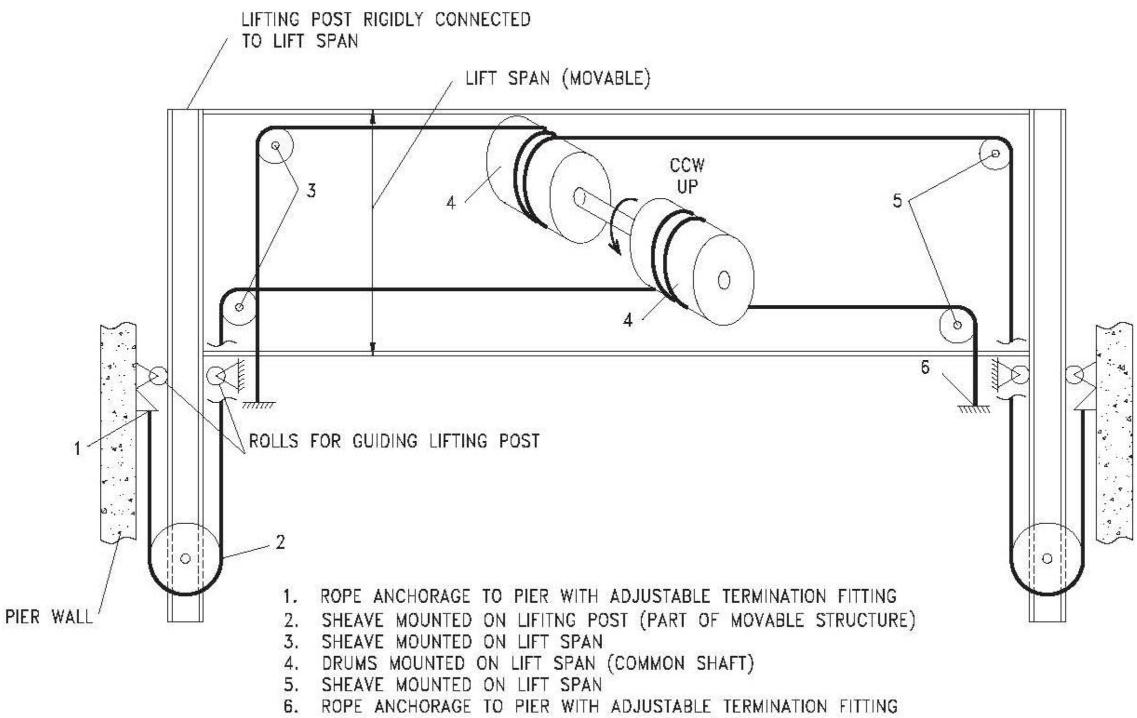


Figure 17.38 Moving Drum Equalizing System (Courtesy of Wisconsin DOT)

- Tread Plates: Tread plates are mating steel plates with interlocking teeth and pockets on rolling bascule bridges. The upper curved tread plate, which is mounted to the bottom flange of the segmental girder on the bascule leaf, rolls along the stationary bottom tread plate, which is mounted to a frame or supporting steel. As the bascule leaf travels along the lower tread plate, the teeth mate with the pockets to ensure proper alignment and travel during the opening of the leaf. These plates see very high loads, as the entire weight of the bascule leaf is resting on it. An example of tread plates is shown in Figure 17.39.

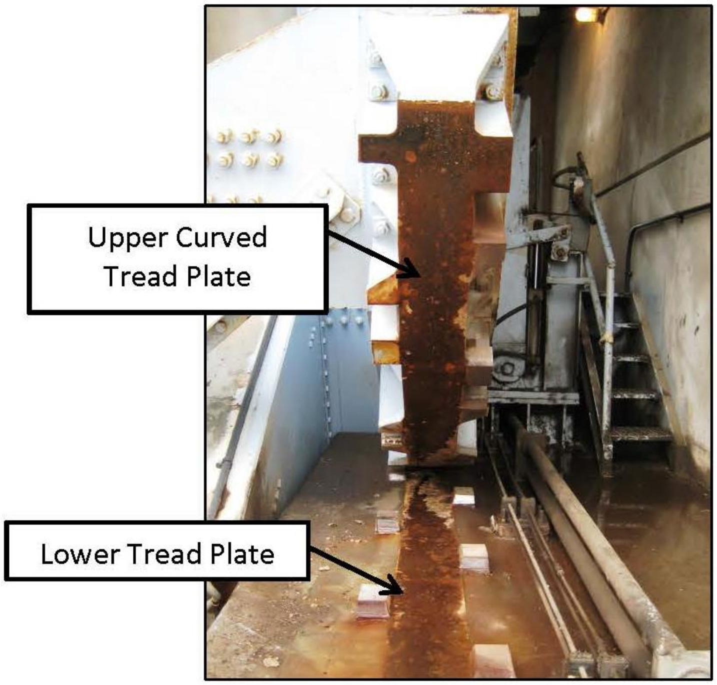


Figure 17.39 Tread Plates

17.2.2.1 Types of Span Drives

Span drives consist of an arrangement of electrical and mechanical components to transfer the high speed, low-torque energy from the motors into the low-speed, high-torque motions of the two pinions.

Drives may be electric motors, hydraulic equipment, or auxiliary drives. Either AC or DC power may be used to drive electric motors. AC power is often used to power wound rotor motors with torque controllers on older bridges, while new bridges may utilize squirrel cage induction motors with adjustable frequency speed control. Hydraulic equipment is usually either large actuating cylinders or hydraulic motors. Adequate pressure and volume of hydraulic fluid must be provided to the cylinder, or motor to power the opening and closing of the bridge. The fluid flow to the cylinder or motor is usually provided by an electrically operated and controlled hydraulic pump.

Auxiliary drives and emergency generators may be provided to serve in the event of power failure. Auxiliary motors and hand operators, and appurtenances, are provided to serve in the event the main drive fails. To avoid the need for larger auxiliary generators, some bridges require auxiliary motor use any time the auxiliary generators are used. The smaller, less powerful auxiliary motors will usually take longer to operate the bridge. An example of an auxiliary drive assembly is shown in Figure 17.40.

Figure 17.40 Auxiliary Drive Assembly

The pinion of the span drive machinery engages with the rack on the movable span when opening and closing the span. The pinion is the last gear in the drive train. As it drives the motion of the span, it is commonly called the drive gear. The rack can be another gear, or a bar, or a track with teeth on one of its sides. The teeth of the rack are machined to match the teeth of a pinion and move the span. The three most common types of span drives are designated as Type 1, Type 2, and Type 3 Span Drives, as discussed on the following pages.

Type 1 Span drives have all the outputs connected mechanically, as shown in the example in Figure 17.41. The motor is connected to the primary speed reduction gearing, usually by a flexible coupling. This gearing is enclosed in a welded steel housing on most contemporary designs, but cast steel and various kinds of cast iron were and are used in manufacturing these speed reducers. Power is distributed from the primary reduction gearing to two (or more) sets of secondary reduction gearing located at the sides or ends of the movable span. Secondary speed reductions are often made with enclosed speed reducers as shown; however, open gearing is not uncommon. Some newer bridges may have a single large speed reducer, rather than smaller primary and secondary reducers.

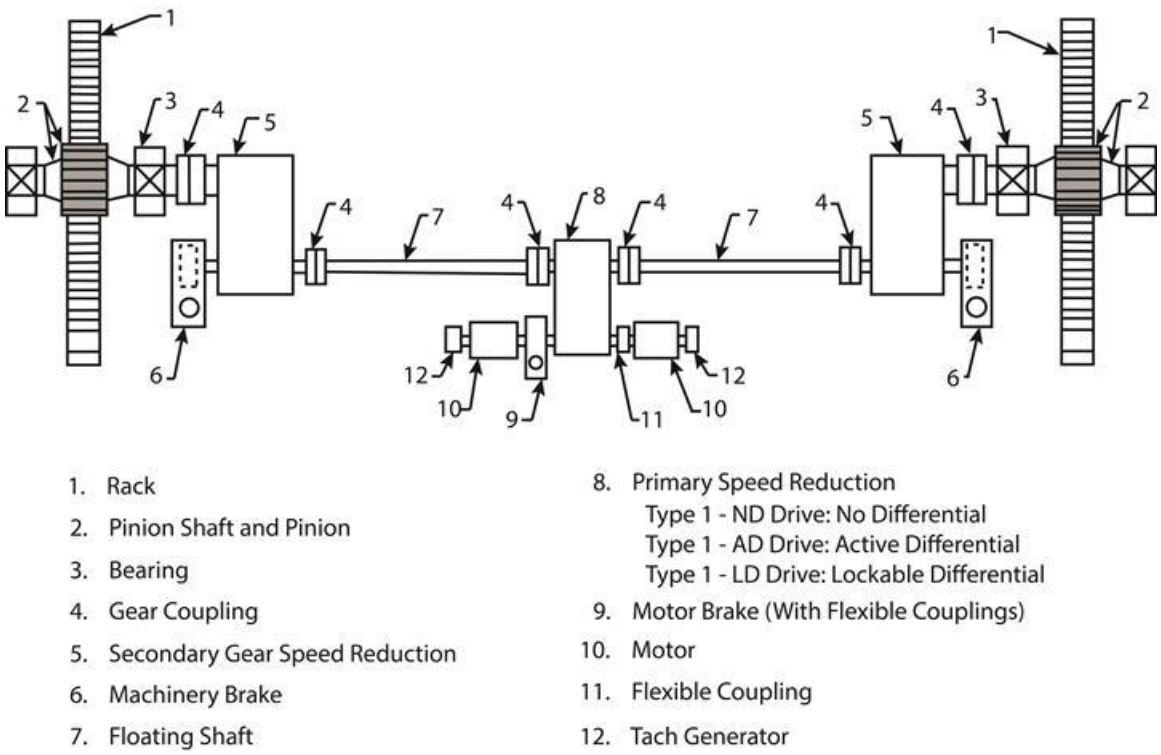
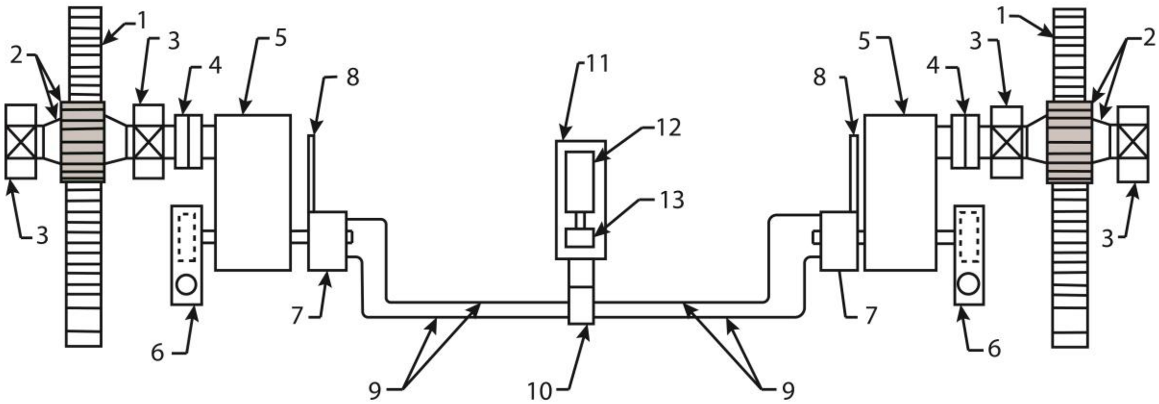


Figure 17.41 Type 1 Span Drive Schematic

A Type 2 span drive has two pinions, each powered by a separate hydraulic motor through a geared speed reduction, as shown Figure 17.42. Because the fluid input to the two motors comes from a common source, the torques applied by each pinion should be nearly equal, assuming that both sets of motors and gearing, and piping, etc., are alike. Open gear trains are also common.



1. Rack
2. Pinion Shaft and Pinion
3. Bearing
4. Gear Coupling
5. Secondary Gear Speed Reduction
6. Machinery Brake
7. Hydraulic Motor
8. Torque Arm
9. Hydraulic Lines
10. Manifold & Valves
11. Tank
12. Motor
13. Pump

Figure 17.42 Type 2 Span Drive Schematic

Type 3 Span drives transmit power to the moving span by linear action, as depicted below in Figure 17.43. Type 3 drives have been installed on simple trunnion bascules, rolling lift bascules, swing bridges, and vertical lift bridges. Hydraulic cylinders are usually used to move the span, but chain, wire rope, and screw drives have also been used. The cylinder mountings shown are for a simple trunnion bascule or a pit vertical lift bridge.

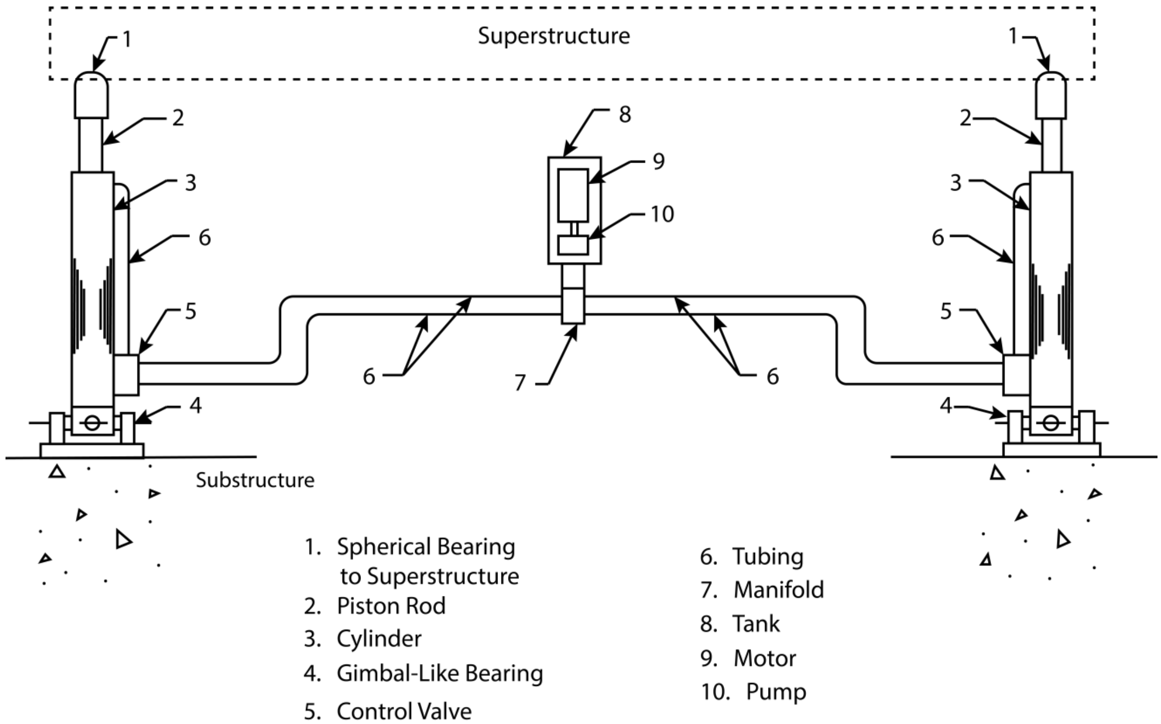


Figure 17.43 Type 3 Span Drive Schematic

The high-speed low-torque output shaft of the motor rotates a pump which pressurizes the hydraulic fluid. Modern hydraulic systems typically use mineral, vegetable, or synthetic oils for hydraulic fluid. Prior to the mid 1800's, hydraulic systems used water. Pressurized hydraulic fluid is transmitted to cylinders, which move the span directly, or to hydraulic piston motors, which move the span by rotating a rack pinion.

17.2.2.2 Open and Closed Gearing

What To Look For

- Worn gearing
- Areas lacking lubricant
- Broken, damaged or missing teeth
- Debris in gear assembly/gear assembly lubricants

Open gearing refers to machinery (gears and shafts) that is not contained in a sealed housing. The machinery are supported by shafting and bearings that are mounted onto fabricated or cast metal structural supports or framing. The gear mesh should usually be as installed, but may become misaligned due to wear or deterioration of the gears, shims, fasteners, bearings or supports. Constant exposure to weather and the presence of abrasive, foreign materials that lodge in the gear mesh serves to accelerate the wearing of open gears.

The most common type of open gearing found on movable bridges is spur gearing. Spur gears or straight-cut gears are the simplest type of gear. They consist of a cylinder or disk with the teeth projecting radially, and although they are not straight-sided in form, the edge of each tooth is straight and aligned parallel to the axis of rotation. Spur gears transmit power and regulate the speeds of parallel shafts using gear reduction. Gear reduction allows the power from the motor shaft, which operates at a high speed but low torque, to be transmitted to the operating machinery shaft, which operates at a lower speed but higher torque. See Figure 17.44 for a spur gear example.

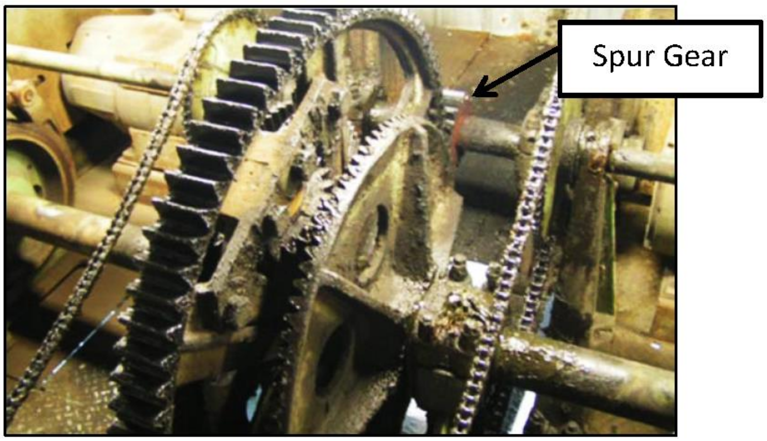


Figure 17.44 Open Gear

The rack and pinion, which are open gears, are the main gears used to operate the bascule leaf. The pinion is attached to the fixed part of the bridge, and the rack is attached to the movable leaf. The shaft delivers the force to the pinion, which engages the rack, moving it to open the leaf. For smooth operation, open gearing as well as rack and pinion gearing should be properly lubricated. An example of rack and pinion gears are shown in Figure 17.45.

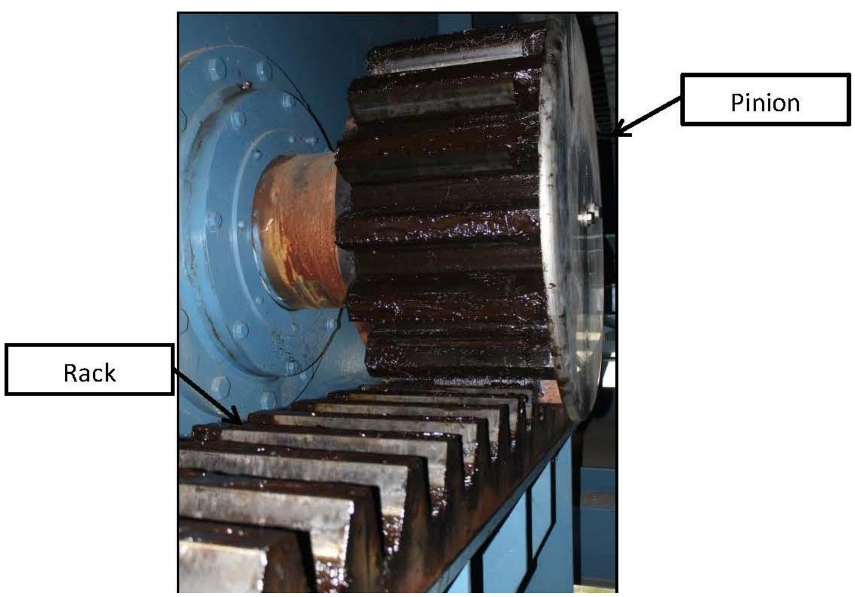


Figure 17.45 Rack and Pinion

Gear assemblies that are mounted in dust-proof, oil-tight, housings are generally referred to as closed (or enclosed) gearing, gear box or transmission. The gear reducers are often the most expensive part of the operating machinery and also one of the least thoroughly inspected components. A gear reducer is a set of gears mounted within an enclosed housing that maintains alignment and provides lubrication. The housing encloses the gear sets providing protection from dirt (and contaminants) while providing an environment where lubricant can be splashed onto the gears. An example of closed gearing is provided in Figure 17.46.

Figure 17.46 Closed Gear (Speed Reducer)

On bridges these assemblies usually function as speed reducers. Speed reducing gearing is designed to transfer the high speed, low torque of the motor to low speed, high-torque to raise or lower the span. In many newer bridges, speed reducers or transmissions are standard equipment manufactured by companies that manufacture mechanical power transmission equipment. Older reducers and transmissions made of cast iron or cast steel. Custom made reducers and transmissions on newer bridges are usually fabricated with welded steel. Reducers/Transmissions are typically equipped with antifriction roller or ball bearings. Housings of mass-produced standard reducers are still cast from various grades of iron and steel.

17.2.2.3 Bearings

Bridge bearings for non-movable bridges are covered in Chapter 12 of this manual. A bearing is typically a device that is used to enable rotational or linear movement, while reducing friction and handling stress. A simple bearing example is a car tire that rolls when loaded. The two primary loads are radial and thrust. Radial loads can be thought of as that force which causes the tire to rotate. If the car goes around a corner, a thrust force acts sideways on the tire. Using this simple example, most bearings are designed to primarily handle rolling, thrust, or a combination of each.

In general, movable bridge bearings provide support and prevent misalignment of rotating shafts, trunnions, and pins. An example of a bearing is shown in Figure 17.47. Virtually all bearings in heavy movable structures have tight inner ring and loose (or floating) outer ring fits. Tight inner ring fits eliminate shaft damage caused by fretting corrosion. Fretting is defined by the ASM Handbook on fatigue and fracture as: "*A special wear process that occurs at the contact area between two materials under load and subject to minute relative motion by vibration or some other force.*"

The loose outer ring fit allows the outer rings to slide axially to accommodate shift in the structure, thermal expansion, and mounting inaccuracies, except on fixed trunnion designs where the bearing outer ring rotates and the inner ring is stationary. In that case, the outer ring has an interference fit and the inner ring is loose. All housings should be specified as to fixed or floating: fixed is designated by the suffix “F”, and floating is designated by the suffix “L”.

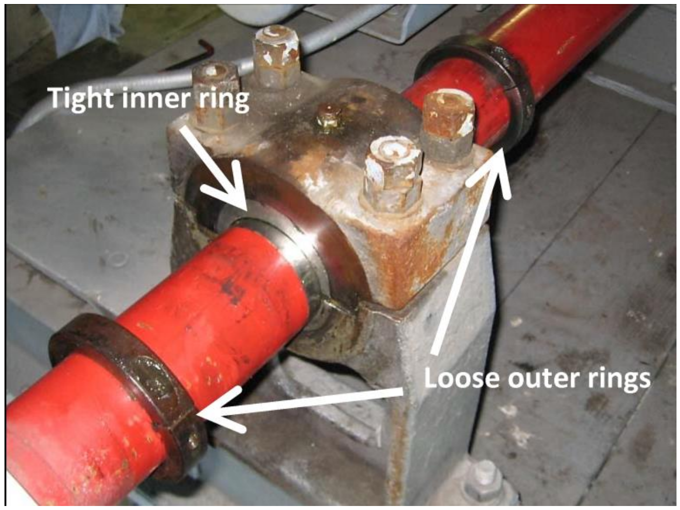


Figure 17.47 Bearing

Several specific types of bearings are discussed below, including:

- Sleeve Bearings or Plain Bearings (for radial motion)
- Roller Bearings
- Linear Bearings
- Thrust Bearings

The type of bearing used depends on many operating factors and how the bearing is going to be used in the operation of the movable bridge. For example, sleeve bearings are generally the most reliable, operate efficiently at high speed, can be repaired, are relatively inexpensive, have a long life and are overall tougher than the other bearings. Roller bearings operate more efficiently and accurately at lower speeds, require no maintenance, and their friction is not set; their friction is lower at lower speeds and higher at higher speeds.

A *sleeve bearing* (also called a *plain bearing* or *journal bearing)* is a fixed cylinder (also called the sleeve or bushing) in which a shaft rotates. The sleeve is usually made of bronze and is held to a fixed point within a steel housing. Housings are usually split in order to accommodate installation, removal of the shaft for repairs, or replacement. The top half is bolted down to the base, and the base is bolted to the structure. The sleeve bearing often has a flange that functions as a thrust surface to hold the shaft horizontally positioned.

Sleeve bearings are common in movable bridge trunnion bearings for vertical lift bridge sheaves and for bascule spans. Due to the high loads, slow operating speeds, and need for lubricant retention (no mechanical seals), grease is most always used. Their size and large bearing clearances provide for aggressive convergence zones that coat ultra-thin films of fresh lubricant into the contact area. An example of a sleeve bearing is shown in Figure 17.48.

Figure 17.48 Sleeve Bearing (Courtesy of NHDOT)

A *rolling-element bearing* or roller bearing is generally composed of a sleeve-like outer ring and several rows of balls retained by cages. The cages were originally machined from solid metal and were quickly replaced by stampings. This bearing type features smooth motion, low friction, high rigidity and long life. They are economical and are easy to maintain and replace. Plain bearings are very similar in design to rolling-element bearings, except they slide without the use of ball bearings. Heavy-duty spherical roller bearings are often used on operating machinery shafts and sheaves, as these elements see higher loads. These bearings are commonly used in trunnion bearings and sheaves. Bearings in vertical lift bridges undergo multiple revolutions in opening and closing the bridge and this increased rotation makes spherical roller bearings the primary consideration for their longer life. An example of a roller bearing is shown in Figure 17.49.

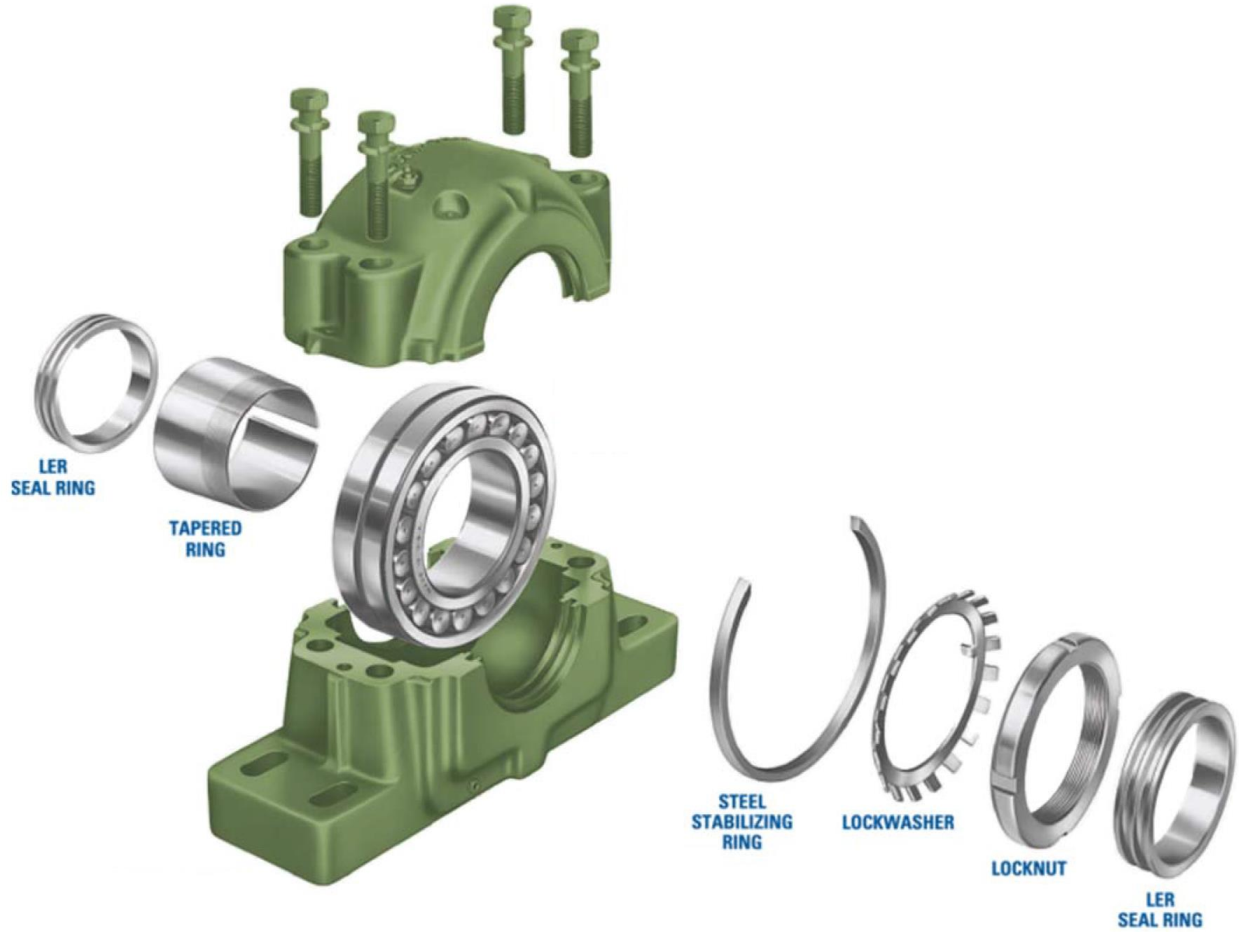


Figure 17.49 Roller Bearing (Courtesy of The Timken Company)

A *linear-motion bearing* or *linear slide* is a bearing designed to provide free motion in one direction. There are many different types of linear motion bearings. These can be rolling element bearing or plain bearing. An example of a linear bearing is shown in Figure 17.50. On a movable bridge, these serve as span guides, centering devices, lifting wedges, toe-locks, or tail-locks.

Figure 17.50 Linear Bearing

Thrust bearings are most commonly used for the larger center pivot bearing used on swing bridges. These large bearings consist of two l discs, one is bronze and the other is steel. The upper disc is a convex shaped while the lower disc is concave shaped with a slightly larger radius of curvature and may have rollers. This slight difference in curvature, amongst other things, provides for a centralized contact area at bearing center with convergence zones surrounding and immediately adjacent. Spherical roller thrust bearings have a higher contact angle resulting in increased stability and thus less sensitivity to seismic or impact loading from vessels or floating debris. An example of a roller thrust bearing is shown in Figure 17.51.

Figure 17.51 Roller Thrust Bearing (Courtesy of The Timken Company)

17.2.3 Electrical Systems

A typical electrical system for a movable bridge comprises four major groups of equipment:

- Power Distribution Equipment
- Electrical Machinery
- Control System
- Lighting Systems

The power distribution equipment includes: electric power sources, protective devices, and distribution equipment. The primary power source for movable bridges is a three-phase electric service from a local utility company. Typical three-phase electric service voltages are 120/240-volt, four-wire systems (usually found on older bridges) and 277/480-volt, four-wire systems. Some bridges may be furnished with ungrounded three-wire 480-volt electric services.

Electric power is supplied to the various motors and electrical equipment through fuses and circuit breakers which serve as protective devices. Fuses and circuit breakers provide overload and short circuit protection to the electrical equipment they serve. These protective devices are housed in panel boards, Motor Control Centers (MCC), and/or enclosed panels.

A panel board contains a group of circuit breakers to distribute power to various electrical devices. Motor control centers house circuit breakers, fuses, motor starters, motor controllers and other equipment required to control and distribute power to motors and other equipment. Motor control centers are modular in construction. In lieu of panel boards and motor control centers, circuit breakers, fuses, motor starters, motor controllers and other motor control equipment may be installed on an enclosed panel. If enclosed panels are used, they are usually custom built for the bridge. An example of a MCC is shown in Figure 17.52.

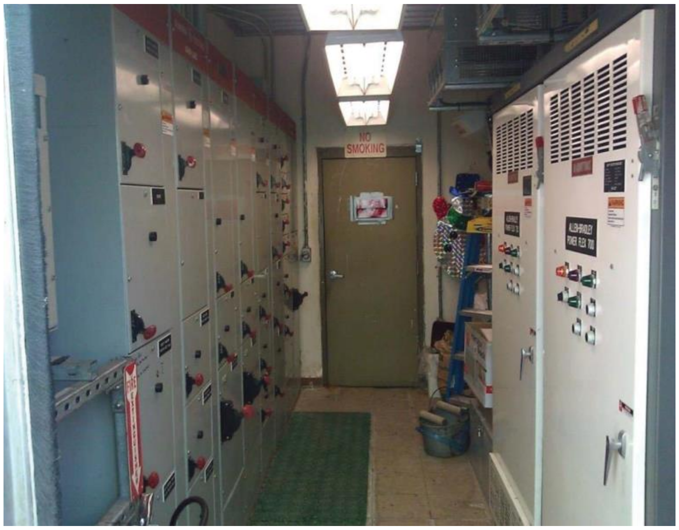


Figure 17.52 Motor Control Center (MCC) (Courtesy of NHDOT)

Electrical circuits are carried from panel boards, motor control centers, enclosed panels and transformers to the electrical devices they supply power to through a raceway system. A raceway system typically consists of rigid metal conduit and junction boxes, an example of which is presented in Figure 17.53. Electrical wires, or conductors, carry electrical current and are installed inside the conduit and boxes that make up the raceway system. Wiring carrying electricity from panel boards, motor control centers, transformers and enclosed panels travels through a raceway system of conduit and junction boxes to the devices to be powered.

Figure 17.53 Example of Electrical Conduit Work Under a Bridge (Courtesy of Kyle Asfahl)

In lieu of a second utility service, a secondary source of electric power can be provided by an engine generator set. An engine generator set utilizes a combustion engine (usually a diesel engine) as a prime mover to operate an electric generator. The generator generates an electric supply with characteristics similar to the utility electric service. An engine generator set may be located permanently at the bridge site or it may be a mobile unit that is brought to the site when needed.

Electrical Machinery refers to electro-mechanical devices that operate the movable span and auxiliary devices such as locks, wedges, and traffic control equipment. The movable span is provided with one or more span motors that serve as the prime mover for the span. Span motors may be of the alternating current (AC) type or direct current (DC) type. Depending on the type motor control equipment employed, the operating speed of the span motors is governed by the bridge operator or by a motor controller. A motor controller provides controlled motor speed and torque to ensure smooth movement of the movable span. The electrical part of span drive is comprised of span motor and motor controller combination.

The bridge operator controls the operation of the bridge and its associated equipment with the control panel, as shown in Figure 17.54. There are pushbuttons, control switches, indicating lights, meters and indicators and often a foot pedal switch mounted on the floor at the control desk. Foot switches can be used to turn electrical equipment on and off with the foot, freeing the hands to perform other operations or providing ergonomic improvement to a workstation. Foot switch applications often require specific electrical ratings, enclosures, pedal actions, cables, and other variations. Typically, foot switches contain single-pull double-throw (SPDT) contacts that are wired "normally open." That is, the switch is “open”, or "off," when not in use.

Figure 17.54 Control Panel

Motor controllers range from simple contactors to motor drives. The equipment may be installed in a panel or motor control center. A standard motor controller consists of a motor protector, a contactor, and a motor overload device. A motor circuit protector is either a circuit breaker or a fuse that has a trip setting to protect the motor controller and motor. An example of a schematic of a motor control system is shown in Figure 17.55.

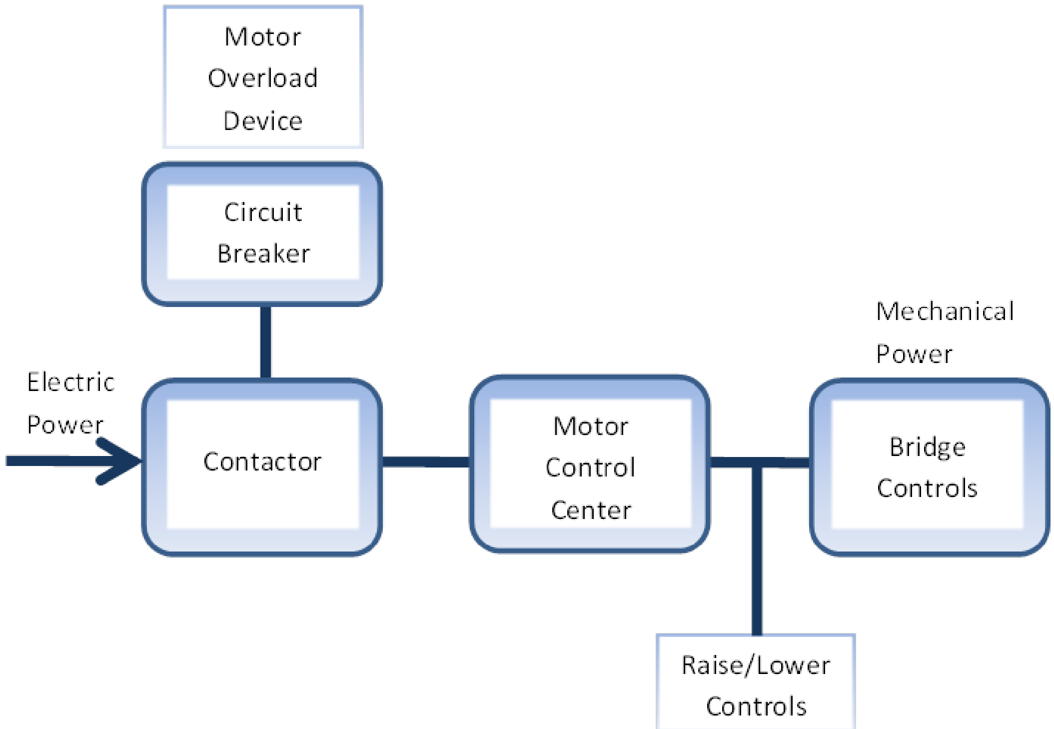


Figure 17.55 Schematic of a Motor Control System

Contactors make or break current to the motor. An example of a contactor is shown in Figure 17.56. When the motor is connected to the current it will operate. When the current is removed, it stops. Contactors may operate the motor in a single direction, or forward and reverse directions. An overload device which is operated by a switch on the MCC is a sensitive, quick acting device that will sense when the motor is drawing too much current and open the contactor to stop the motor. Motor overload devices are intended to be faster in reacting to a motor fault than a circuit breaker or fuse, and more sensitive to minor faults that would not trip a circuit breaker.

Figure 17.56 Drive Motor Contactor

Drum controllers are a common method of motor control on older bridges. Primary drum controllers are used with DC motors and secondary drum controllers are used with alternating current (AC) wound rotor motors. The rotation of the drum controller handle changes the motors speed and direction. An example of a drum controller switch is shown in Figure 17.57.

Figure 17.57 Drum Switch to Control Motor Speed and Direction (Courtesy of Brian D. Luster)

Limit switches regulate the limit of travel for machinery and provide an electrical signal to stop or change operation. The limit switches in routine use include: lever arm, plunger type, rotary, and proximity. An example of a limit switch is shown in Figure 17.58.

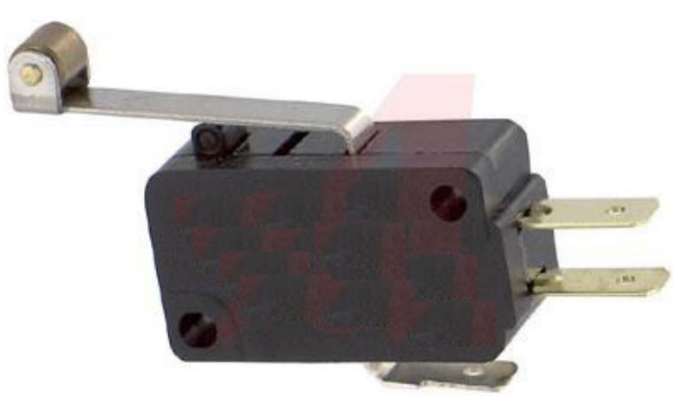


Figure 17.58 Example of a Limit Switch

Relays are low current switching devices that provide logical control of a bridge. They can be used independently or concurrently with a programmable logic controller (PLC) system. Multiple relays are required to provide control for an entire bridge where the relays are generally located in a panel or enclosure. Relays are also used as part of auxiliary systems, such as traffic gates, for control of local equipment.

Programmable Logic Controllers (PLC) processors are computer controllers that provide the logical control of the bridge. They are generally rack-mounted in cabinets in the control room. There may be multiple remote Input/Output (I/O) drops throughout the bridge, an example of which is shown in Figure 17.59. Input/Output, or voltage, drop is a measure of how the supplied energy of a voltage source is reduced as electric current moves through the passive elements (elements that do not supply voltage) of an electrical circuit. Voltage drops across internal resistances of the source, across conductors, across contacts, and across connectors are undesired; supplied energy is lost (dissipated). Voltage drops across loads and across other active circuit elements are desired; supplied energy performs useful work. Since PLC's are computer technology, their processors can use communication networks to transmit information from a remote drop to the main processors. Small switches on the processor and I/O cards called dip switches are configured to allow proper operation. Changing these switches will alter PLC operation. Any changes to PLC dip switches should be done by qualified individuals who are familiar the PLC programing and the logic basis for the particular bridge's operation sequence.

Figure 17.59 I/O Blocks Controlled by the PLC (Courtesy of NHDOT)

Bridges are often equipped with roadway lighting to illuminate the roadway for vehicular traffic. Illumination levels from bridge to bridge may vary depending upon the speed and volume of traffic and local requirements. Roadway lights are typically pole mounted fixtures with an offset mast arm that overhangs the roadway. Roadway lighting on bridges is usually owned, operated, and maintained by a local agency.

Service lighting and receptacles are often provided throughout the structure to enable work and inspection in dark areas or during limited ambient light. Lighting fixtures have various types of bulbs. Receptacles that are exposed to the elements should be covered in compliance with current electrical codes. Service lighting and receptacles are installed to provide light and power to specific areas and equipment, not to illuminate the entire structure.

Warning gates similar to gates used at RR crossings are used to warn approaching cars and vehicular traffic during bridge operation, as shown in Figure 17.60. Warning gates alert the traffic that it must stop and indicate the vehicle exclusion area. The gates are usually equipped with flashing lights that also warn the traffic. Traffic signals, or red flashing lights, are used to initially stop the traffic at a pavement marking (stop bar). Once the traffic has stopped, the warning gates are lowered to exclude vehicles.

Figure 17.60 Traffic Barrier and Warning Gates

The lights should begin operating when the warning signals are activated and operate until the bridge is reopened to traffic. An example of warning signals is shown in Figure 17.61. They should operate from the time the traffic signals initiating bridge opening are activated until the gates are raised.

Figure 17.61 Warning Lights and Gong

Some bridges are equipped with resistance gates or barriers that can physically stop a vehicle that is either out of control or whose driver failed to realize the bridge was opening. Resistance gates are rated for a certain size of car traveling at a certain speed. They may be equipped with flashing lights. An example of a resistance gate is shown in Figure 17.62. An example of a drive motor cabinet for a resistance gate is shown in Figure 17.63.

Figure 17.62 Resistance Gate (Courtesy of MaineDOT)

Figure 17.63 Drive Motor Cabinet for Resistance Gate (Courtesy of MaineDOT)

Gongs (bells) or horns are used to alert the vehicular traffic travelling on the bridge to be alert to traffic signals. They are intended to operate at the beginning and end of a bridge operation. The traveling public expects the bridge to be in the closed position. To prevent sudden and unexpected stops, the gongs aid in making the traveling public aware that traffic conditions are changing. They are used in tandem with flashing lights and warning signs. The gongs should start operating when the warning signals are activated to stop traffic and should continue to operate until the locks, jacks, and wedges are released. They should operate again from the time the locks, jacks, and wedges are engaged until the gates are raised. The gongs should make a loud, audible sound.

Navigation lighting and signals are provided to guide and alert the channel water traffic. An example of is shown in Figure 17.64. Red lights mounted on the piers or fenders mark the channel for the boats to pass through. Alternating red and green lights mounted on the span notify the boat operator that the span is either not fully open (when the light is red) or is fully open and it is safe to proceed (when the light is green). Lights are installed in accordance with Coast Guard standards and guidelines. Proper maintenance of the navigation lights is essential for the safety of the waterway traffic. An air horn or similar audible device is used to warn the water traffic that a bridge operation is about to start. It is sounded before opening bridge.

Figure 17.64 Navigation Lights

When evaluating switchboard for maintenance needs, two checks should be undertaken. First, the lights on the control panel should be activated to verify their operation. Usually, there is a switch or pushbutton that will test all the indicator lights on the panel. Any light that operates improperly should be noted and scheduled for repair. The bridge should also be operated several times to verify that all pushbuttons, control switches, indicating lights, meters, and indicators operate properly.

17.2.3.1 AC and DC Motors

Span motors may be alternating current (AC) type or direct current (DC) type. An example of a motor is shown in Figure 17.65. Depending on the type of motor control equipment employed, the operating speed of the span motors is governed by the bridge operator or by a motor controller. A motor controller provides controlled motor speed and torque to ensure smooth movement of the movable span.

Figure 17.65 Motor

AC motor design is comprised of three windings contained in the stator, or stationary part of the motor that drives a rotating shaft, called the rotor. The AC current drives the coils, causing them to develop rotating magnetic fields. A changing magnetic field generated by AC voltage causes a rotor in the AC motor to spin around the motor shaft. An example of an AC motor is shown in Figure 17.66. The photo is a cutaway of an AC motor so that the specific elements can be identified.

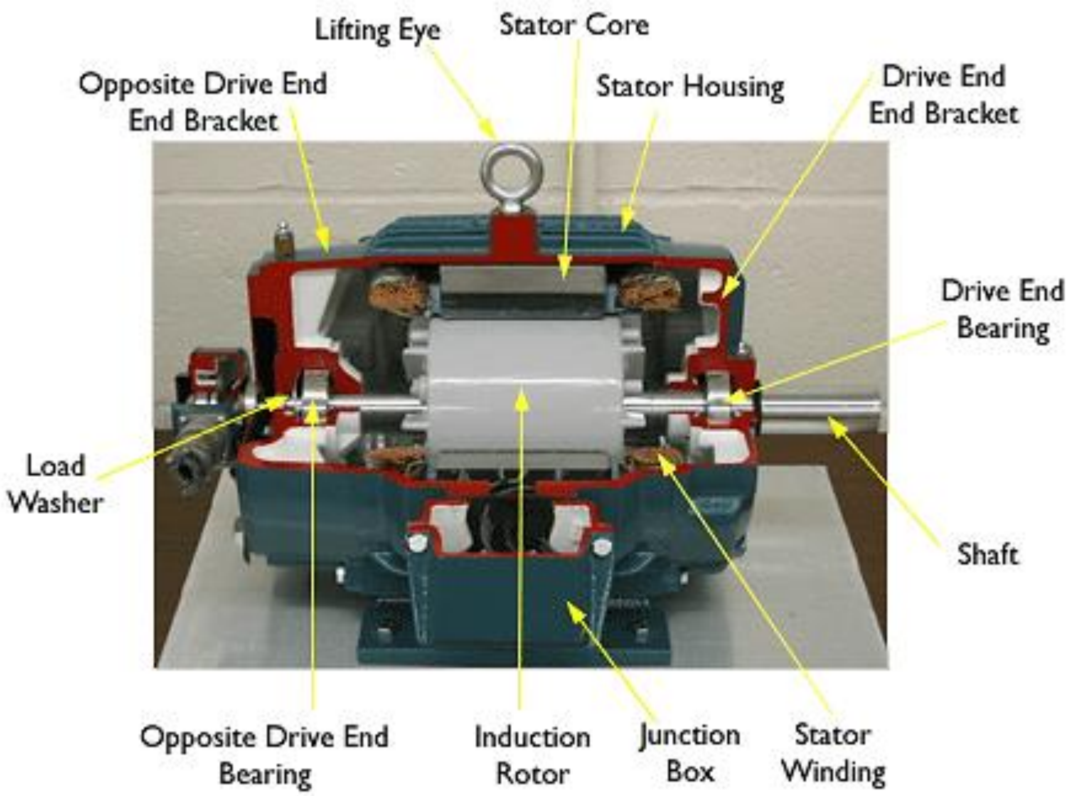


Figure 17.66 AC Motor Cutaway (Courtesy of Darby Electric Co., Inc.)

Probably the most common type of electric motor used as the prime mover in movable bridge drives has been, and still is, the AC wound rotor induction motor. Its most notable characteristics are its high starting torque and the variety of speed/torque settings (which can be altered in the field). Most movable bridges applications that use AC motors will use either NEMA Type D or Type M motors depending on the type of speed control used for span operation.

AC motor speed control involves the use of AC inverter drives, which in turn require relatively expensive electronic parts. Typical AC motors should not operate at less than approximately one-third of the motor's base speed due to thermal reactions in the motor.

DC motor designs include a magnetic field generated by the motor stator by either electromagnetic windings or permanent magnets. In a brushed-type DC motor, a set of permanent magnets form the stator and a set of coils sit on the rotor. Direct current, switched between the coils, creates a repulsive force against the permanent magnets, turning the rotor. An example of a DC motor is shown in Figure 17.67. The photo is a cutaway of a DC motor so that the specific elements can be identified.

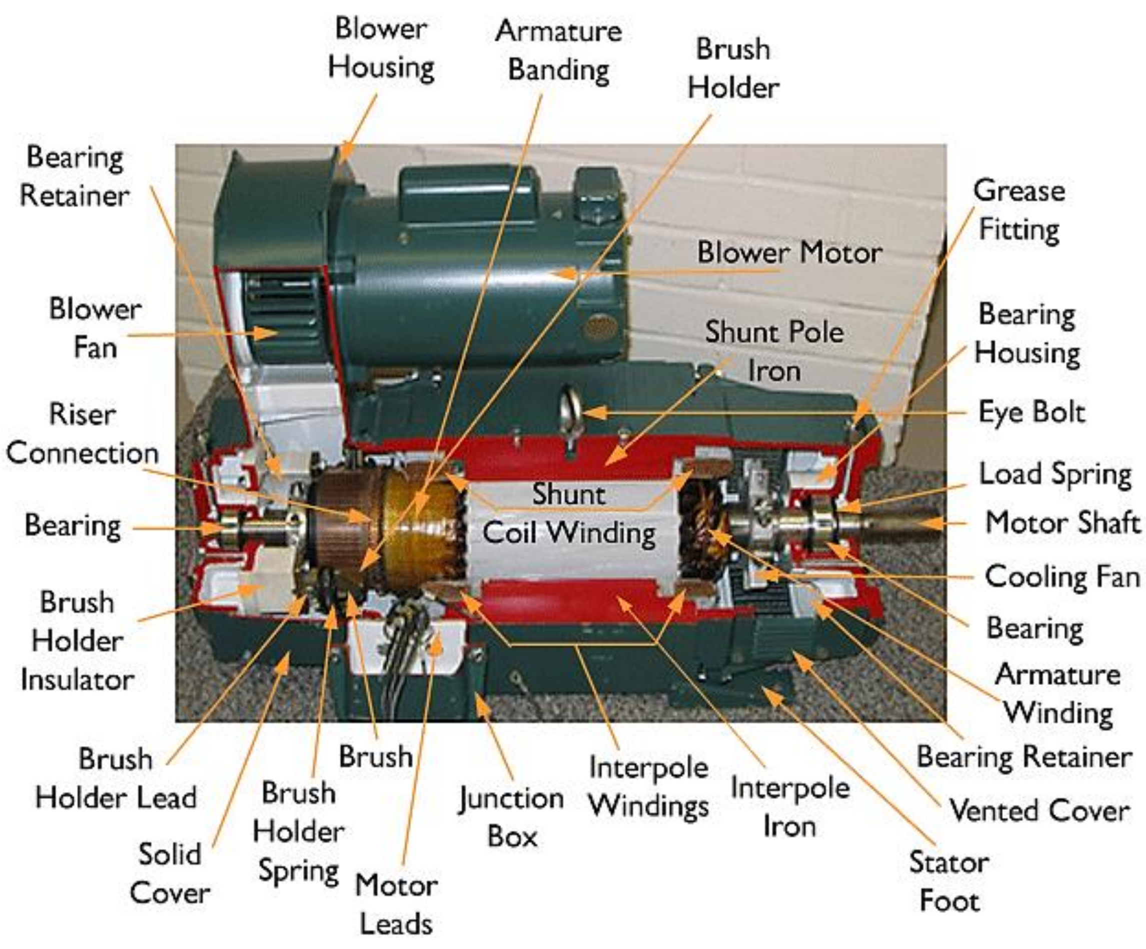


Figure 17.67 DC Motor Cutaway (Courtesy of Darby Electric Co., Inc.)

Series DC motors are used in movable bridges because of their high starting torque. They are best used for loads that require a lot of initial power to set the machinery in motion. This eliminates the need for two separate units (one to start the load and the other to keep the load moving). This type of motor is classified as a constant speed motor; constant speed motors are some of the easiest motors to control. If the load slows down, the current in the rotor goes up. Since the rotor and field coil are wired in series, the field coil current will go up too. This increases the torque of the motor and its ability to return the load to the correct speed. They will speed up if the input voltage is increased and slow down if the voltage is decreased. DC series wound motors have a high power-to-weight ratio. This helps to reduce installation costs and provides for space savings.

Pulse width modulation is also an effective method of speed control for this type of motor. This method controls motor speed by changing the amount of time during which power is applied to the motor.

17.2.3.2 Interlock System

Sensors, triggers, and switches refer to devices designed to prevent the initiation or continuation of particular movements of the span. For instance, sensors are triggered with a traffic gate that fails to make contact with its strike plate, or if the loading becomes unbalanced, or if the wiring /conduits have failed. Examples of switches and sensors are shown in Figure 17.68 and Figure 17.69.

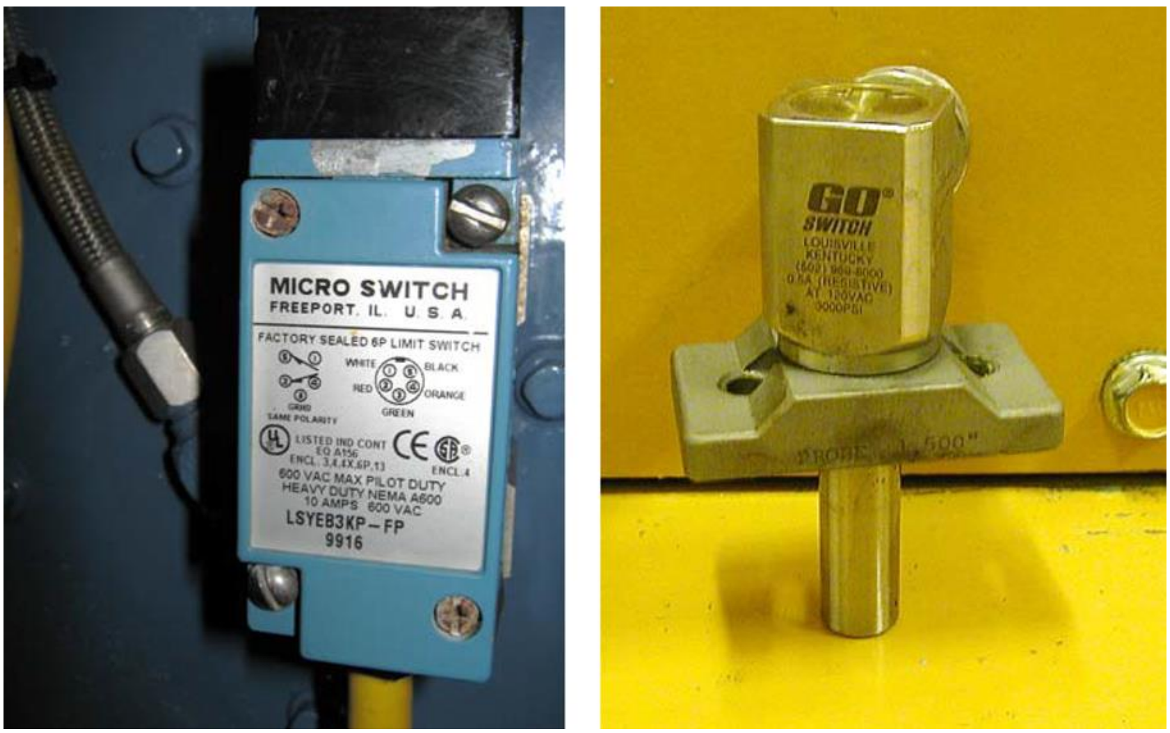


Figure 17.68 Examples of Switches (Courtesy of MaineDOT)

Figure 17.69 Limit Switch Indicates Machine Brake Position (Courtesy of NHDOT)

The bridge failing to operate is usually caused by an element of the control circuit indicating that "it is not safe to operate". In other words, a safety circuit is preventing operation. These safety circuits or "permissives" are embedded within the operating sequence of the control system, which performs checks to assure that specific actions have occurred in the proper sequence. An example of a permissive circuit for a swing bridge is assuring that the wedges have been fully retracted and the rails lifted prior to rotating the span. The devices which tell the control system that certain actions have occurred are generally limit switches. Mechanical failure of a limit switch often results from the contact arm or its support becoming damaged such that the switch does not operate mechanically. These failures are caused by corrosion, misalignment of other equipment, or inadvertent damage. Any mechanical failures should be immediately repaired. If the device failure does not cause the bridge to become inoperable (e.g., the circuit can be by-passed), the impetus to perform the repair is greatly reduced. It should be noted that by-passing safety circuits becomes an opportunity to cause severe damage and impact safety.

17.3 Preventive and Basic Maintenance of Movable Bridges

Maintenance costs for movable bridges are considerably higher than that of a fixed bridge, because (1) movable bridges have moving parts subject to additional wear, as compared to a fixed bridge and (2) by their nature, movable bridges are closer to the water and subject to more moisture than fixed bridges. Deterioration is the primary concern since they are located over waterways, and often close to the coast, which constitute conditions suitable for corrosion, causing section losses. In addition to the usual deterioration mechanisms of all bridges, movable bridges can experience operational failures. Operational failures are typically the result of misalignment, poor maintenance practices, bearing and gear wear, and trunnion scoring. One study attributed more than half of all failures were the result of improper actions taken by the maintenance staff. The improper actions were categorized as:

- Performing a temporary repair instead of a permanent repair
- Failure to install all covers and guards
- Making a system modification without documenting the change
- Incorrect diagnosis of the problem

- Bypassing of the interlock system

Deterioration and damage is also observed due to moving parts, friction, and wear of the structural and mechanical components. Fatigue can be a problem due to the reversal or the fluctuation of stresses as the spans open and close. Breakdowns cause problems for both land and maritime traffic. Maintenance staff needs to understand how the bridge systems function together so that they can identify potential equipment overload conditions. As an example, if the span is improperly balanced, the motor drives may not have the capacity to accommodate the new loads. There have been cases where back-up drives (motor controls) were not of sufficient capacity when span weights were changed.

Just as serious structural deficiencies may lead to localized failures or collapse of a bridge, mechanical and electrical defects can cause a movable span to become unstable in either, or both, the closed or open position. Serious defects of the span drive or stabilizing machinery should be reported in a manner similar to structural deficiencies. A movable span may be unstable in any position (open, closed, or in-between) due to defects in the span drive or stabilizing machinery. Much depends on the type of movable bridge and redundancy of the overall system. Because of the variations in movable bridge design, no firm rules can be set down. It is a matter of analyzing each situation.

Preventive maintenance takes the form of those tasks which must be performed to keep the movable bridges in operation. The following general tasks should be performed on a regular basis to ensure that a movable structure is in proper working order:

- Greasing of Gear Trains, Bearings, and Other Movable Parts: This task should be done often (based on the number of openings or manufacturer's recommendations for each mechanical component) to insure that the bridge lifting and locking mechanisms are properly lubricated. An inspection of the components, such as motors, gears, tracks, shafts and linkages, overspeed controls, and brakes should be done frequently. The most common causes of machinery malfunctions are the result of insufficient lubrication and a loss of bolts due to vibration. Each movable bridge should have a specific Operations and Maintenance Manual detailing the preventative maintenance items, including a detailed lubrication schedule and specifications, which should be performed on a regular basis.

Recommendation

An inspection of the components, such as motors, gears, tracks, shafts and linkages, overspeed controls, and brakes should be done frequently.

- General Housekeeping: Make sure all lubricant leaks or spills are cleaned up and that waste materials are properly disposed of. Pools of lubricants or piles of waste materials pose a trip hazard to maintenance personnel. Examine every portion of the bridge where water can collect. All pockets that are exposed to rain and snow should have a removable cover. Debris, birds, animals, and insect nests in the throughout bridge should be removed.

- Personnel Safety: Machinery and brake covers should be replaced and fastened promptly after completion of routine maintenance. Each bridge should have a site specific lockout/tag out procedure for electrical and machinery components to ensure safety during maintenance.
- Cleaning Stringers and Floor beams on Open Grid Decks: Cleaning of these superstructure components should be done in each spring using pressure waters (3,000 psi) and shovels to break up the dirt and clean the stringers and floor beams on the open deck bascule bridges. This cleaning will help reduce the amount of extra weight on the lift span to maintain proper balance, as well as reduce the amount of deterioration of the structural framing members. Certain bridges see a greater amount of debris accumulation than others; therefore these bridges may need to be cleaned more frequently.
- Cleaning of the Counterweight Pits and Sump Pumps: Pits should be pumped dry and regularly cleaned of debris. Debris and water accumulate quickly and contribute to the deterioration of the concrete pit walls and the deterioration of the steel superstructure. Where sump pumps exist, the intakes should be cleaned of debris to ensure they will not clog. All drainage elements, including the counterweight pocket weepholes should be free from debris.
- Maintenance Painting: Maintenance painting, overcoating, and total paint removal should be performed on a regular basis to prevent deterioration of mechanical and structural elements. Overcoating and maintenance painting can be done by bridge maintenance crews; however, maintenance workers should always consult an engineer before painting mechanical components to ensure that paint will not have any detrimental effects on the operation of the machinery. An example of a painted over limit switch on a brake assembly is shown in Figure 17.70. Total removal and re-coating is typically done by contractors. Refer to Chapter 18 for more information on coatings and painting.

When to Call the Engineer

Consult an engineer before painting mechanical components to ensure that paint will not have any detrimental effects on the operation of the machinery.

Figure 17.70 Painted Over Limit Switch on Brake Assembly

- Reliability Testing: Reliability testing of bridges should be done in advance of periods when there will be more frequent bridge openings to allow for adjustments to the bridge limits which insure proper operation for opening and for center and heal locks. This will help to avoid problems when there is higher demand for the bridge to be operated. At a minimum, reliability testing should be done at each biennial inspection. Gates should be checked and repaired if necessary. Live load bearings should be cleaned, shimmed, and checked for proper adjustment at the anchor columns.
- Maintaining Operational Lighting: All lighting on the bridge should be operational to ensure safe operation of the bridge and to ensure the safety of the traveling public and maintenance personnel. Replace burnt out bulbs and remove moisture from lens covers, as required.

17.3.1 Open Gears

What To Look For

- Scoring or gouges in teeth of gears
- Cracks at root of gear teeth
- Uneven grease patterns across the tooth width at the pitch line
- Excessive machinery noise during operation
- Coupling failures
- Excessive lubricant leakage
- Machinery vibration
- Deformation of teeth

The open gears are the main gears, which are part of the leaf main girder and receive the torque from the rack and pinion assembly. Excessive strain, out-of-plane rotation and misalignment are common problems for open gears. Routine maintenance is required on the gear teeth. Unless they are kept lubricated at all times, wear and corrosion due to grinding of the rack and the pinion will occur. Another concern is the loading sequence. When the drive shafts begin to advance in a delayed sequence, there can be an adverse effect on the open gears, causing impact loading. Sequence control is the method by which starters are connected so that one cannot be started until the other is energized. This type of control is required whenever the auxiliary equipment associated with a machine, such as high-pressure lubricating and hydraulic pumps, must be operating before the machine itself can be operated safely.

The teeth of all gears should be smooth at the contact area. Scoring or deep gouges are signs of deterioration of the tooth surface. The root of each tooth should be free of cracks (this is the area of highest bending stress). An example of visible wear on gear teeth is shown in Figure 17.71.

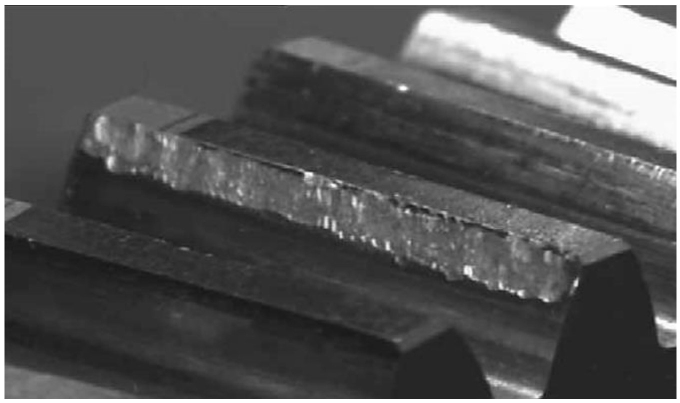


Figure 17.71 Worn Gear Teeth

Visible patterns in the grease after operation should show even contact across the full tooth width at the pitch line. (The pitch line is the ideal line in the rack and pinion assembly where the gears mesh so that the gears move in opposite direction and at the same speed). If the pattern is heavier on one edge of the tooth, or the pattern is not along the pitch line, it indicates that the shafts are not parallel to one another. If the grease patterns indicate misalignment, the degree of misalignment should be determined. Misalignment is determined by measuring the backlash between the mating gears.

In gears, alignment is defined by gear mesh, backlash and angular misalignment, or tooth contact. Bevel gears are conically shaped, as shown in Figure 17.72, and are most often matched with a rack set at an angle (commonly at 90 degrees) to the bevel gear. Bevel gears on movable bridges are commonly out of alignment. Common misalignment problems are indicated by a heavy contact at the heel portion of the tooth or at the toe portion of the tooth. Most likely, the shafting is not aligned so that the gears are at a true 90-degree angle with respect to each other.

Figure 17.72 Bevel Gear

Misalignment is easily identified in extreme situations but can be quite difficult to spot when it is less severe. Indicators of misalignment are excessive machinery noise as the machinery operates, the binding of the shafts, elevated heating or failures at the couplings, excessive lubricant leakage from the bearings, vibration of machinery components (particularly shafts), loose mounting bolts, extreme or rapid wear of gears (plastic deformation of teeth). Excessive noise can stem from a lack of lubricant or machinery that has experienced a respectable degree of wear and needs a thicker lubricant.

17.3.2 Closed Gearing (Speed Reducers)

What To Look For

- Adequate lubricant levels
- Leaking lubricants
- Abnormal leaking
- Abnormal vibration

The gear box/transmission/speed reducer contains the assembly that transmits the torque generated by the motor to the shafts. The gear box is equipped to provide the necessary amount of oil to the various gear meshes and bearings. The gear boxes should be checked for the proper amount of lubricant and signs of leaking. An example of a closed gear box (reducer) lubrication gauge is shown below in Figure 17.73, whereas an example of a leaking speed reducer (closed gear) is shown in Figure 17.74.

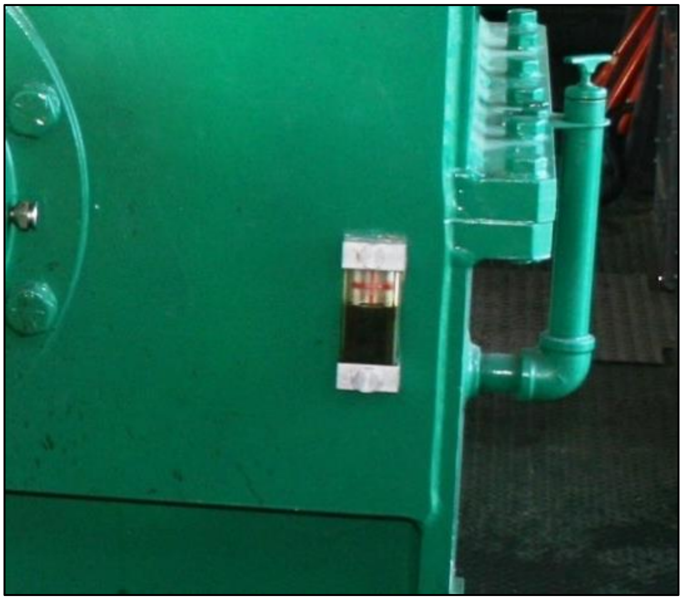


Figure 17.73 Closed Gear Box (Reducer) Lubrication Gauge

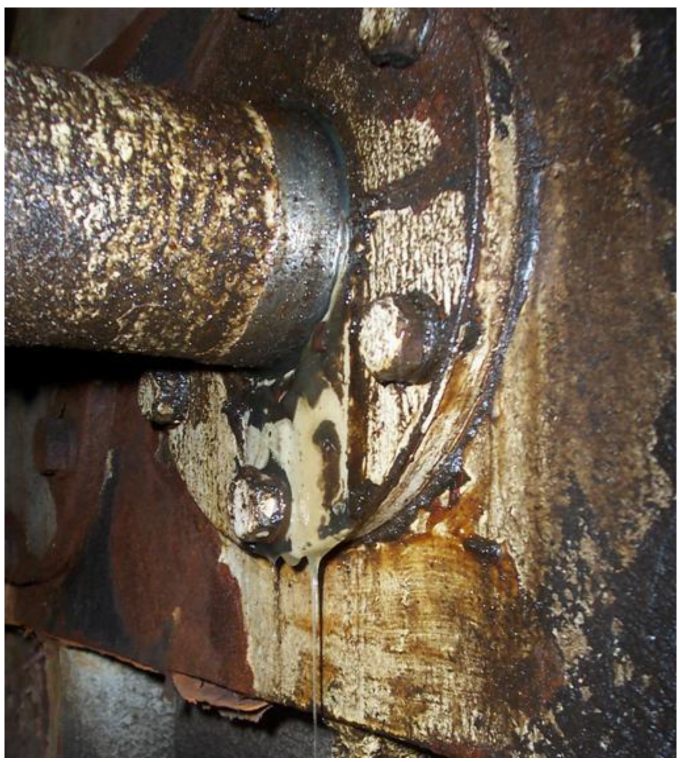


Figure 17.74 Leaking Speed Reducer (Closed Gear)

When the speed reducers experience deterioration and/or lack of lubrication, some change in the vibration and sound characteristics during the bridge operation may be heard. Abnormal vibration is an indicator of wear in the gears. The viscosity of the oil is an important parameter for proper functioning of the gearbox. The manufacturer's recommendations should be followed for changing the oil.

17.3.3 Shafts and Couplings

Shafts undergo significant twisting and strain and are subject to misalignment with other parts of the machinery system. Cracks, if suspected, may be detected using Non-Destructive Evaluations (NDE) such as magnetic particle or dye penetrant.

The coupling hubs, housings, and bolts should be free from leaks and in good condition. See Figure 17.75 for an example of a leaking gear type coupling.

Figure 17.75 Leaking Gear Coupling

17.3.4 Bearings

What To Look For

- Warm or hot bearings. If bearings get warm or hot during operation, it may be an indication of inadequate lubrication or bearing wear.

A common mechanical component to fail on movable bridges is the bearings. Gears fail because their bearings failed. Mechanical failures are generally detected by abnormally loud operating levels, component failure (gears or shafts), or irregular/intermittent operation. The most common cause of gear failure or abnormal wear is misalignment. Gear misalignment results from bearing clearances becoming excessive.

Bearing clearance is the gap between the shaft and the bearing liner. A rule of thumb for this clearance is 0.001 inches per inch of shaft diameter. For example, a 6 inch shaft should have 0.006 inches of clearance between the shaft and the bronze bearing liner. This clearance can be easily measured by the use of feeler gauges. As bearings wear, this gap increases, thus changing the alignment of mating gears and/or couplings. For a bearing to achieve optimum life it requires a lubricant that sufficiently separates the rolling surfaces. The effectiveness of the lubricant is primarily determined by the degree of separation between the rolling contact surfaces. To form an adequate film, the lubricant must meet the specified minimum viscosity at the bearing operating temperature. This minimum required viscosity is primarily determined by the bearing size and rotating speed. Lower speeds require higher minimum viscosities.

The bearing housings, pedestals, and supports should be free from cracks and leaks. The bolts in housings and those used for anchors should be tight and free of corrosion. Grinding noises and vibration can be caused by the lack of lubricant.

In sleeve bearings, bushings should be inspected for damage and excessive wear. Sleeve bearings require lubrication at the sliding surfaces of the shaft and the bushing. Normally one or more grease fittings are located at the top of the housing. A path is drilled through the housing and bushing and meets with grooves machined into the surface of the bushing. The groove is usually in a spiral pattern, which helps to lubricate the entire surface of the journal. During lubrication, confirm that old grease is squeezed from the exit ports. Clearance between the shaft and the bushing should be measured using feeler gages. The bearing housing should remain cool to the touch during operation. Any heat generation may indicate improper lubrication or damage to the bearing.

Typically heavy-duty roller bearings are used to transmit power. An example is shown in Figure 17.76.

Figure 17.76 Heavy-Duty Roller Bearing on Bascule Bridge

Lighter duty ball bearings are commonly used for instrumentation that drives electrical control feedback devices. In general, the clearances of the bearing are set during installation, and the unit is sealed for operation. Little wear occurs at these bearings, so wear measurements are not required. Indications of potential problems or failure of roller-type bearings are overheating, unusual noises and shaft or bearing vibration. Contributing factors to failure include too much or inadequate lubrication, dirt, rust or foreign materials in the bearing, a faulty ball or roller, seal failure, and loss of clearance or preloading. Antifriction bearings should operate smoothly and quietly during operation.

Sleeve-type bearings and roller-type bearings should not leak oil; an example of a leaking bearing is shown in Figure 17.77. Check the seals, mounting bolts, and housing for leaks, loose connections, cracks or damage. The oil level should be checked using the external level gage or the portal in the housing. Fill the reservoir as required with the specified lubricant. During operation, listen for any abnormal noises. The bearing housings should not be hot to the touch.

For spherical roller bearings grease is recommended in virtually all bridge applications. For the main trunnion bearings for bascule bridges and the main sheave bearings for vertical lift bridges, greases with a calcium sulfonate thickener are recommended. This thickener provides excellent corrosion and water resistance as well as extreme pressure protection under boundary lubrication. Greases that use molybdenum sulfide should be avoided since this additive can become corrosive in the presence of moisture. For spherical roller thrust bearings used for the center pivot bearing in swing bridges, oil lubrication is generally recommended since the bearing can be filled entirely with oil without relying on seals to retain the oil.

Figure 17.77 Leaking Sleeve Bearing

In general, maintenance of the trunnion bearings (see Figure 17.78) is the same as for bearings. The alignment of the trunnion is critical to prevent premature wear of the trunnion bearings and to reduce out-of-plane web distortions that introduce fatigue damage. Misalignment in the trunnion axis can cause additional load on the trunnion-hub assembly and distress on the main girder plate, causing distortions, and eventually web buckling. Trunnion misalignment is also a major cause of wobble that can result in mismatch of the leaf tips, disturbing regular operation. In-depth assessment involves disassembly of the bearing caps and dye-penetration, magnetic particle, and/or ultrasonic testing of the shaft fillet by a trained professional.

Figure 17.78 Example of a Trunnion Bearing (Courtesy of MaineDOT)

17.3.5 Brakes

Braking devices should be checked for the proper setting of the braking torque and to ensure for the complete release of the brakes when actuated. An example of a braking device is shown in Figure 17.79. Brake drums and shoes wear out, corrode, become misaligned and stick. Hydraulic disc brake systems should be free from leaks. Check the brakes, limit switches, and stops (cylinders and others) for excessive wear and slip movement. Observe the surface of the brake drum for indications of contact with the brake shoes. Check the pressure developed by each disc brake power unit to be sure the brakes are releasing. Also check the manual release on all of the brakes.

Figure 17.79 Brake Assembly Exhibiting Moderate Brake Dust Accumulation

Brakes should be equipped with covers, to prevent debris or grease from affecting brake operation. Grease, oil, water, and dirt in the brake drum will reduce the braking capacity and facilitate corrosion. Heaters or heated enclosures can also be installed to eliminate corrosion caused by condensation. During a bridge operation, time the length of operation for the brake to fully release and the brake to set while monitoring the brake shoe and drum. If the shoe and drum are not aligned, they will come into contact during operation. This contact could produce smoke and damage the brake.

If the brakes are not operating in the correct timing sequence, wear can increase dramatically. The brakes generally specified are designed for duty well beyond what is experienced on a movable bridge. In other words, when they wear out it is because of either mis-adjustment or a problem with the sequencing of when they are applied. A properly adjusted brake should have even clearance between the brake shoes and the drum when the brake is released. This clearance depends upon the brake drum size (check with the manufacturer) but can be easily checked with a feeler gauge. If the brake drum surface is corroded, then the coefficient of friction between the pads and the drum will not be the intended value. The brake torque setting should be checked every few years such that they are properly adjusted. See Figure 17.80 for a brakewheel that exhibits excessive wear grooves.

Figure 17.80 Close-up of Brakewheel Showing Significant Wear and Deep Grooves

17.3.6 Air Buffers

Air buffers should be checked for corrosion of the exterior housing and the connectors. Additionally, the buffer pistons should be observed on a regular basis to make sure they descend during operation of the bridge. The pressure in the buffers should be checked periodically to ensure that there are no leaks in the piping and that the buffers are providing adequate absorption during seating of the span.

17.3.7 Locks

The toe locks and tail locks (if used) on double-leafed bascule spans, and the end locks on single-leaf bascule bridges, swing bridges, and vertical lift bridges should not have excessive deflection. Span locks are some of the members that often fail due to deterioration or incorrect operation. Check the locks for fit and for movement of the span or leaf (or leaves). Check lubrication and for loose bolts. Verify that the lock housing and its braces have no noticeable movement or misalignment. The paint adjacent to the locks will have signs of paint loss or wear if there is movement. Check lock bars, movable posts, linkages, sockets, bushings, and supports for damage, cracks, wear, and corrosion. An example of a corroded span lock is shown in Figure 17.81.

Figure 17.81 Span Lock Rusting due to Aged and Contaminated Lubrication

Check all rear locks in the withdrawn position for clearance from the path of the moving leaf as it opens and for full engagement when the leaf is closed. Examine the gap, if any, between the locking bar and the receiving slot for sloppiness. Adjustments may need to be made if the gap does not allow for smooth operation. If the locking unit is hydraulically driven, check for leakage of oil and operation for correct length of movement of the lock.

On bascule bridges, see if the live load bearings fit snugly. Also observe the fit of tail locks at the rear arm and of supports at the outer end of single-leaf bridges.

Examine actuators for operational characteristics, including leakage if hydraulic. Note both the quantity and quality of the lubricant. Check for alignment, and analyze the type of wear that is occurring.

17.3.8 Steel Counterweights and Auxiliary Counterweights

The counterweights should be inspected for corrosion of the steel components, especially the connections to the other mechanical components (pin plates at the connections to the counterweight ropes on vertical lift bridges and the connections to the girder/truss leaves on bascule bridges). Steel members that pass through or are embedded in the concrete of the counterweight are subject to corrosion. An example of section loss of a counterweight support member is shown in Figure 17.82.

Figure 17.82 Section Loss Repair of Steel Frame Connection with the Counterweight

Additionally, concrete counterweights should be checked for excessive spalling that could affect the span balance of the structure. Most counterweights have hollow pockets or areas where extra concrete balance blocks or metal plates are located to provide additional counterweight. These areas should be inspected periodically to ensure that there is not accumulation of water and that there is not excessive deterioration of the concrete balance blocks or metal plates. Counterweights should move freely with no obstructions.

17.3.9 Live Load Bearings and Strike Plates

Live load bearings and strikes plates should be checked regularly for corrosion and should be free of excessive debris accumulation. Inspect live load supports periodically for proper alignment and proper bearing during seating, see Figure 17.83 for nonbearing support. Improper bearing of the live load supports could mean that the span is not properly balanced and may lead to overstress of the other bearing components. Expansion live load supports should move freely when bridge is not in the seated position. Figure 17.84 shows a frozen live load bearing on a vertical lift bridge.

Figure 17.83 Fixed Live Load Support Bearing Not Fully Engaged in Seated Position

Figure 17.84 Frozen Expansion Live Load Support

17.3.10 Wire Ropes

The wire ropes that support the counterweights and lift span on vertical lift bridges should be greased regularly as part of a routine maintenance schedule. Additionally, the wires should be inspected periodically for corrosion or broken strands. The wires should also be checked for wear or flattening of the strands caused by contact with the sheaves or operating drums during operation. Overloading of the movable span can lead to accelerated wear and flattening of the wire rope strands, as shown in Figure 17.85.

Figure 17.85 Flattened Wire Rope Strands

17.3.11 Counterweight Sheaves and Operating Drums

Counterweight sheaves and operating drums should have adequate lubrication and should be cleaned and re-lubricated on a regular basis. Any corrosion or wear should be addressed and debris removed. Check the sheaves and drums for indications of rubbing between ropes and between ropes and grooves.

17.3.12 Span Guides

Lubricate span guide rollers regularly to ensure proper rotation along the span guides. Check rollers periodically for flat spots or wear of the roller. Span guides should be should be checked periodically for wear, which can be a sign of an improper alignment of the span or lack of proper lubrication. Figure 17.86 shows a span guide roller that has been painted over so that the free rotation has been impeded. Note that all span guide rollers may not always be in contact with the guides. For instance, lateral span guide rollers on vertical lift bridges will only come into contact with the guides under a heavy lateral (wind) loading.

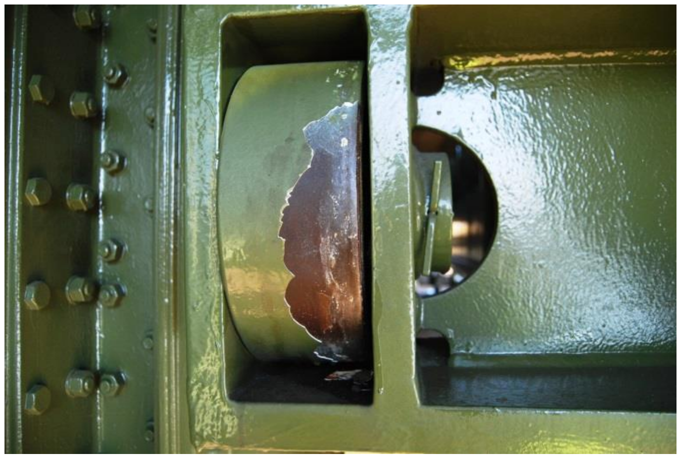


Figure 17.86 Painted Over Span Guide Roller Impeding Free Rotation

17.3.13 Tread Plates and Racks

Tread plates and racks should be inspected periodically for deterioration and cracks due to overstress and for overall alignment. Special attention should be paid to the gear teeth, as these elements see the highest stress. An example of worn teeth on a rack is shown in Figure 17.87.

Figure 17.87 Worn Teeth on a Rack

Figure 17.88 and Figure 17.89 show a tread plate pocket and corresponding tread plate tooth on a Scherzer bascule bridge that has become worn and rounded along the edge due to a misalignment of rack relative to the tread plate. Ensure that elements are properly greased to prevent corrosion and grinding of the components.

Figure 17.88 Excessive Wear of Curved Tread Plate Pocket

Figure 17.89 Excessive Wear of Tread Plate Tooth

17.3.14 Traffic Barriers

The traffic barriers should be maintained regularly to ensure proper operation, as these elements are essential to public safety. Ensure that elements requiring lubrication are properly greased and that broken or damaged elements are replaced. Cabinets housing electrical wiring should be kept clean and free of water and debris. Replace all burnt out or broken lighting components.

17.3.15 Electrical System

The electrical system for a movable bridge is quite complex. When a short circuit occurs, the electrical circuit for the bridge is effectively changed to an unknown configuration. Electrical equipment tends to fail for several reasons: the equipment is overloaded due to a mechanical or structural failure, the insulation of conductors has broken down resulting in a short circuit, loose connections have caused an overheating condition, or the equipment is past its useful life.

One of the most common failure modes on movable bridges is insulation failure resulting in short circuits. This situation usually occurs due to wear, breaks, or corroded conduit which exposes the conductors to heat and moisture. Dirt and debris can trap moisture which leads to the breakdown of insulation. A preventive maintenance action is to vacuum out all electrical cabinets on an annual basis. Insulation quality can be tested using a megger insulation test. This test needs be carefully used as current is passed through the conductors. This test also requires that the bridge electrical system is de-energized (effectively closed to marine traffic). These tests are appropriate for large conductors where a failure would cause an extended outage.

Figure 17.90 Twisted Droop Cable with Exposed Wiring

Vibrations that occur on a bridge will cause the terminals to loosen over time. Loose terminals will cause heating in the wires and reduce the useful life of the equipment. Compression terminals traditionally have the least resistance to vibration and the wires will sometimes become loose and even fall off the terminal strips. Ring-tongue terminals provide the best resistance to vibration, as the compression screw travels through the ring on the cable. If the screw becomes loose, the ring will still maintain contact. Examples of compression terminals and ring-tongue terminals are shown in Figure 17.91.

Figure 17.91 Examples of Compression Terminal (left) and Ring-Tongue Terminals (right)

An example of a ring tongue terminal assembly is shown in Figure 17.92.

Figure 17.92 Ring-Tongue Terminal Assembly

When a broken conduit is found, it needs to be repaired immediately (repair does not include electrical tape nor wire nuts). Loose connections result in greater resistance through the connection which results in heating of the connection. The heating and cooling cycle results in the connection becoming looser until it fails or overheats causing a small fire. Ongoing minor maintenance will maintain safety circuits in a state of good repair, significantly reducing failures or interruptions. When corroded or broken electrical conduit is not immediately repaired, moisture will accumulate and the wire (conductor) insulation will deteriorate until a short circuit occurs. Short circuits on movable bridges are very dangerous because the bridge controls can effectively become rewired into an unknown configuration (causing equipment to operate when it is not intended to operate). It is not uncommon for a short circuit in one location to cause failures throughout the control circuitry. Figure 17.93 shows an aerial cable junction box where the aerial cables have slipped down inside box several feet placing stress on the conductors and terminal strips. Using recommended electrical conduit and connections will prevent this type of problem.

Figure 17.93 Aerial Cable Junction Box Where the Aerial Cables have Slipped

The electrical motors generate the torque required for the opening and closing of the bridge. Some of the indicators for improper functioning of the electrical motors are high amperage, high temperature, high vibration level and high revolution speed. The operation of each motor should be observed during opening. Motor shafts should be checked to determine if there is normal end play. Motors should be examined to verify that they are smooth running and free from vibration. Motors and bearings should be checked for overheating. Any unusual noises generated during operation should be noted. If the motor is fan cooled, check for proper operation of the fan and that the motor is being properly cooled.

Brushes in electrical motors are subject to friction and wear. They eventually wear out and need replacement. Wound rotor alternating current (AC) motors, synchronous AC motors, and direct current (DC) motors use brushes to carry current to rotating parts of the motor. All brushes should be inspected for wear. Each brush holder should be set so the face of the holder is approximately 1/8 inch from the collector-ring. When removing brushes, be sure to reinsert them into their original holder and in its original orientation. Marking on one side of the brush before removing it will ensure it is placed back in the proper location and alignment. If the remaining portion of any brush is less than 1/4 inch or less, all brushes on the motor should be replaced. The entire surface of the brush that rides on the collector-ring should display a polished finish – this indicates full surface contact. If evidence is observed that indicates that a brush is not making full contact over its entire surface, the springs that push the brushes against the collector-rings should be inspected. Improper spring pressure may lead to collector-ring wear or excessive sparking. In this case, the springs should be replaced.

Warning: High and medium voltage cables require special protection and must be de- energized before inspecting. Only personnel trained on such equipment should perform the inspection. Before performing any inspection of the electric service contact the utility and arrange for power to be disconnected.

Specialty cables are installed in areas that cannot be serviced by wire in conduit. These include flexible cables and submarine cables. Flexible cables are cables routed between fixed portions to movable portions of the structure. Cables from the pivot pier to the swing span, cables from the rest pier to the bascule leaves, and cables from the tower to the lift span all require flexibility. The benefits of flexibility are offset by reduced jacket protection. The softer, more flexible, cable jackets that bend and move with the bridge tend to wear more quickly from rubbing and abrasion.

Submarine cables are routed into the channel through the water from one side of the bridge to the other. The cables are typically trenched into the bed of the waterway. Submarine cable is typically manufactured with a steel armor wire wrapping and polyethylene covering to protect it from the harsh conditions. The portions of the cables that are near the waterline and exposed to fluctuations in water level are usually the first areas to fail.

17.3.16 Hydraulic System

"Open" and "Closed" loop hydraulic circuits are both used on movable bridges. Open loop hydraulic circuits are the most common in movable bridge applications. Most hydraulic movable bridges are actuated by hydraulic cylinders that require large volumes of fluid and use differential flow rates in and out of the hydraulic cylinders. Open loop systems take up relatively large space due to the large volume of oil required.

In open loop circuit applications, the pump draws fluid from a reservoir and pushes this fluid into the hydraulic system. After passing through the control valve circuitry and the actuator, the fluid returns to the storage reservoir. The reservoir typically is sized to hold at least three times the volume that can be displaced by the pump in one minute. Open loop systems move fluid in one direction only. Open loop pumps normally have a large diameter low pressure inlet port and a smaller high pressure outlet port.

In a closed loop circuit design a single hydraulic pump is used to drive one or more hydraulic motors. The fluid that passes through the actuator is returned directly to the low pressure side of the pump. The pump receives the same quantity of oil at the inlet as it is pumping through the outlet. Pressure, flow, and directional control are all achieved by the controlling elements of the pump.

The advantages of the closed loop system are that high horsepower systems are compact, they require a minimum amount of excess fluid storage and they are highly efficient. The pump controls direction, acceleration, deceleration, speed, and torque of the hydraulic motor actuator, and hence separate pressure and flow control components are not needed. These systems also provide excellent dynamic braking control, which is desirable in most movable bridge applications.

There are various types of hydraulic system controls employed to regulate the amount of oil and the pressure. The three common types are called "constant horsepower control", "electronic proportional control", and "hydraulic cylinder control". Each is described below.

Constant horsepower control (also known as horsepower limiting) uses an electric motor to drive the pump at a constant speed. System controls sense the pressure in the system and regulate pump flow accordingly. If the pressure is low, the flow is increased. This type of system uses a system pressure relief valve. Once constant horsepower is achieved, the slightest increase in system pressure will open the relief valve and bypass the minimum pump flow back to the tank.

Electronic proportional control utilizes a proportional solenoid to vary the pump displacement. As DC current is applied to the proportional solenoid, the solenoid pushes the pilot spool with a specific force. When the current, and therefore the force, is high enough the pump begins stroking and producing flow. Further increases in signal current will increase the pump's output flow proportionally.

Hydraulic cylinder control utilizes a hydraulic adjusting cylinder and pilot system to control pump flow. The pilot circuit is designed to meet the flow requirements. This type of control can be used in both open and closed loop hydraulic circuits. An example is shown in Figure 17.94.

Figure 17.94 Low Speed, High Torque Hydraulic Motor

The relatively low usage of movable bridge hydraulic systems combined with the high reliability of modern hydraulic system valves means that valve problems should be infrequent. However, dirty system fluid or poor adjustment could cause problems with hydraulic valves. Adequate and proper system filtration is the most important aspect of maintaining any hydraulic system. The operating environment of movable bridge hydraulic systems makes proper system filtering critical.

Modern movable bridge hydraulic systems typically utilize either standard mineral oil or environmentally friendly synthetic vegetable oil as their working fluid. The useful life of these fluids is limited. Factors that influence the life of hydraulic fluids include system usage, operating temperature, system cleanliness, and water intrusion. Synthetic vegetable oils are likely to oxidize after several years and require replacement. The fluid should be tested annually to determine viscosity, contamination levels, wear elements and water content. Most commonly this can be done with a visual inspection. This will also help in determining when the hydraulic fluid requires replacement.

The abrasiveness of tiny particles wearing the close tolerance surfaces of internal components will cause degradation failure of hydraulic system components. Degradation failure spreads throughout the system, and is usually not detected until the damage is irreversible. Indication that degradation failure has occurred include Sluggish system response, loss of speed adjustment accuracy, inability of the system to produce full load, and/or overheating, may indicate degradation system failure.

Catastrophic failure is the immediate failure of a system component and usually results from large particles causing moving parts to jam or stick. In pumps, dirt can block lubrication passages and cause pump failure. Large debris can collect in orifices which supply oil to the pilot circuit of pilot operated relief valve, pressure compensated flow controls, etc. Because contaminants are a leading cause of failure, proper system filtration is critical to the long term performance of the hydraulic system.

Plumbing systems for hydraulic movable bridge machinery often consist of complex arrangements of high pressure piping, stainless steel tubing, and hoses. Piping runs usually contain many bends, elbows, fittings, and mountings due to the complex nature of the bridge structure. Vibration from operation of the equipment, vibrations from vehicular traffic, as well as movement of the equipment itself has the tendency to loosen piping fittings and piping supports. This in turn can cause system leaks as well as damage to the plumbing from not being adequately supported.

Any damaged, nicked, or worn hoses should be replaced immediately. Any loose fittings should be tightened, including the mounting hardware and hangers. O-ring or other seals should be replaced as required or on schedule. Check for leaks around the manifold interface. Replace seals and O-rings as necessary. The pressure settings on all relief valves should be checked and adjusted as necessary.

17.3.17 Predictive Maintenance

Predictive maintenance that can be applied to movable bridges includes:

1. A measurement and record of the clearance for all bearings in a movable bridge machinery system
2. Repeat these measurements every year and compare the values recorded.
3. When the measured clearance exceeds a nominal value, remove shims from the bearing to obtain the proper clearance.

In existing installations, misalignment can be detected by monitoring the wear of bearings and gears. Since misalignment causes shaft bending and hence excessive bearing loads, abnormal wear in sleeve bearings is easily measured. The backlash in gear sets can also be measured and recorded. If these measurements are recorded over time and compared, a pattern will emerge. Movable bridges are machines and should be considered as such. A simple technique to monitor alignment is to annually measure and record the backlash. This approach can be used for other components, such as span locks, bearings, and sheave grooves, as well.

A dial indicator is used to check ring gear backlash in a ring and pinion gear set. It is used to measure distances and to check flat surfaces like the engine flywheel for run out. It is also used to check shaft end play. Dial gauges are used to measure back and forth movement in different areas of an automobile: brakes, engine, transmission, etc.

Backlash between the ring and pinion gear is set after the pinion gear is installed and adjusted. Side bearing preload is adjusted while performing the backlash check. After these bearing preloads have been adjusted, it is good practice to check the gear tooth pattern. Use the appropriate dye or marking compound to complete this task.

Both the side and pinion bearings are adjusted by changing the shim thickness on each side of the case. Some differentials have adjusting nuts at each end that can be turned to adjust preload and backlash. Be careful whenever working with a differential case, they are heavy, and can slide out of the differential housing easily. Always use manufacturer's specifications when making these adjustments.

More sophisticated inspection techniques, such as vibration monitoring for motors, can also be incorporated into a predictive maintenance regime.

What To Look For

Alignment can be checked through measurement and recording of backlash.

It is important to remember that the path to equipment failure is often predictable. This path can be measured such that an accurate estimate to failure can be made.

17.3.18 Structural Health Monitoring

Structural Health Monitoring (SHM) applications have gained a considerable attention as an objective methodology to evaluate the condition and performance of the structures. The Florida DOT has investigated the use of SHM for movable bridges. Electronic sensors to measure strain, displacement, acceleration, and rotation can be used to detect deficiencies in the performance of structural, mechanical and electrical components of movable bridges early and allow for proactive assessment and maintenance actions. Some investigators have explored the possibility of incorporating imaging and optical devices and combining them with sensing technology. At this time, there are only a few and limited attempts of real life testing and implementations of these ideas.

17.3.19 Generator Maintenance

Test the generator by operating the bridge under generator power as specified in the Operations and Maintenance Manual. Record the voltage of the generator while lightly loaded and when fully loaded. A full-load test should be conducted every three to five years.

Full-load testing involves placing a 100 percent capacity load on a generator and allowing it to run for a while. This not only brings to light any problems in the generator and in the engine and its cooling system; it also benefits the engine by properly seating the rings and dislodging buildup in the combustion chambers and on the valves. Diesel engines especially need a periodic load test in order to maintain performance and fuel economy.

Observe the generator vibration during operation and compare the amplitude to the manufacturer’s specifications. Inspect the airflow in the generator room and verify that the generator exhaust evacuates the room quickly and safely. Verify that the airflow in the generator area is sufficient for cooling the machinery. This can be done by feeling the machinery for excessive heat or by placing thermometers at various locations.

Pay close attention to the generator fuel tank and batteries for any leakage or corrosion. An example of an exterior grade auxiliary generator is shown in Figure 17.95.

Figure 17.95 Exterior Grade Auxiliary Generator

17.3.20 Lubrication of the Gears and Bearing Mechanisms

All gears and bearings require lubrication; however, the type of lubricant varies between different types of gear and bearings. Using the wrong type of lubrication can damage the mechanism and void any associated manufacturer's warranty. Therefore, maintenance personnel should always use the lubricant specified by the manufacturer of the gear or bearing, which should be detailed in the lubrication procedure of the operations manual. If a question arises regarding the use of a different lubricant than the one specified by the manufacturer, it is recommended that the manufacturer of the mechanical component be consulted prior to application of the lubricant. An example of a lubrication schedule and the associated details is included in Table 17.2.

While it is recommended that the lubricant specified by the manufacturer always be used, the following sections give a general overview of types of lubricants and selection criteria, in case that the manufacturer recommendations are not available.

Table 17.2 Lubrication Schedule for Exterior of Drum Girder for Swing Bridge

Item Name	Location	Drawing Number	Type of Lubricant	Application Method	Greasing 5/21/12	Greasing 6/18/12	Greasing 7/23/12	Greasing 8/20/12	Greasing 9/17/12
Right Angle Reducers	One of each side of operating machinery	10314-L3 10314-L4	Mobil GEAR 600 XP 320	Reservoir					
Right Angle Reducers Top Bearing	Top of Right Angle Reducers	10314-L3 10314-L4	SWEPCO SWEPCO 101	Grease Gun Alemite Fitting					
Right Angle Reducers Bottom Bearing	Below each Right Angle Reducers	10314-L3 10314-L4	SWEPCO SWEPCO 101	Grease Gun Alemite Fitting					
Rack Vertical Couplings (Top & Bot)	Below each Right Angle Reducers	10314-L3 10314-L4	SWEPCO SWEPCO 101	Grease Gun Alemite Fitting					
Pinion Shaft and Housing	Outside of Drum Girder	10314-L3 10314-L4	SWEPCO SWEPCO 101	Grease Gun Alemite Fitting					
Rack & Pinion	Drum Girder Rack Bottom Pinion	10314-L3 10314-L4	SWEPCO SWEPCO 164	Brush					
Slewing Bearings	48 Fittings above Drum Girder Rack	10314-L4	SWEPCO SWEPCO 101	Grease Gun Alemite Fitting					

17.3.20.1 Types of Lubrication

There are two types of lubricants for movable bridges, oils and greases. Lubricating oils are used in closed systems that typically use mechanical devices to continually lubricate gears and/or shafts. The oils can be derived from animal and vegetable products, petroleum oils, synthetic oils and solid lubricants. The fatty oils derived from animal and vegetable products tend to oxidize and develop sludge and contaminates. These oils have been largely replaced by synthetic oils that have improved material characteristics suitable for heavy machinery. Oils are generally limited to enclosed gearboxes, some radial-bearing applications and central pivot bearings on swing bridges.

In general, oils are best suited for applications where higher surface speeds are in balance with the loading conditions. Oils are used where operating temperatures are high (above 180 °F), so that heat may be carried away with system flow.

Grease on the other hand is more functional under conditions created by slower speeds and higher load relationships. Since grease has retention it has the ability to stick to interacting surfaces which also gives good protection during irregular loading (i.e., vibrations, impacting, start-ups, metal to metal contact). The downside is that greases do not function well where high operating temperatures are experienced and for the most part, are not filterable. However they serve as excellent sealing devices themselves and in many applications do not require oil-tight sealing. Due to their simplicity they are more cost effective to design, build and operate than oil systems and usually require less frequent servicing. An example of grease on an open gear is shown in Figure 17.96.

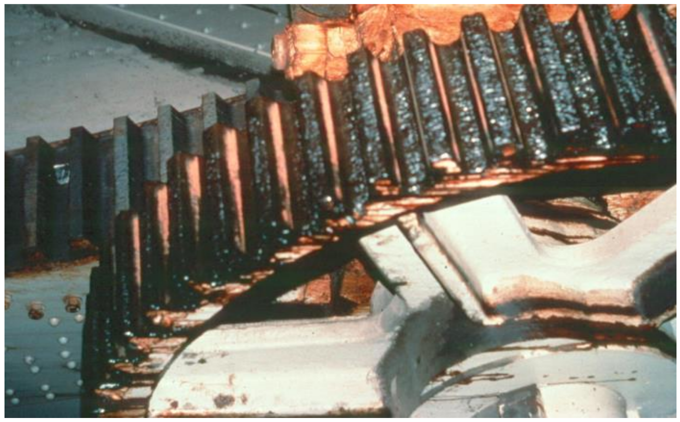


Figure 17.96 Grease on Open Gear

Greases are the preferred method of lubrication for the majority of mechanical devices due to simplicity, service requirements and relative cleanliness. Greases are essentially lubricating oils mixed with dispersions of thickening agents to create a solid or semi-solid lubricant. Greases are designed to “bleed” lubricating oil when undergoing shear. Though the thickener has lubricating properties of its own, the oil bleeding from the grease is the actual lubricating agent. As shear pressure begins to fracture the grease structure, the grease begins to bleed like a sponge being squeezed of water. As the oil film is subjected to extremely high pressures within the contact zone and for an instant undergoes a dramatic increase in viscosity. This enables the lubricant film to withstand the high contact stresses while preventing metal to metal contact between the rolling surfaces.

As a freshly lubricated roller bearing begins to rotate, the grease moves off the rolling elements and is pushed out to the housing. A small portion of it remains inside the bearing itself where shearing will take place releasing the oil lubricant. The discharged bulk of the lubricant will build wall-like damming structures along the sides of the bearing. This grease dam helps to trap the released oil product. As bearing elements continue to rotate, the grease dam will slump back in towards the rolling element slowly over time. The grease dam will then be pulled back in and behind a passing roller where the cycle will begin again. To ensure the longest possible life, it is important that roller bearings are never over filled and should be periodically cleaned out before the cavity is filled completely.

Greases are commonly used where oil circulation systems and sumps are not practical, in gearing that needs the lubricant to remain on parts or contacting surfaces, when enhanced sealing action is required due to dirty/mist environment or to protect against corrosion. On movable bridges, greases are used to lubricate a number of different types of bearings and gears. Common bearings are radial bearings, both plain and friction-less roller type, linear bearings, and thrust type bearings used on center pivoting swing bridges. Grease is used to lubricate open gears, simple spur-type gears and bevel gears because the product adheres to the contacting surfaces.

Lubricants for each component on movable bridges should be specified and followed for both repairs and maintenance actions. Lubricants are designed for the specific types of friction encountered in the mechanism. The film thickness of lubricants is affected by the speed of the machinery, the viscosity of the fluid, and the load on the machinery. Determining the proper lubricant requires a good understanding of the application, its environment, the material characteristics of the lubricants, the mechanical properties, properties of the additives, compatibility with one another, practicality, availability, and costs.

17.3.20.2 Lubrication Conditions

Three types of conditions under which the machinery is designed to function when lubricants are used to separate the machine surfaces are called hydrodynamic lubrication (commonly called full film lubrication), elastohydrodynamic lubrication (commonly called mixed film lubrication), and boundary film lubrication. Knowing which machinery operates in these environments is necessary for the selection of proper lubricants. Each and every application will produce a specific film characteristic and will require particular lubricant types and properties for a successful operation.

In full film lubrication surfaces slide on a fairly consistently thick layer of lubricant. An increase in speed or viscosity will produce a thicker film, while increasing the load will decrease the film thickness. This condition is typically achieved in internal combustion engines and is rarely, if ever, generated on movable bridge applications.

Mixed film lubrication occurs under very high pressures. Surfaces move over each other on varying layers of lubricant. On moving bridges this condition would exist in bearings on high to mid speed shafts (higher than 10 feet per minute) and between some high-speed gear engagements. Hydrostatic bearings produce low friction and have high load capacity in addition to longer life. The benefits would be ideal for the large trunnion and thrust bearings found on movable bridges; however they require a greater maintenance effort and are costly.

Boundary film lubrication conditions occur on slow moving roller and plain type bearings, including slower moving gears under extreme pressures. As the surfaces begin to rub increasingly against each other the oil film becomes thinner. Lubricant at the molecular level must be present to prevent damaging the high surface finishes. Often, additives are needed to protect the moving parts. Slow moving rotary and oscillating mechanisms are common in movable bridge applications.

17.3.20.3 Selecting a Lubricant

Selecting any kind of lubricant requires the consideration of several factors. The most important of which are the desired or anticipated mode of film condition (full, mixed, or boundary film conditions), the relative speed of moving parts, the types and size of loads, and operating temperatures of the machinery.

Misapplication of lubricants is very common on movable bridges. More lubrication is not necessarily better. Oils or greases are formulated for specific functions. Even if the correct lubricant type is specified, differences in composition by the manufacturers may result in a contaminated condition.

Some of the things to look for are: excessive oil-bleed or pooling on or around grease lubricated bearings. This may be an indication that the wrong grease product is being applied, product is expired, bearing may be running hot, or product is contaminated. Color changes in the grease product. Darkening indicates the product has been contaminated or is oxidizing. Hardened grease is depleted of oil and not suitable as a lubricant, and should be removed.

Each of the various types of lubricants is designed for specific purposes and has characteristic properties suitable for their function. Lubrication oils and greases each have their own characteristic properties to consider.

Some of the essential material characteristics of lubrication oils for movable bridges are:

- Viscosity
- Viscosity index (VI)
- Oxidation stability
- Rust prevention
- Demulsibility or water separation
- Cloud point
- Pour point
- Lubricity
- Tackiness
- Extreme Pressure
- Consistency
- Compatibility

Viscosity is essentially the ability of the material to flow. A high viscosity indicates a resistance to flow. The *Viscosity Index (VI)* indicates the rate of change in viscosity for a specific change in temperature. A high VI indicates a minimal change in the materials ability to flow. For most mechanical operations a high VI is desirable. The most important aspect to be considered while selecting any lubricant, whether it is oil or grease, is its base-oil viscosity.

Oxidation stability measures the resistance to oxidation. Oxidation is a chemical process that will break down a lubricant. The lubricant may become acidic and form a sludge. Generally the process is slow and on regularly maintained systems it usually does not become a problem. If the lubricant is acidic, it needs to be changed immediately.

Rust prevention can be inherent in the base material or a corrosion inhibitor can be added. Good rust protection is important in applications that are open to moist environments such as trunnion-type bearings, and open gear systems.

Demulsibility (also referred to as Water-Separation) is the ability of the oil to separate from water. The number indicates the ability of an emulsion of oil and water to separate. This is an important property is applications exposed to run-off, driven rain, marine tides, and in areas of high humidity.

Cloud point is the low temperature at which the oil will begin to crystalize and become wax-like in appearance. This value is important as it indicates the temperature where the lubricant may clog filters or small orifices.

Pour point is the lowest temperature at which a lubricant can be poured from its container.

Lubricity is a measure of the film strength of the oil. Not all oils have the properties to maintain adequate lubrication where machine surfaces begin to increasingly rub against each other (boundary film conditions). Generally lubricity is enhanced with additives.

The base properties of greases are enhanced with additives. Many of the additives used in oils are common to greases and serve the same purposes. For greases, properties of tackiness, extreme pressure and consistency, and compatibility are important.

Tackiness refers to the ability to “stick” to a surface. Crater compound is commonly used, however its resistance to oxidation is very low and it does not function well in cold weather.

Extreme pressure (commonly denoted as EP) additives provide increased protection against friction and wear specifically where heavy loadings apply physical metal to metal contact (boundary film conditions).

Consistency or firmness of grease is the principal reason why grease is chosen over oil for certain applications. Consistency is the measure of the firmness of the base material. Consistency is determined by the depth at which a cone penetrates into the grease. Grease consistency may be affected by temperature cycling, time in storage, and exposure to the environment.

Compatibility is an assessment of how a particular grease will interact with other greases formulated with alternative thickeners. Non-compatible greases may solidify, loosen, and bleed-out base oils when mixed.

Thickener types are the second most important consideration in selecting grease products. Grease generally consists of a thickening agent emulsified with mineral or vegetable oil. Soaps are the most common thickening agent used, are widely produced, come in a variety of base-oil viscosities and consistencies, and can be enhanced with an assortment of additives. The selection of the type of soap is determined by the application. Soaps include calcium stearate, sodium stearate, lithium stearate, as well as mixtures of these components. Fatty acids derivatives other than stearates are also used, especially lithium 12-hydroxystearate. The nature of the soaps influences the temperature resistance (relating to the viscosity), water resistance, and chemical stability of the resulting grease.

Since grease soaps are not totally inert, they will tend to oxidize in storage and deplete themselves by bleeding-out base oil. This is the storage-ability of the product and is typically in the range of two years for most soaps. Therefore, 2 years is the absolute longest any grease product should be around, whether it’s in service or not. If it is in service, the existing product should be entirely cleaned out and recharged with new grease.

Lubricant manufacturers are an excellent source of information regarding lubricant properties and additives. Industry associations such as the International Standards Organization (ISO), the American Gear Manufacturers Association (AGMA), the National Lubricating Grease Institute (NLGI), and the Society of Automotive Engineering (SAE), generally used for automobile gear oil, have instituted classification systems to aid in the selection of lubricants suitable for heavy machinery.

The NLGI consistency number (sometimes called “NLGI grade”) is a measure of the relative hardness of a grease, as specified by the standard classification of lubricating grease established by the NLGI. Those with a NLGI No. of 000 to 1 are used in low viscosity applications. Examples include enclosed gear drives operating at low speeds and open gearing. Grades 0, 1 and 2 are used in highly loaded gearing. Grades 1 through 4 are often used in rolling contact bearings. Greases with a higher number are firmer, tend to stay in place and are a good choice when leakage is a concern. Most movable bridge applications work well with NLGI 1 or 2 consistencies. Non-enclosed linear sliding bearings may consider a No. 3 grease for increased water wash stability. A lubrication expert or NLCI application guides are a good source of information for specific recommendations. NGLI consistency numbers and applications are presented in Table 17.3. Additional considerations when selecting a grease are operating temperature ranges, pump-ability, channeling, slumping, retention, and sealing ability.

Table 17.3 NLGI Classification and Consistency Numbers

NLGI number	ASTM worked (60 strokes) penetration at 25 °C *tenths of a millimeter*	Appearance	Consistency food analog
000	445-475	Fluid	Cooking oil
00	400-430	Semi-fluid	Apple sauce
0	355-385	Very soft	Brown mustard
1	310-340	Soft	Tomato paste
2	265-295	“Normal” grease	Peanut butter
3	220-250	Firm	Vegetable shortening
4	175-205	Very firm	Frozen yogurt
5	130-160	Hard	Smooth paste
6	85-115	Very hard	Cheddar cheese

Determining the correct grease for an application is made easier with the introduction of multi-service greases. With the exception of extreme conditions such as water wash, high and low temperatures, and chemical contamination, most multi-service greases, regardless of thickener type, will perform satisfactorily in the majority of applications. Other factors include, but are not limited to, the realistic time frame between service intervals, extreme temperature conditions, the presence of contamination (to include foreign matter and moisture), the possibility of metal to metal contact (impacting, vibrations, loss of lubricant), the inherent effectiveness of sealing functions, and system's cost or customer's preferences.

Any time a new lubricant is used (either a different type or the same type from a different manufacturer); all of the existing lubricant must be removed to avoid contamination. It is very important that lubricants do not become contaminated. When a lubricant becomes contaminated, it generally becomes acidic. An acidic condition over a long period of time can result in accelerated bearing and gear wear. The acidity of the lubricants should be tested annually. Removal of existing lubricant is done manually and combined with flushing with mineral spirits.

17.3.20.4 Removing Grease

An assessment of the existing grease may provide feedback as to its effectiveness. Unusual smells may indicate burnt lubricant or an oxidizing condition. Varnish or lacquer formations on bearings race are a product of an oxidizing condition. Varnish is generally associated with contamination or expired product, while lacquer is a result of an overheating condition. Small dark tarnished areas or spots on bearing surfaces may indicate formation of rust due to insufficient rust inhibiting property, product breakdown, wrong product or contamination.

One very important servicing issue is the proper method of cleaning lubricated devices. Crews should refrain from the use of solvents for cleaning purposes. Solvents are strongly discouraged since they tend to leave residue which will result in contaminated lubricant. The best method of cleaning any device is by mechanical means. Highly polished running surfaces should be cleaned using rubber gloves. If there is any residue or stiff grease that is tough to remove, try soaking parts with heated oil for a few hours or even a day if need be. On parts that still present a problem, kerosene is very effective in loosening thick black clogged product. Afterwards, flush continuously with light mineral oil before relubricating.

Sometimes grease deposits are so hard and thick they look like plastic. In this case, solvents could be considered. Once the fouled product has been removed allow the solvent to evaporate, hair dryers work perfectly. Then flush continuously with light mineral oil until all solvent residue has been removed and re-lubricate. It is imperative that no solvent is left to contaminate fresh lubricant. If unusual bleeding occurs shortly after a solvent was used in the cleaning process, it may indicate that the new grease has been contaminated.

Most lubrication problems are easily resolved with minimal effort. On the other hand, some problems can be much more complicated and may require an extensive effort. Part of exercising a good preventive maintenance effort is staying alert and paying attention to the slightest details of each component. Keeping things clean and monitoring each device as frequent as possible during operation is a good practice. An excellent way to monitor a device is to lay a hand on it during operation. You will become accustomed to the way it heats and vibrates during operation enabling you to detect any early signs of problems.

Lubrication misuse is perhaps one of the greatest causes of long term mechanical failures. Application of lubricants needs to be careful and consistent. Often times a lubricant is specified for use on sleeve type bearings such as EP-2 grease. Often those using the product do not understand that EP lubricants tend to become corrosive when exposed to contaminants, moisture and temperature. If these lubricants are not purged through the bearing quickly enough, their chemical reactions can cause degradation in the bearing journal. This effect is commonly seen on counterweight trunnion shafts that look like they have been scored by some foreign material. This scoring usually occurs due to chemical reaction with the lubricant accelerating the phenomenon of “micro-pitting”, as described below.

Micro-pitting is where the bearing surfaces contact at the microscopic level resulting in extremely high pressure, such that the material actually flashes due to the heat. This situation occurs over and over again until such time as the shaft appears to be scored and the trunnion friction increases.

The other common problem with lubricants is that when they chemically react some types become hard, preventing new lubricant from reaching the surfaces under load. The result is that these surfaces are in effect, not lubricated. One of the most common causes of lubricant contamination is the addition of a different type of lubricant. Unfortunately, not all lubricants are compatible with one another. If changing brands of lubricants, it is likely the new lubricant will react adversely to the existing lubricant.

When removing existing lubricant from closed mechanical components such as reducers and trunnion, inspect the grease for the presence of metal particles. If metal particles are observed in the grease, this is a sign that the gears are being worn and an internal inspection of mechanical component is warranted.

What To Look For

Metal particles in the grease are an indication of worn gears.

Figure 17.97 shows grease from a trunnion bearing on a bascule bridge that exhibits bronze particle pickup.

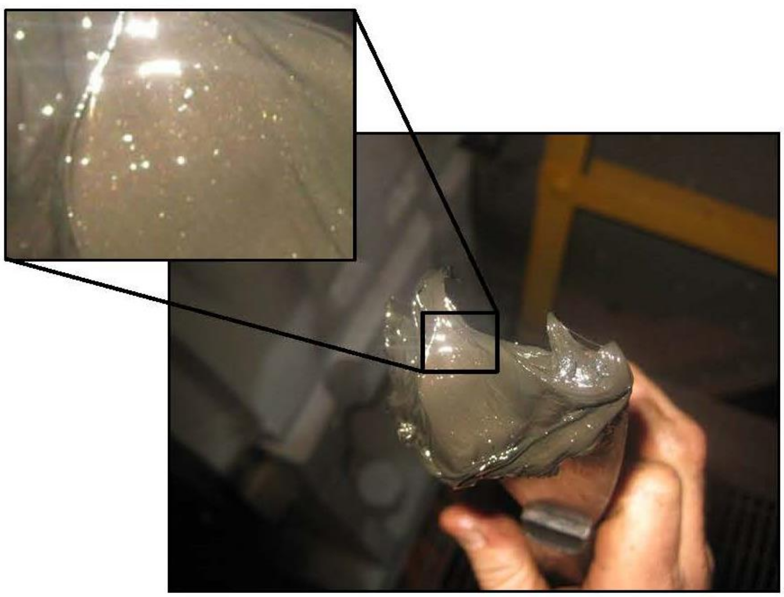


Figure 17.97 Grease Exhibiting Extensive Bronze Pickup

17.3.20.5 Lubricating Movable Bridge Components

The two most commonly recurring types of damage on the components of movable bridges are leakage from the gear box and inadequate or improper lubrication of the gearing. Over lubrication can also have detrimental effects on the machinery components and may lead to the failure of internal seals on bearings and couplings, an example of which is shown in Figure 17.98. Early detection of these faults may help to avoid operational problems and major damage to the machinery.

Figure 17.98 Trunnion Bearing with Broken Seal Due to Excessive Lubrication

Open Gears

Open gears are susceptible to corrosion due to a lack of lubrication, excessive strain, out-of-plane rotation and misalignment. If the gear teeth are not kept lubricated at all times, wear and corrosion due to grinding will occur. An example of a properly lubricated open gear is shown in Figure 17.99.

The partial rotation of the rack and pinion is done at low speed, then reversing direction results in metal-to-metal contact occurring within the bearing. These types of bearings are typically lubricated with an Extreme Pressure (EP) grease to aid in supporting the load. Solid molybdenum disulfide (moly) or other additives are added to the grease to enhance the load-carrying capability of the lubricant.

Generally, if the open gear lubricant is to be applied by a drip system, force-feed lubricator or spray system, it must be sufficiently fluid to flow through the application equipment. For brush applications, the open gear lubricant must be fluid enough to be brushed evenly on the teeth. In any case, during operation, the open gear lubricant must be viscous and tacky enough to resist squeeze-out from the gear teeth. When open gears are lubricated by dripping into a splash pan or through the use of splash and idler immersion systems, the open gear lubricant must not be so heavy that it channels as the gear teeth dip into it. Finally, when open gears are lubricated, the consistency or grade and its ease of pumpability must permit easy application under the prevailing ambient conditions.

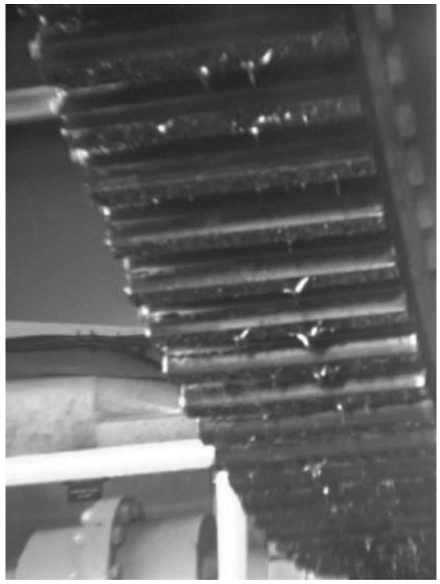


Figure 17.99 Properly Lubricated Open Gear

Closed Gears (Speed Reducers)

Access to the closed gear sets is generally by ports (or covers) which can be removed. It is quite difficult to measure the backlash of the gear sets in an enclosed reducer.

Bearings

Greases are used to lubricate most of bearing types found on movable bridges. However, some bearings and thrust bearings on swing bridges are lubricated with oils. For oil lubricated bearings, the oil level should be just high enough to submerge half of the lowest bearing to prevent churning and foaming. The use of EP additives should be avoided. Oils that do not contain solid lubricant additives should be used, as solid lubricants work as a contaminant in this application.

Thrust bearings commonly experience extremely slow speeds and are required to support millions of pounds (boundary film condition). The proper oil lubricants for thrust bearings should have a high viscosity, but not excessively high to where it will restrict good penetration into the contact area. The selected oil should also have excellent lubricity, good rust and oxidation stability, and be EP rated. Solid lubricant additives should also be considered.

Thrust bearings on swing bridges cannot be accessed for cleaning and greasing. Therefore, oil bath systems are normally used. The oil level is maintained at some point above the highest elevation of the upper disc so that the entire interface is submerged. Oil is usually drained from center of the lower bearing. Oil grooves are provided in the bronze disc to provide lubricant coverage, which also facilitates settling out of contaminants into the lowest point.

Sleeve bearings require lubrication between the sliding surfaces of the journal and bushing. It is important that the bearing be kept full of fresh clean grease and be periodically cleaned of old grease. Normally one or more grease fittings are located at the top of the housing. When lubricating the bearing, it should be confirmed that old grease exits from the space between the journal and bushing. The disadvantage of these bearings is that they cannot be conveniently disassembled for cleaning and have the tendency to retain old product despite the best re-lubrication efforts. Old grease will eventually breakdown and may become reactive and oxidize, solidify, bleed out, and/or produce lacquer or varnish type coatings on journal surfaces. These coatings are destructive in that they may prevent certain additives from developing oil-soluble surface films.

The sleeve bearings should be well secured and free of damage. The bearing housing should be free from cracks. There should be minimal radial movement during operation to minimize wear on the bushing. The clearance between the shaft and the bushing should be measured, using feeler gages, and the measurement recorded. The exterior housing of the bearing should remain cool to the touch. Any heat generation may indicate improper lubrication, or damage to the bearing.

The best grease product for sleeve bearings are those with a high base-oil viscosity, are extreme pressure (EP) rated, and contain solid lubricant additives for added protection. In addition these products should have good oxidation and corrosion protection for increased service life.

Selecting grease products for roller bearings should have a NLCI consistency rating that will provide good channeling as well as be able to slump throughout the entire operating temperature range. Base oil viscosity needs to be just heavy enough to develop film integrity, yet light enough to prevent adverse temperature conditions and churning.

Linear bearings operate under slow speeds and high loads (boundary-type film conditions). Lubrication that can withstand extreme pressures in the bearing and the ability to withstand direct exposure to rain or tidal action, water run-off, and/or scraping-off must be extremely tenacious in nature. Crater grease, sometimes called grease tar, is a residual asphaltic compound well suited for this application. These compounds are usually brushed or sprayed on with solvents; pay attention to health warnings.

Some linear bearings are designed to operate using more standard type grease products. In these applications, a NLCI No. 2, 3, or even 4 EP rated greases with solid lubricants, good channeling, minimal slumping, tackiness agents, water stable, that are oxidation and rust stable are best suited. Due to the harsh environment, frequent servicing is advised for optimum life.

Bearings supporting the shafts in the reducer are generally mounted in the housing and are not readily accessible. After the unit has been operated, these bearings can be touched to determine if they are getting warm. If a bearing becomes warm after one or two bridge openings, it should be checked.

Wire Ropes

A wire rope is constructed by spinning strands of wire into a bundle. These bundles are then spun around a core to construct the rope. The typical ropes are 6 by 19 with a fiber core. The 6 indicates that six (6) bundles of nineteen (19) wires are wrapped around the core. As the group of bundled wire passes over drums or run over sheaves, friction between the bundles and the wires will occur. To minimize abrasion within the rope, the ropes must be properly lubricated. If a rust color appears on the rope it should be carefully inspected. It is important to understand that wire ropes have a tendency to fail from the inside out. Wire ropes which are properly installed will provide decades of reliable service. An example of wire rope sockets and fittings is shown in Figure 17.100.

Figure 17.100 Wire Rope Sockets and Fittings at Lifting Girder

Wire ropes are used for counterweights, auxiliary counterweights and for operating the span (span drive vertical lift bridges). In general the maintenance required for wire ropes is to assure that they are properly lubricated, that the wire rope tension is correctly set, and that the sheaves that the ropes run over are functioning properly. An example of wire rope lubrication is shown in Figure 17.101. Wire ropes should be visually checked once a year for broken wires, rusting, evidence of rubbing during operation, and flat spots. For an example of fouled wire ropes, see the photo in Figure 17.102. Flat spots greater than 1/4 inch long for ropes under 1-inch diameter and greater than 1/2 inch long for ropes over 1-inch diameter should be brought to the attention of the engineering staff.

When to Call the Engineer

If flat spots are discovered on wire ropes which are more than ¼ inch long on ropes less than 1 inch diameter, or more than ½ inch long on ropes over 1 inch diameter.

Figure 17.101 Lubricating Wire Ropes (Courtesy of California Department of Transportation)

Figure 17.102 Fouled Wire Ropes (Courtesy of California Department of Transportation)

The largest components on a vertical lift bridge are the counterweight sheaves. From engineering and design criteria, it is imperative that the wire rope grooves, the pitch line, and the trunnion journals are all concentric to evenly load all ropes and operate smoothly.

When replacing counterweight ropes, wire rope shrinkage will occur and the counterweight wire ropes will not regain their preloaded length until the ropes are actually operated. After installing a new rope, it is necessary to run it through its operating cycle several times (known as break in period) under light load (approximately 10 percent of the Working Load Limit) and at reduced speed. Start with light loads and increase gradually to full capacity. This allows the rope to adjust itself to the working conditions and enable all strands and wires to become seated. Depending on rope type and construction, some rope stretch and a slight reduction in rope diameter will occur as the strands and core are compacted. The initial stretch (constructional stretch) is a permanent elongation that takes place due to slight lengthening of the rope lay and associated slight decrease in rope diameter. Constructional stretch generally takes place during the first 10 to 20 lifts.

Wire Ropes are usually made slightly larger than nominal diameter to allow for reduction in size which takes place due to the compacting of the structure under load (break in period). Keep a record of the new rope diameter after break in period for future reference.

The drums and sheaves have grooves which control and support the wire ropes. If slippage between the rope and the grooves occurs, then both the rope and groove wear. This wear is accelerated when a sheave bearing fails and the rope is dragged across the sheave. The best way to identify these problems is to observe the operation of each sheave while the span is in operation. Unfortunately no adjustments are available for the rope groove size. When rope grooves become too large, the wire rope deforms from a round to an oval shape as it passes over the drum or sheave. This deformation accelerates wear of the ropes.

17.3.21 Alignment

Seasonal and daily temperature changes, as well as sudden temperature shocks, affect the alignment and fittings on different components of the bridge. As the bridge materials expand or contract due to temperature changes, alignment of the mechanical components can be affected. This may lead to an increase in friction between moving parts. During bridge operation, significant changes in mechanical friction may be an indicator of a need for maintenance or adjustments in component alignment. For example, in summer, the operators on the West Third Street Bridge in Cleveland, OH are often seen watering down the end, not to keep the dust down, but to keep the steel cool so the bridge does not bind.

Live load bearings, when misaligned or improperly balanced so that the bridge is not fully seated, cause the dead load and traffic load (live load) to be transferred to the gears and shafts. This puts an enormous strain on the machinery. Small gaps also lead to the girders pounding on the live load bearings, which results in further misalignment, additional stresses, fatigue damage and excessive wear.

The operation of the live load bearings should be checked to assure consistent proper seating. A simple method to assure consistent operation is to place indicators on the bearings and the seat (e.g., using marking crayons) to check consistency of operation. As bearings become worn or improperly adjusted, they can become “stuck”. Sometimes the lubricant has chemically reacted causing the mating surfaces to become rough (increased coefficient of friction). Sometimes the drive linkages are so worn that a significant amount of power is lost to machinery inefficiency (the drive system does not have sufficient power to pull the bearings under extreme condition).

Span lock sockets are typically welded or cast housings equipped with adjustable wear shoes. Adjustment is made by adjusting the shim material. The lock bar is operated within the sockets by a crank mechanism, which is driven by gearing and a motor. Linear lock bar operators are also common. The locks should be adequately lubricated. There should be little, if any, relative span movement of the locks under traffic. If movement is observed, gaps between bar and sockets should be measured with feeler gages and recorded.

The alignment of the guide socket and receiving sockets and lock bars should be match marked, aligned and shimmed at manufacturing point duplicating field conditions as closely as possible. This may require re-aligning when actually assembled into place. Any locking system should be properly aligned and fastened rigidly to prevent any possible movement. If movement does take place, the locking systems are easily misaligned and will not realign themselves. The locking system is not a bridge alignment tool and if not properly aligned damage will occur.

Some common problems are associated with locking systems, alignment, air buffers, shop tolerances versus field practices, and translation of design drawings into workable shop detail drawings. From a practical standpoint, it is advantageous to pre-assemble and simulate the field conditions as much as possible in the shop, to eliminate as many field problems as possible and to insure proper operation in the field.

17.3.21.1 Repair of the Pivot/Rack Assembly

The rolling bascule bridge is a straight forward manufactured mechanical system with a straight rack and pinion, a machinery frame and the tread and track plates. The tread and track plates may be fabricated out of high strength, low alloy plate steel, machined, and have the lugs either pressed in place or machined.

The trunnion type bascule bridges rotate around their trunnions and trunnion bearings and are commonly driven through curved racks that are bolted or fabricated to the rack support. The movement is designed to follow the pitch line (or pitch circle). The pitch line usually cuts the teeth at about the middle of their height. When aligned properly, movement occurs without backlash (loose play in the gears).

Shims can be used to eliminate an inconsistent backlash with the use of shims placed between the rack support and the girder. It is important that the pitch diameter be consistent with the top flange of the rack support. In addition, for swing spans, the track must be installed level and in true relationship to the center pivot to establish proper tracking with the balance wheel assemblies.

Repairs to the track and tread should be done in the shop, when possible. The track and tread should be actually blued, (a chemical process that provides some corrosion protection) match marked and rolled the length of travel and tested after all machine work is completed to insure proper contact and tracking ability. A track example is shown in Figure 17.103.

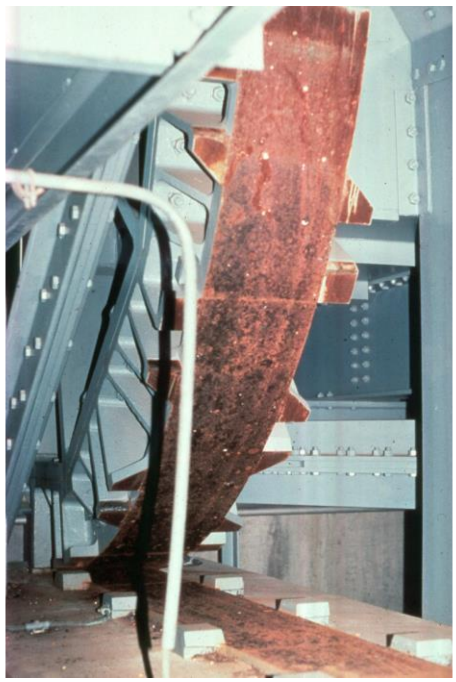


Figure 17.103 Track (Courtesy of Wisconsin DOT)

Extremely accurate measuring equipment must be available during the repair. Sometimes, specialty tools may be required that may have been supplied by the mechanical supplier after the initial installation.

Decisions regarding the operation system and mechanical parts require special expertise and knowledge of the structure. A malfunction of any component can cause an unexpected failure of bridge operation.

17.3.21.2 Balance Testing

Balance and alignment are affected by rehabilitation, repairs and deterioration. To track bridge balance and alignment and other effects on the operation, such as environmental effects, the bridge balance should be monitored and performed real-time for each bridge operation. Incorrect balance condition will lead to different support reactions and internal stresses and a fundamentally different behavior. Measurements taken as the bridge is lifted and closed are used to determine whether or not the bridge requires balancing.

Bridge balancing and shimming is necessary on all movable bridges as they deteriorate. The balancing procedure is relatively unsophisticated, relying on current draw from the motors to gage relative balance. Engineers oversee the balancing operation to determine whether or not to add or remove counterweight blocks to achieve balance. Bridge shimming is critical for proper seating of the bridge when closed and under load. Bascule bridges are shimmed to within approximately one-quarter inch of full bearing on the anchor column and "just seated" on the live load bearings under a "no live load condition”.

Swing bridges may be symmetrical or to have unequal length arms. Arms that are not of equal length are termed unsymmetrical or bobtailed. The dead load (self-weight) of a swing span is usually balanced about the pivot. Hence, bobtailed spans require counterweights at the ends of the shorter arms. When open, the swing bridges must maintain their own weigh. When closed, the spans are supported by a center pier and abutment at each end with wedges driven in to lift the bridge ends, preventing damage to the bridge under live load conditions. As a result, swing bridges are generally either center-bearing structures or rim-bearing ones.

The bridge load in center-bearing swing bridges is carried on the central pivot with balance wheels placed on a circular track on the outside of the central pivot to prevent tipping. Balance wheels are found only in center-bearing swing bridges. As the structure load is balanced on the center pier, it is vital to have the mechanism support unbalanced loads. In rim-bearing swing bridges, the pivot pier places the structure load on a circular girder or drum to beveled rollers. These rollers are located within the pier on a circular track, spaced by concentric spacer rings . The central pivot in this type of swing bridge also carries part of the structure load.

There are three main ways to perform a balance test:

- Drift Test
- Strain Gauge Testing
- Motor Current Balance Testing

The most accurate methods of balance testing involves the use of strain gauges and electrical current tests.

For bascule and lift bridges, drift tests can be used to make correcting adjustments to the counterweight. To conduct a drift test, the span is raised to 10 degrees open and held. The brakes are then manually released. The spans should slowly drift to the closed position (be sure the brakes are working properly before proceeding). The test is repeated at 10 degree intervals until the spans are fully open.

If properly balanced, the span should drift to close when held at the near half open positions. Near the mid-open point the spans may either drift closed, remain in the mid-open position, or drift open. If the span drifts down too quickly or drifts down from the full open position, it may be too span heavy. Spans that don't drift down are counterweight heavy. Counterweight adjustments are made accordingly to maintain the span in proper balance.

Strain gauge testing incorporates strain gauges to measure the torque in the span drive pinion shaft. This method can be used on spans that are not driven by rack and pinion drive systems, such as rack and pinion bascule spans.

Motor current (or amperage) balance tests use ohm meters to determine the current draw on the electrical motors that control the movement of the spans. Variations in the current drawn by the motors provides an indication that the span may be out of balance.

These tests should be performed under the direction of an engineer. Based on information from balance testing, recommendations can be made concerning balancing and/or lubrication of components.

When to Call the Engineer

Call the Engineer for direction in performing balance testing.

17.4 Chapter 17 Reference List

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