## CHAPTER 2.8 – PROCEDURES

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

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

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

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

### 2.8.1 – STRUCTURAL INSPECTION PROCEDURES

Inspection of typical structural components (such as floor beams, trusses, stringers, substructure, superstructure, etc.) that are common to fixed and movable bridges is covered in depth in FHWA *Bridge Inspector's Training Manual 90* (BITM 90) (Reference 69) and the AASHTO *Manual for Condition Evaluation of Bridges* (Reference 9). Inspector should observe the global operation of the movable span or spans.

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

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

*C2.8.1*

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

## CHAPTER 2.8 – PROCEDURES

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

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

### 2.8.1.1 Substructure

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

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

*C2.8.1.1*

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

- Check if the span or counterweight contacts the substructure during span motion.
- Check if the substructure interferes with full opening of the span. This can restrict the horizontal or vertical clearance in the navigational channel limits.
- During in-depth inspections these checks should be made in all areas. During routine inspections only, the worst examples of a particular type of defect should be fully cleaned, measured, and tested.

### 2.8.1.2 Superstructure

Routine inspection of the superstructure components should include the following:

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

*C2.8.1.2*

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

### 2.8.1.3 Ship Ladders, Walkways, and Platforms

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

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

### 2.8.1.4 Counterweights and Counterweight Pits

During routine inspections, check the following:

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

- During in-depth inspections, scheduling, cleaning, and NDT of any deteriorated counterweight members should be considered to check for internal cracks.

### 2.8.1.5 Pier Protection System and Other Waterway Protective Devices

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

The pier protection system should be inspected in a manner similar to that used for inspecting the main substructure elements including an underwater inspection at the same frequency required for the underwater portions of the bridge structure (NBIS, Reference 8f). During routine inspections, check the following:

- Check connections for loose or missing fasteners, cracks, or other defects.
- In concrete pier protection members, check for impact damage, spalling and/or cracking of concrete or corrosion of the reinforcing steel.
- Check the splash zone (i.e. up to 2.0 ft. [0.6 m] above high tide or mean water level) carefully for deterioration.
- Examine steel parts for corrosion, cracks, impact damage or other defects.
- Check paint specifications to determine if spark arresting paint was used on painted pier protection components.
- Review previous inspection reports and take core borings to verify the condition of areas of suspected internal timber deterioration.
- During underwater inspections, check the following:
- Investigate for deterioration of piles at the mudline and waterline, and check for structural damage caused by marine traffic impact.
- Check timber pier protection members between the high waterline and the mud line for marine borers, limnoria or other defects.

*C2.8.1.5*

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

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

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

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

### 2.8.1.5.2 Bolts, Washers, Steel Corner Plates

During routine inspections, check the following:

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

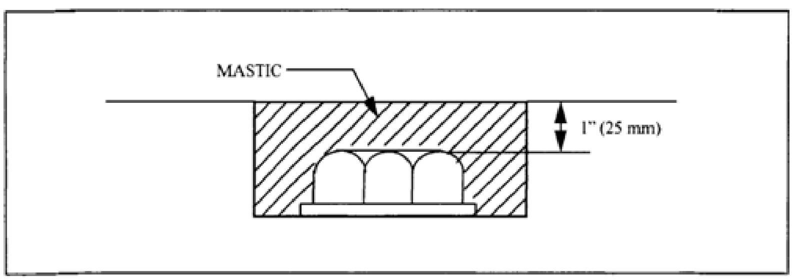


**Figure 2.8.1.5.2-1** Countersink depth for bolts in timber fendering

### 2.8.1.5.3 Debris Collection

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

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

### 2.8.1.5.4 Dolphins and Pier Protection Cells

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

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

**Figure 2.8.1.5.4-1 –** Pier dolphins

**Figure 2.8.1.5.4-2 –** Pier protection cell and fenders

**Figure 2.8.1.5.4-3 –** Nose dolphins

**Figure 2.8.1.5.4-4 –** Damaged pier protection cell

### 2.8.1.5.5 Kinematic Pier Protection Systems

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

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

### 2.8.1.5.6 Clearance Gauge Inspection

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

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

DEPARTMENT OF HOMELAND SECURITY
UNITED STATES COAST GUARD
BRIDGE ADMINISTRATION DIVISION
HEIGHT AND VERTICAL SPACING
FOR CLEARANCE GAUGE NUMERALS
33 CFR 118.160

*C2.8.1.5.5*

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

*C2.8.1.5.6*

*33 CFR § 117.47 (Reference 33) states that clearance gauges are required on movable bridges over navigable waters discharging into the Atlantic Ocean south of Delaware Bay, or into the Gulf of Mexico except the Mississippi River. See Reference 33, Part 117 Subpart A and Subpart B for exact listings on canals, Mississippi tributaries and requirements on specific movable bridges elsewhere. Gauges may be painted directly on the bridge channel pier or pier protection structure if the surface is suitable and has sufficient width to accommodate the foot marks (graduations) and numerals. Infrequently on opened higher level movable bridges the clearance in relationship to mean high water (MHW) may be painted right on the lift span. To make the clearance gauges more visible to the larger vessels or larger tows, the clearance gauges may be mounted on top of the fender system (see Figure C2.8.1.5.6-1). These gauges are also illuminated for nighttime navigation. These and the other board gauges*

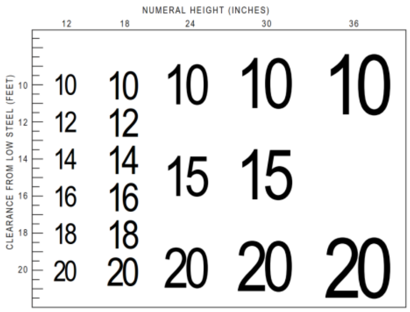


**Figure 2.8.1.5.6-1 –** Relative sizes of clearance gauges

- On bridges where clearance gauges are required by federal regulations, at least two clearance gauges should be present indicating the vertical distance between "low steel" of the bridge channel span and the level of the water, measured to the bottom of the foot mark, read from top to bottom.
- Each gauge should be located on the end of the right channel pier or pier protection structure, facing approaching vessels. The range of the gauge should cover at least the distance between low steel to the low level of the water.
- Does the gauge extend to a reasonable height above high water so as to be meaningful to the viewer, as in Figure 2.8.1.5.6-2?
- Is each gauge permanently fixed to the pier or pier protection structure?
- Is the gauge made of durable material of sufficient strength to provide resistance to weather, wind, tide, ice, and current?
- Is each gauge marked by black numerals and foot (meter) marks on a white background? Paint, if used, should be of "good" exterior quality and resistant to excessive chalking or bleeding. Manufactured numerals and background material may be used.
- Navigation lights, signs, and pilings should not obstruct the view of the mariner to clearly read the gauge.

*can be made using retroreflective material. The lighting can be by a shielded light that shines on the clearance gauge without blinding the mariner or destroying his night vision or by the use of lite pipes with the numbers mounted on the pipes. The lite pipes provide background illumination around the numbers. Digital electronic gauges may also be installed in addition or as an alternative to the standard gauges prescribed in 33 CFR § 118.160.*


***Figure C2.8.1.5.6-1 –** Clearance mounted on fender*

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

### 2.8.1.6 Operator's (Tender's) House

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

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

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

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

*C2.8.1.6*

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

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

- Refer to Section 2.8.3.13 for the requirements to inspect the control console.

### 2.8.1.7 Traffic Signs and Signalizations

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

- Observe the device during a complete operation cycle. Check structural supports and connections for movement during operation.
- Check connections between the device and its structural supports for loose or missing fasteners, cracks, or other defects.
- Check members of the structural supports in accordance with the current criteria for the inspection of fixed bridges listed in Chapter 1.2 of this Manual, and MUTCD regulations (Reference 73).
- Check connections between the structural support and its foundation structure for loose or missing fasteners, cracks, settlement, displacement, or other defects.

#### 2.8.1.7.1 Resistance Gates

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

- Observing the gate during a complete operation cycle. Check structural supports and connections for movement during operation.
- Check connections between the barricade and its structural supports for loose or missing fasteners, cracks, or other defects.
- Check members of the structural supports in accordance with the current criteria for the inspection of bridges listed in Chapter 1.2 of this Manual and NCHRP Report 350, *Recommended Procedures for the Safety Performance Evaluation of Highway Features*.
- Check connections between the structural support and its foundation structure for loose or missing fasteners, cracked

welds, fatigue cracks, settlement, displacement or other defects.

## 2.8.2 – MECHANICAL INSPECTION PROCEDURES

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

The mechanical components are intended to provide a controlled, appropriate type of motion. Controlled means moving only when authorized and at the correct speed. Appropriate motion means that only the intended motion (e.g. horizontal rotation) is provided while other types of motion—vertical rotation, horizontal translation (sliding) and vertical motion—are prevented by the machinery.

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

*C2.8.2*

*There are many ways in which complex machinery can fail to perform its intended function. More than 80 percent of the movable highway bridges in the United States were built prior to 1970 and almost 50 percent were built before 1940. Time, wear, environmental conditions, and degree of maintenance can have a deleterious effect on the condition of aged components.*

*To avoid duplication, mechanical components have been grouped into a general and a special machinery section. The components in Chapter 2.8.2.10 are common to most types of movable bridge: swing, bascule, and lift spans. Chapter 2.8.2.11 covers mechanical components that are unique to each specific movable bridge type. Inspection of brakes is covered in Chapter 2.8.3.*

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

### 2.8.2.1 Open Gearing

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

Two types of gears, spur and straight bevel, are normally used

*C2.8.2.1*

*Open gearing presents a potential hazard to inspectors and maintainers during operation of the bridge. Reference 55 (OSHA) requires enclosures or guards on gears, sprockets, and chains in 1910.219f.*

*Caution: Before removing covers or touching gears or other moving parts, be certain the bridge operator clearly* as open gearing on movable bridges. However, other types: helical, herringbone, spiral bevel, and worm gears, may be present in encased speed reducers. Spur gears transmit power and regulate the speeds of parallel shafts while bevel gears perform the same function for shafts that are mounted at an angle to one another, usually 90°.

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

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

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

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

*understands that the machinery is not to be operated until sufficient notice is given to the inspection team and he receives a positive response that it is okay to proceed with operation. If possible, inspectors should mechanically lock out power or the controls to prevent operation and possible accidents.*

*Inspection of open gearing is complicated by the presence of covers, lubricant, and other coatings that may obscure the defects. Inspectors should have flashlights, inspection mirrors, borescopes, or other inspection aids as necessary to perform gear inspection without the need to disassemble guards unless such disassembly is scheduled as part of the work. It may be necessary to steam or solvent clean open gearing during inspection to check for defects in the teeth. The contact height of the wear zone typically increases over time as the teeth "wear in." The critical dimension for determining percentage of full faced contact is the width of the wear zone as compared with the full possible width of the tooth contact. Pinions are often wider than the teeth they engage, so 100 percent full face contact on a pinion may occur over less than the full width of pinion tooth.*

*Information about gear mechanics, gear tooth shapes, and formulae and examples for determining the gear tooth dimensions is provided in Appendix B – Gear Mechanics.*

### 2.8.2.1.1 Gear Alignment

Proper alignment of gear sets is critical to reliable, efficient performance. Misaligned gears are subject to accelerated wear and/or fracture of teeth due to overstress. Correct alignment is

*C2.8.2.1.1*

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

defined as the condition where the tooth faces of the gear and pinion are parallel, the full effective faces are in contact and the proper amount of backlash is present. Backlash is the space between adjacent, non- contacting teeth. It may be thought of as the freedom of one gear to move while the mating gear is held stationary. All gear sets require backlash in order to provide a space that allows for the presence of lubricant and that prevents engagement of both tooth faces at the same time.

### 2.8.2.1.1.1 Spur Gears

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

There are several frequently encountered conditions that cause misalignment that the inspector should be able to identify quickly. It must be remembered that the bridge machinery gearing is required to transmit loads when the bridge is being opened as well as during closing so that contact, and resultant wear, will be present on both sides of the teeth.

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

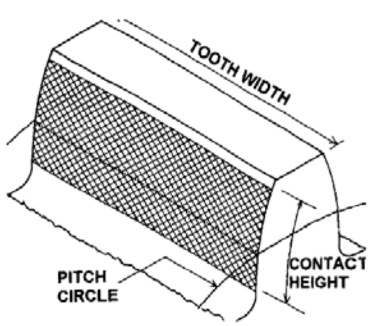


**Figure 2.8.2.1.1.1-1 –** Shaded area indicates the contact wear zone of a well aligned tooth.

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

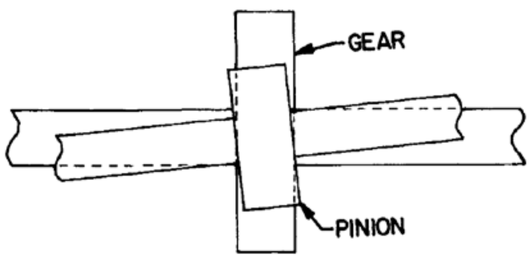



**Figure 2.8.2.1.1.1-2 –** Out of parallel shafts cause cross bearing in the gear set

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

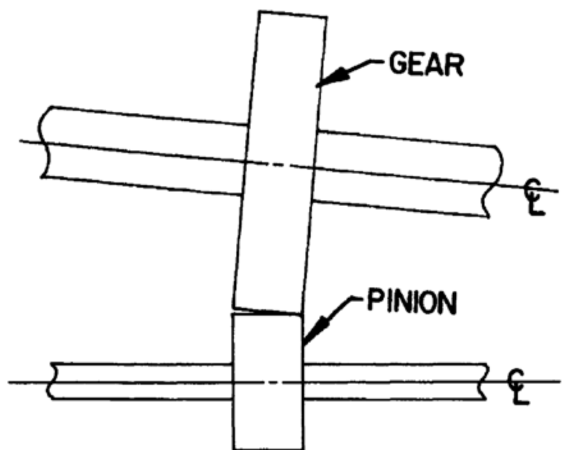



**Figure 2.8.2.1.1.1-3 –** Convergent, nonparallel shafts result in end load

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

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

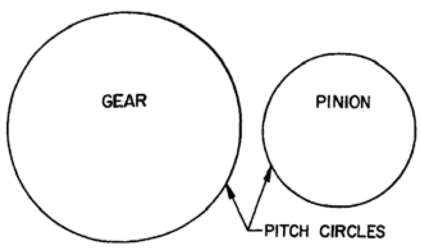



**Figure 2.8.2.1.1.1-4 –** Separated pitch circles show the center distance is too great

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

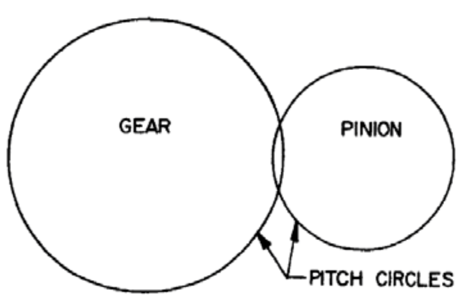



**Figure 2.8.2.1.1.1-5 –** When pitch circles are overlapped, the center distance is too short

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

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

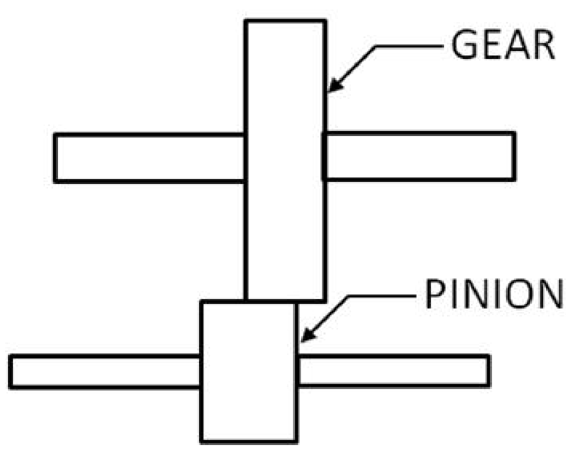



**Figure 2.8.2.1.1.1-6 –** Axial misalignment

### 2.8.2.1.1.2 Bevel Gears

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

*C2.8.2.1.1.2*

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

for these discussions.

- End-loading will occur at the heel of the teeth if the angle of engagement is greater than 90°, as in Figure C2.8.2.1.1.2-1. If the angle is less than 90°, end-loading will be present at the toe end of the teeth.
- Cross bearing results when the shaft centerlines are not in the same plane and do not intersect, Figure 2.8.2.1.1.2-3.

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

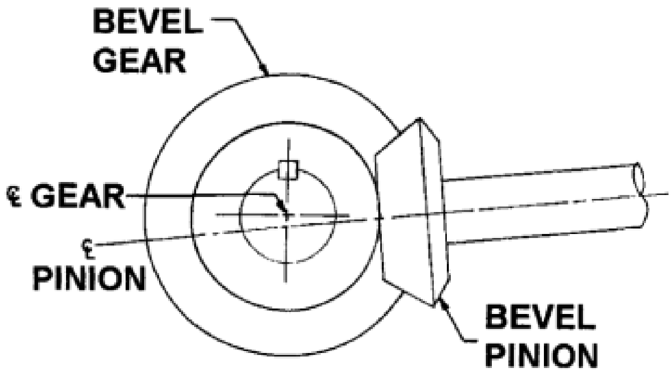



**Figure 2.8.2.1.1.2-3 –** Non-intersection of shaft centerlines causes cross bearing in bevel gears

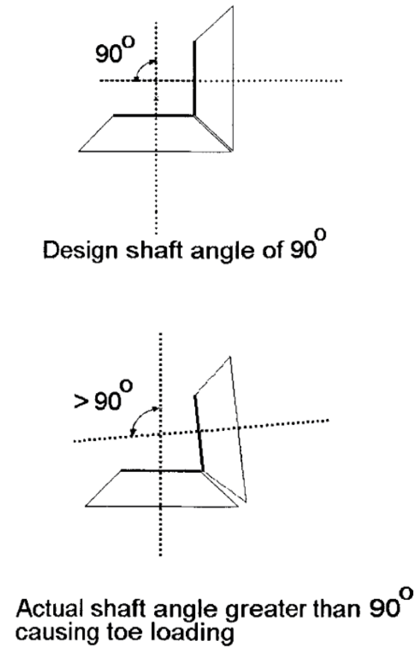



***Figure C2.8.2.1.1.2-1 –** Toe loading due to actual shaft angle being greater than the design shaft angle*

### 2.8.2.1.2 Gear Tooth Wear Measurements

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

*C2.8.2.1.2*

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

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

### 2.8.2.1.2.1 Measuring Gear Teeth

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

*C 2.8.2.1.2.1*

*The purpose of accurately measuring gear teeth is to determine how much wear has occurred by comparing the present tooth*

## CHAPTER 2.8 – PROCEDURES

Figure 2.8.2.1.2.1-1 schematically illustrates the use of a vernier tooth caliper. The vertical vernier scale is set to the proper chordal addendum and the caliper placed squarely on the tooth so the vertical anvil is tangent to the tooth outside diameter at the tooth midpoint. The horizontal vernier scale then measures the chordal tooth thickness at the pitch line. In order to have the caliper firmly seated on the tip of the tooth any burrs, fins or other upset metal should be filed off. Chordal thickness should be measured at both ends and the midpoint of spur gear teeth. On bevel gears, tooth thickness readings are taken both at the large end, and heel, of the tooth.

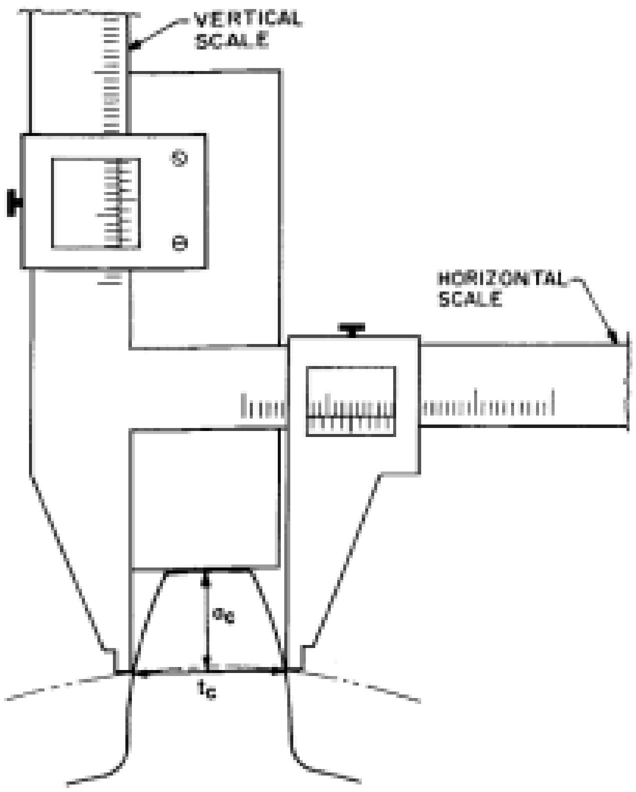



**Figure 2.8.2.1.2.1-1** – Vernier tooth caliper

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

*thickness to the original amount. To do this, it is necessary to know the original thickness. Sometimes the chordal dimensions are given in the as built drawings. Another possible source is previous inspection reports. Often this information will not be available and the inspector will be required to calculate the original measurements from the pitch, number of teeth, pressure angle, pitch diameter and backlash. See Appendix B – Gear Mechanics for worked examples for calculating chordal addendum and original chordal tooth thickness for a given gear tooth.*

tangent to the tooth faces over which the measurement is being made.

Obtaining span measurements is restricted to the length of vernier caliper available. Usually it is impractical to use verniers over 24 in. (610 mm) long in the field so that when span dimensions are longer than the available caliper tooth measurements should be made with tooth verniers. Racks on swing spans and trunnion bascules as well as ring gears on counterweight sheaves and operating rope drums on vertical-lift bridges are typical locations that are not suitable for making span measurements.

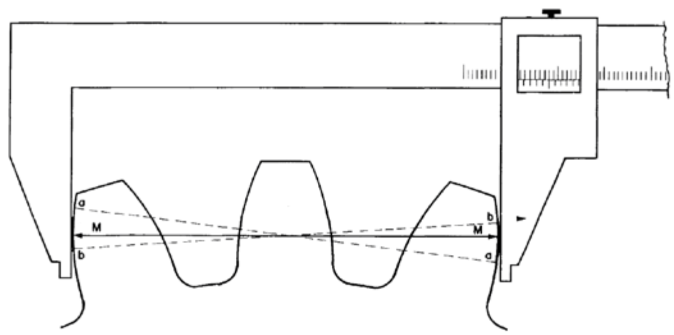


**Figure 2.8.2.1.2.1-2 –** Taking span measurements using a vernier caliper. The caliper jaws do not need to be on the pitch line; chords M-M, a-a, and b-b are all equal.

### 2.8.2.1.3 Appearance and Identification of Gear Tooth Wear and Destruction

From the instant gears are installed on a bridge they are subject to wear and deterioration. Most wear occurs during operation of the span but gears are also exposed to adverse influences of the environment. Dirt and debris, rust and corrosion, the presence of foreign materials and shock loads caused by improper adjustment of the locks and live load shoes all have adverse effects even when the leaf is not moving. Reference 18, ANSI/AGMA 1010-E95, *American National Standard – Appearance of Gear Teeth – Terminology of Wear and Failure* (2007), extensively covers the subject of gear tooth wear and destruction, including photos; this standard should guide Mechanical movable bridge inspectors' reporting on gear condition.

### 2.8.2.1.3.1 Wear

Operating gears are subjected to wear from many sources. Improper, inadequate or abrasive materials in the lubricant;

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

### 2.8.2.1.3.1.1 Polishing

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

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

### 2.8.2.1.3.1.2 Abrasive and Corrosive Wear

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

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

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

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

### 2.8.2.1.3.1.3 Tip and Root Interference

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

### 2.8.2.1.3.1.4 Scuffing

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

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

### 2.8.2.1.3.2 Surface Fatigue

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

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

### 2.8.2.1.3.2.1 Pitting

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

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

### 2.8.2.1.3.2.2 Spalling

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

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

### 2.8.2.1.3.3 Plastic Flow

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

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

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

### 2.8.2.1.3.4 Tooth Breakage

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

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

### 2.8.2.1.3.5 Gear Tooth Wear Observations and Inspections

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

Before cleaning away the lubricant during routine

*C2.8.2.1.3.5*

*A pinion having a width greater than the gear can be checked by taking gear tooth or span measurements on the unworn portion of the tooth. The measurements should ideally be made early in the life of new gears when the as measured dimensions may be slightly more than the standard values. If such an unworn shoulder exists, it will serve as an independent* inspections, visually observe the gear sets in operation. Watch for any peculiar movement of the gears and listen for any unusual and/or loud noises. Then inspect each gear set for signs of misalignment, “poor” tooth contact and other indications of distress. Take color photographs of the teeth.

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

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

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

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

### 2.8.2.2 Enclosed Gearing

Gear sets that are mounted in dust proof, oil tight housings are generally referred to as enclosed gearing. These assemblies are also generally called speed reducers. In most cases, they are manufactured by companies that specialize in the design and manufacture of mechanical power transmission equipment. Those in movable bridge usage are normally special units,

*check of calculated standard dimensions in the gear tooth thickness inspection forms.*

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

custom-made for the application and are not available as standard, stocked items. See Figure 2.8.2.2-1.

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

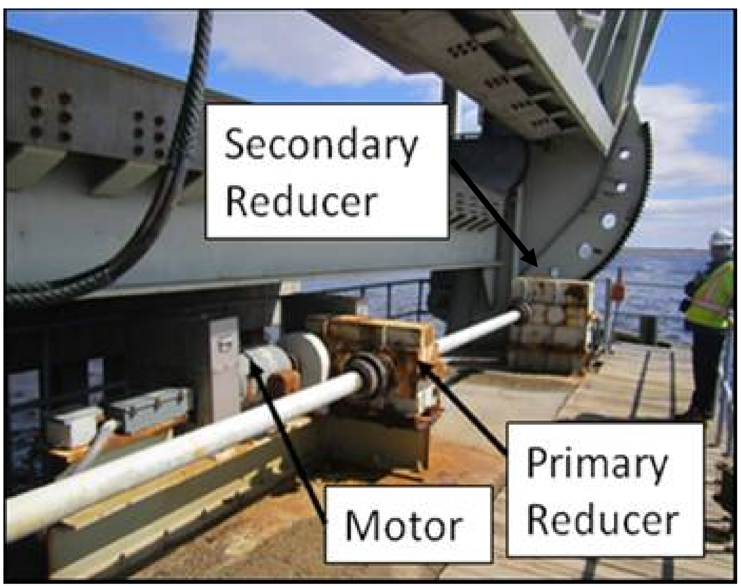



**Figure 2.8.2.2-1 –** Primary and secondary reducers on a bascule bridge

Bearings supporting the shafts are typically ball or roller type as required by Reference 7. They have typically been selected very conservatively and usually have extremely long service lives. Prior to adopting the use of anti-friction bearings as usual design practice, sleeve type bronze, or occasionally babbitt, bearings supported the shafts. Many of these sleeve bearing units are still in service today, but are more prone to wear and should be carefully checked for excessive radial clearance during inspection.

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

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

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

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

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

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

Performance records of reducers on movable bridges indicate they have very long service lives. It is not unusual for speed reducers on movable bridges to provide trouble free operation for more than 50 years. Enclosed gearing is more prevalent in newer designs and at present Reference 7 states that speed reducers should be used in preference to open gearing for new movable bridge designs.

### 2.8.2.2.1 Parallel Shaft Reducers

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

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

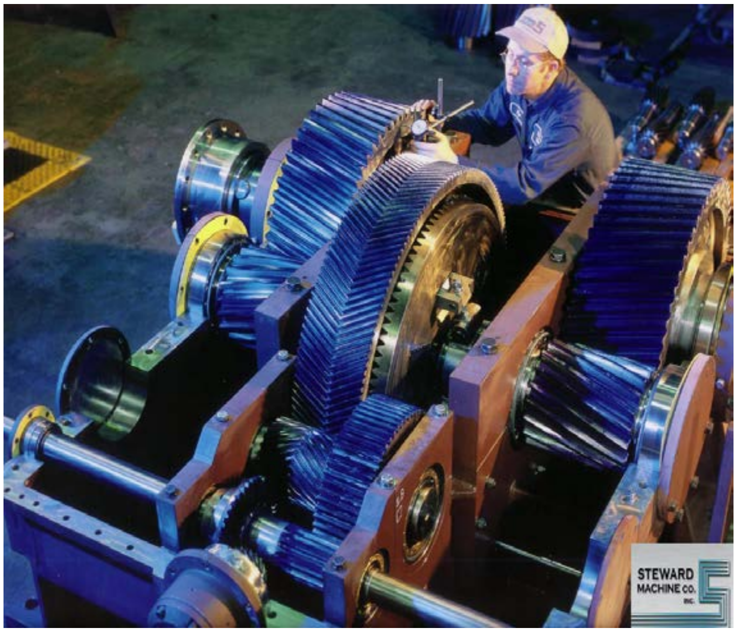



**Figure 2.8.2.2.1-1 –** Balanced helical/herringbone gear, parallel shaft speed reducer with a differential

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

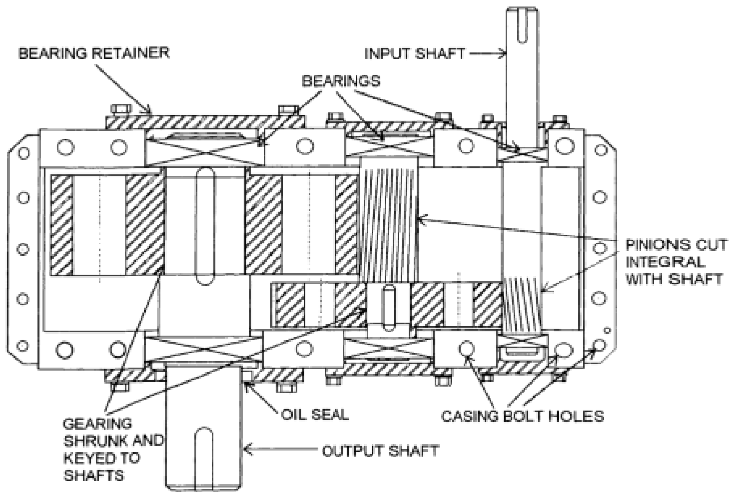



**Figure 2.8.2.2.1-2 –** Offset helical gear parallel shaft speed reducer

### 2.8.2.2.2 Right-angle Reducers

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

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

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

*C2.5.3.2*

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

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

### 2.8.2.2.3 Differential Reducers

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

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

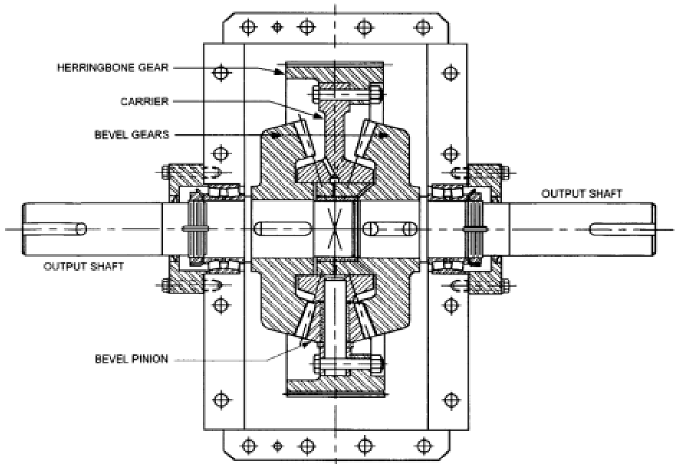



**Figure 2.8.2.2.3-1 –** Cross-sectional view of bevel gear type differential

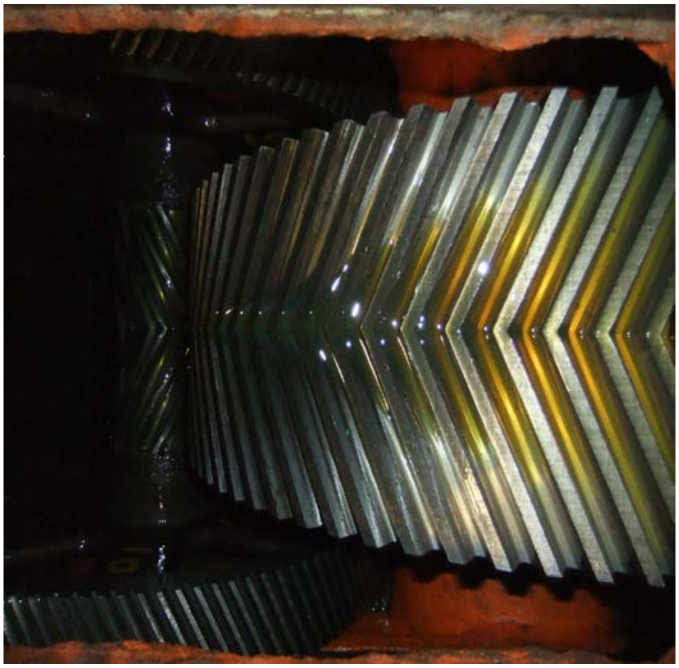


**Figure 2.8.2.2.3-2 –** Close-up of herringbone type gear

### 2.8.2.2.4 Inspection

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

*C2.8.2.2.4*

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

### 2.8.2.2.4.1 External Inspection

During routine inspections:

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

### 2.8.2.2.4.2 Operational Inspection

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

- Observe the entire unit, particularly as the span starts to raise and again as it is seating, to see if there is any small movement of the unit during starting and stopping of the span. If the anchor or turned bolts are not secure the unit may move slightly when torque is increased or reduced during acceleration or deceleration of the span.
- Look for any radial or axial movement of the input and output shafts relative to their bearings.

- Listen carefully for any abnormal noises. A correctly functioning reducer should run quietly. Noises can indicate a problem. Unusual metallic sounds, a whine, clunks, screeches, or hard knocks indicate some part is worn, deformed, out of position and/or not properly lubricated. If possible, check the operational noises with a decibel sound meter. Periodic checks will reveal any changes in noise level and alert the inspector to possible problems.

### 2.8.2.2.4.3 Internal Inspection

During in-depth inspections:

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

*C2.8.2.2.4.3*

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

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

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

distribution pipes or tubes.

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

### 2.8.2.3 Bearings

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

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

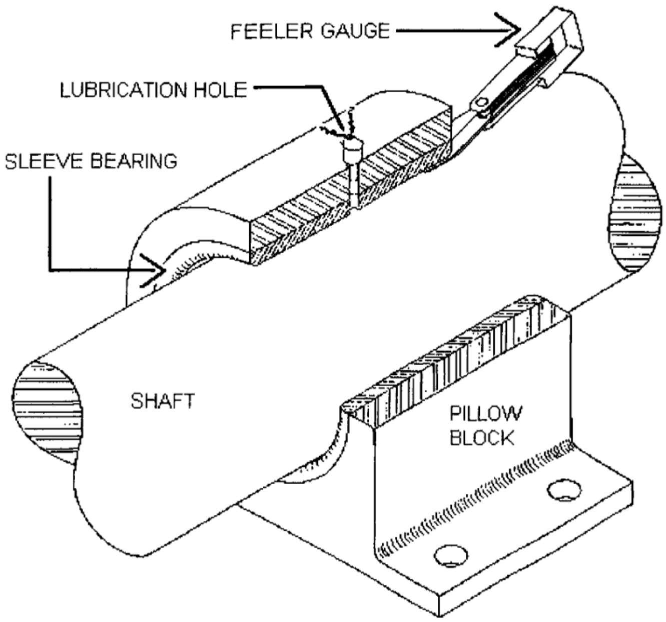



**Figure 2.8.2.3-1 –** A sleeve bearing pillow block supporting a transverse shaft

### 2.8.2.3.1 Sleeve Bearings

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

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

Often split bearings were used to facilitate assembly in locations where the bearing is positioned between a gear and coupling, or other member, that makes installation and removal difficult. These split units have the same elements as a one piece

*C2.8.2.3.1*

*Clearance on split sleeve bearings is typically accomplished by use of shims. If the bearings are opened, inspectors should exercise care not to misplace or damage the shims and also to match mark shim locations to provide for proper reassembly* housing unit except the sleeve bearing and housing are split along the longitudinal center line, Figure 2.8.2.3.1-1.

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

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

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

Sleeve bearings may be lubricated with either oil or grease. Generally speaking, bearings in enclosed housings and designed to operate at higher speeds are oil lubricated, while those in solid or split housings designed to work at lower speeds (possibly not even making a full revolution) are grease lubricated. Examples of oil lubrication are inside speed reducers or electric motors. Grease lubrication examples are transverse and longitudinal span drive shaft support bearings, or crank and lever bearings on wedge drive systems. In most cases the housings will be equipped with grease fittings or oil cups for replenishing the lubricant. Occasionally, the lubricant is introduced through drilled openings in the shaft and fittings will be located on the shaft's end. Figure 2.8.2.3.1-3.

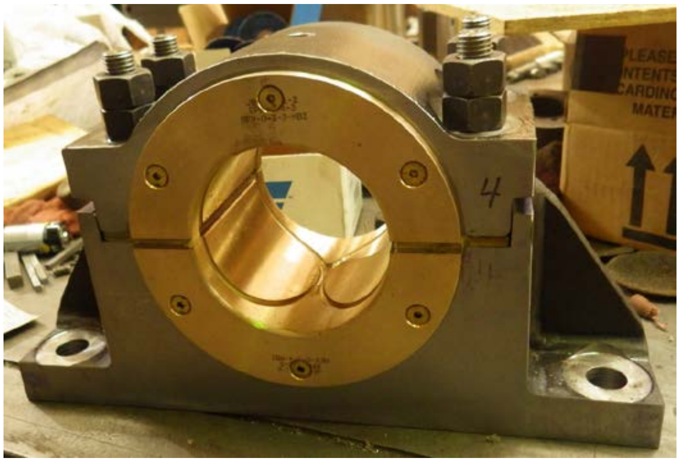


**Figure 2.8.2.3.1-1 –** A split pillow block (Image Credit: Steward Machine Company)

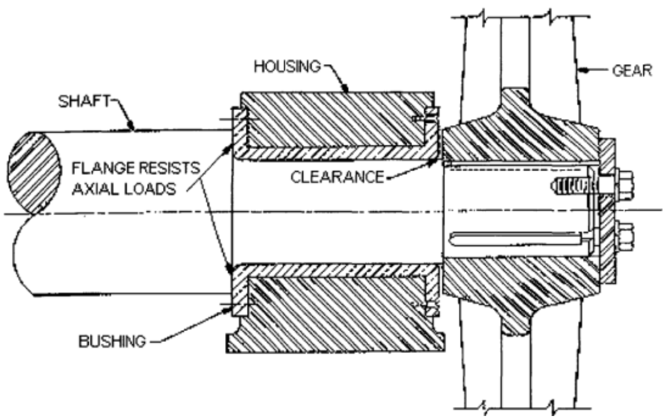



**Figure 2.8.2.3.1-2 –** Flanges on a sleeve bearing may support axial loads and locate the shaft

### 2.8.2.3.1.1 Inspection

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

- Examine the bearing support for signs of distress or cracking and check all foundation, or mounting bolts and nuts.
- Clean and check the entire housing exterior for cracks and/or corrosion and note general overall condition. Make certain the cap bolts and nuts are secure and not deteriorated, cracked or loose. Observe the lubrication fittings to make certain they are in place and function

*C2.8.2.3.1.1*

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

*Two methods may be used to determine bearing clearances.*

*Feeler gauges as shown in Figure 2.8.2.3.1.1-1 may be used without disassembly. This method would be used during routine inspections on split sleeves and in all cases on solid sleeve bearings.*

*Disassembly and direct measurement of the ID of the sleeve and the shaft on split sleeve bearings allows accurate measurement with a vernier caliper or micrometer and also permits* properly, as in Figure 2.8.2.3.1.1-1. Inspect the fillet areas, in-depth, between the feet and body of pillow blocks and between the flanges and body of flange units, for cracks. At times these cracks will be readily visible to the naked eye; however, suspect areas should be checked with dye penetrant, as in Figure 2.8.2.3.1.1-2.

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

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

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

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

**Figure 2.8.2.3.1.1-1 –** Corroded pillow block

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

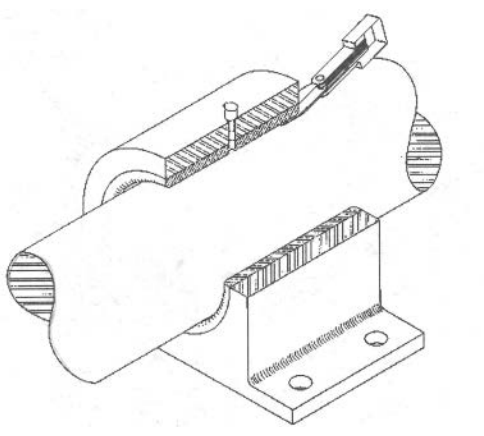


**Figure 2.8.2.3.1.1-3** – Measuring internal clearance in a sleeve bearing with feeler gauges

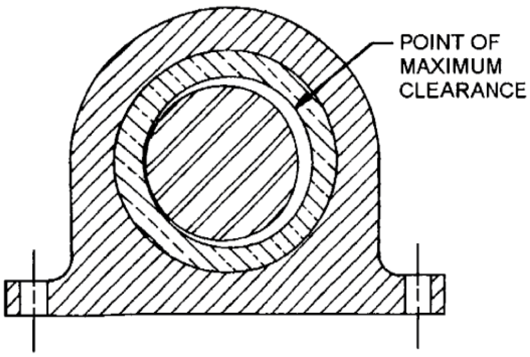



**Figure 2.8.2.3.1.1-4A –** Maximum clearance is not always at the top of the shaft

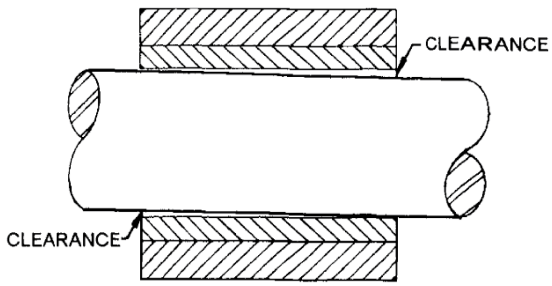



**Figure 2.8.2.3.1.1-4B –** Checking both ends of the bearing will help in revealing shaft misalignment

### 2.8.2.3.2 Anti-friction Bearings

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

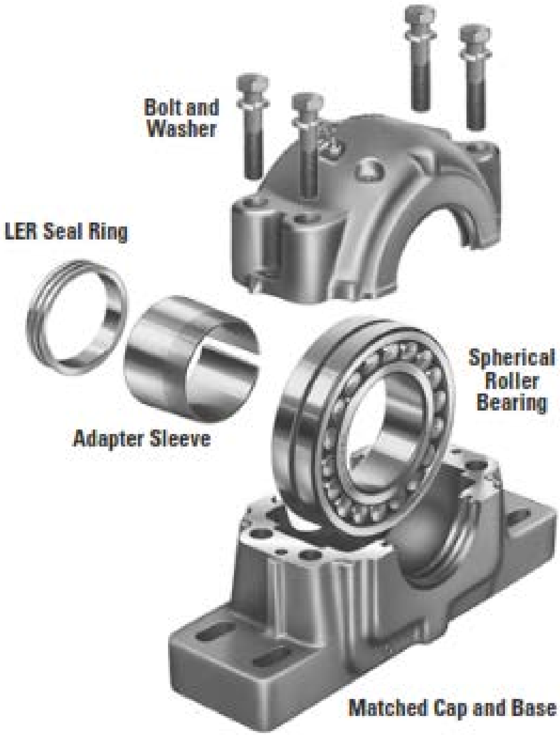



**Figure 2.8.2.3.2-1 –** A roller bearing pillow block with its bearing cap removed (Image Credit: Torrington)

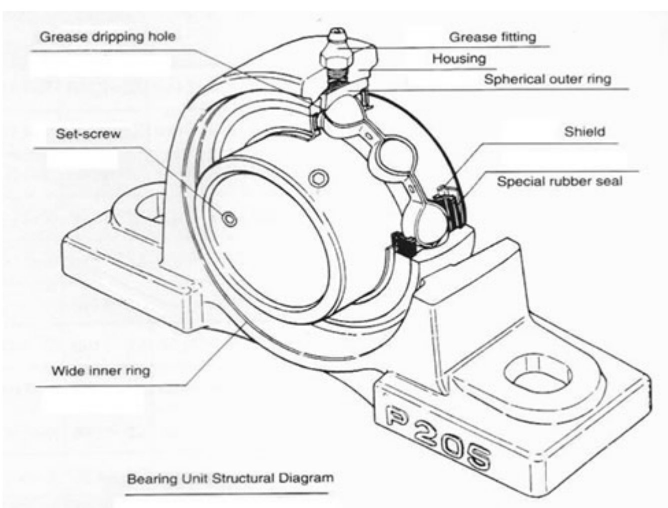



**Figure 2.8.2.3.2-2 –** A ball bearing pillow block. (Image Credit: Sup Bearing)

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

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

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

### 2.8.2.3.2.1 Inspection

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

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

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

### 2.8.2.3.3 Trunnion Bearings

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

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

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

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

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

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

### 2.8.2.3.3.1 Inspection

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

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

## 2.8.2.4 Shafts, Couplings, and Brakes

### 2.8.2.4.1 Shafts

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

In general, there are few problems with properly designed shafts. When problems do arise, cracking is the most usual defect. Normally cracking originates in an area of stress concentration, such as a keyway or shoulder where the shaft

*C2.8.2.4.1*

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

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

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

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

### 2.8.2.4.1.1 Inspection

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

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

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

- In some cases the areas to be inspected are not readily accessible and inspection of them would require removing the bridge from service for an extended period of time. If cracks are suspected in such locations the inspector should

*C2.8.2.4.1.1*

*Nondestructive testing is discussed at length in Reference 9, Chapter 4. For the convenience of users of this Manual, portions of the data therein is reproduced in Chapter 2.10 of this Manual. The discussion in this portion of the text is limited to general recommendations specific to the inspection of the shafts, where cracking is a key problem requiring special attention.*

recommend that further in-depth examination be scheduled as soon as possible. Nondestructive means, such as ultrasonic or radiographic inspections, are frequently used to examine areas that are hidden from view. These methods should be performed only by experienced technicians using specialized equipment (see Chapter 2.10).

### 2.8.2.4.2 Couplings

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

### 2.8.2.4.2.1 Rigid Couplings

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

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

### 2.8.2.4.2.1.1 Inspection

During routine inspections:

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

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

### 2.8.2.4.2.2 Flexible Couplings

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

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

### 2.8.2.4.2.2.1 Gear Couplings

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

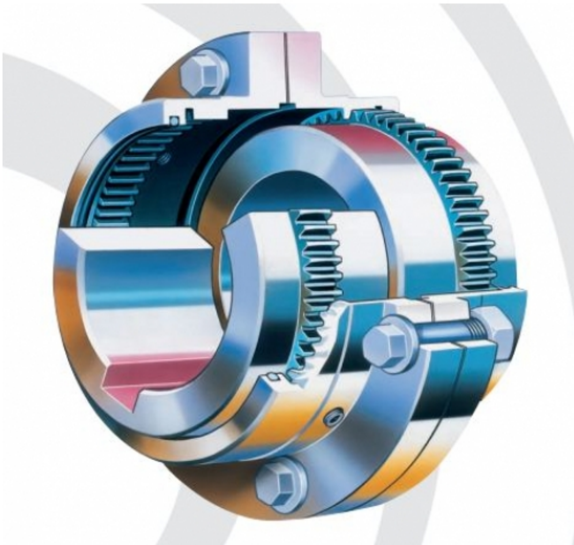


**Figure 2.8.2.4.2.2.1-1 –** Gear coupling (Image Credit: Falk)

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

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

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

### 2.8.2.4.2.2.2 Grid Couplings

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

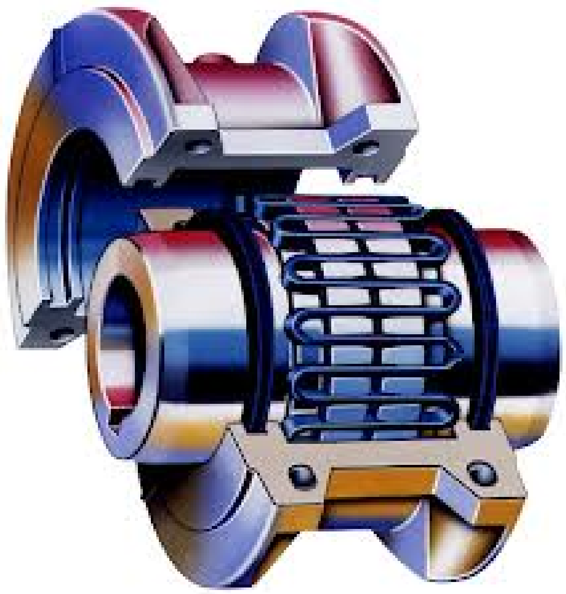


**Figure 2.8.2.4.2.2.2-1 –** Grid Coupling (Image Credit: Falk)

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

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

### 2.8.2.4.2.2.3 Chain Couplings

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

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

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

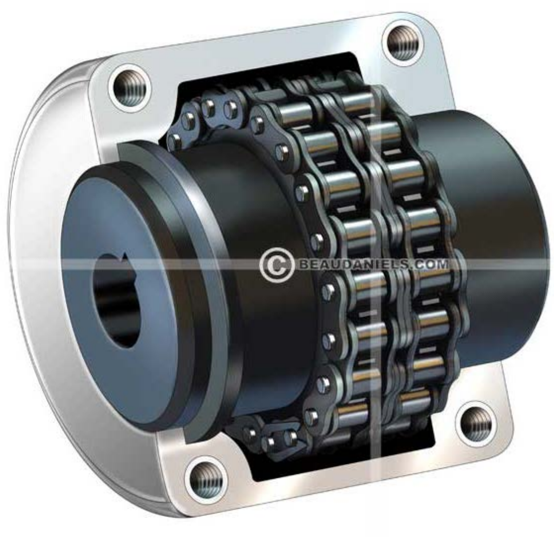



**Figure 2.8.2.4.2.2.3-1 –** Chain coupling (Image Credit: Beau Daniels)

### 2.8.2.4.2.2.4 Insert Couplings

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

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

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

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

### 2.8.2.4.2.2.5 Jaw Type Couplings

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

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

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

### 2.8.2.4.2.2.6 Inspection of Flexible Couplings

During routine inspections:

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

- Visually inspect jaw type couplings for corrosive deterioration or cracks in lugs. Inspect keyways for tightness and cracks.
- When jaw type couplings are used as clutches, make certain that they are adequately lubricated and can be engaged and disengaged as necessary.

**Figure 2.8.2.4.2.2.6-1 –** Interior of a well lubricated grid coupling. Note broken grids

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

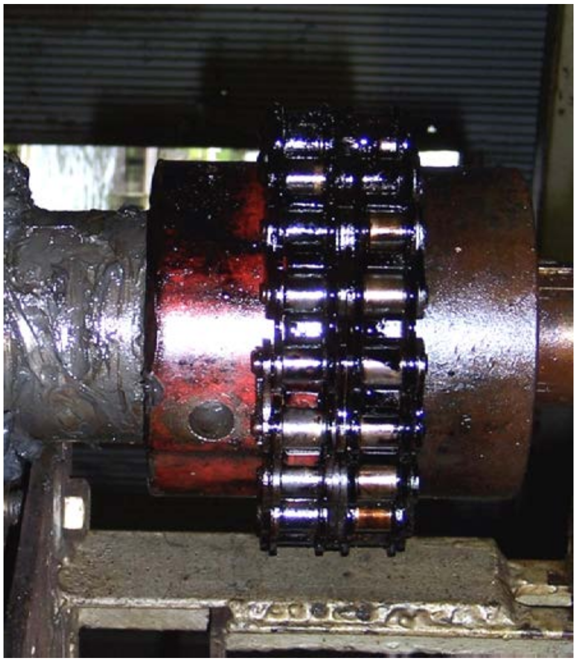


**Figure 2.8.2.4.2.2.6-2 –** Chain coupling in service without a protective cover

### 2.8.2.4.3. Brakes

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

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

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

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

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

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

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

### 2.8.2.5 Buffer Cylinders

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

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

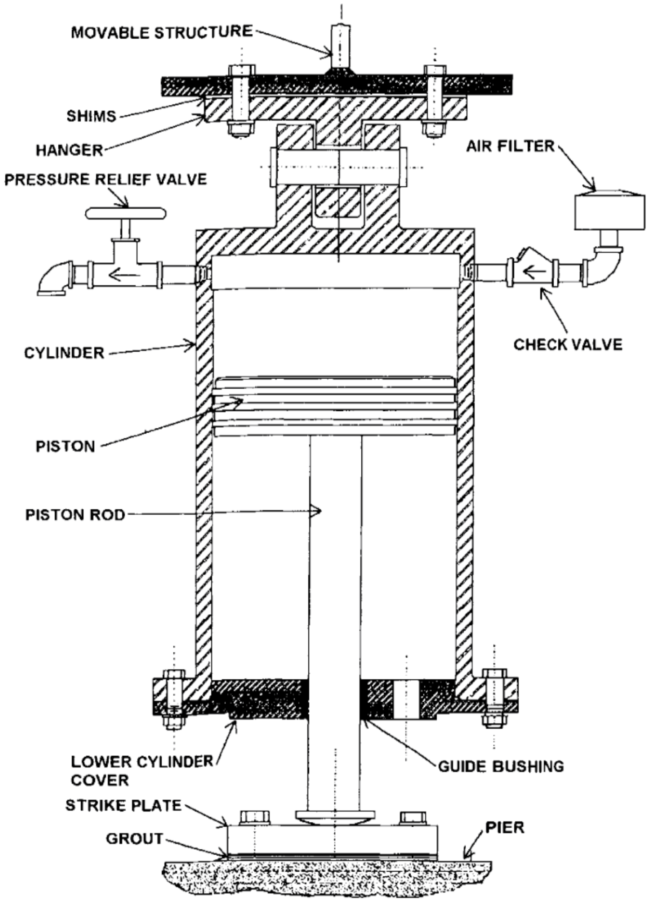



**Figure 2.8.2.5-1 –** Construction of a typical buffer cylinder

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

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

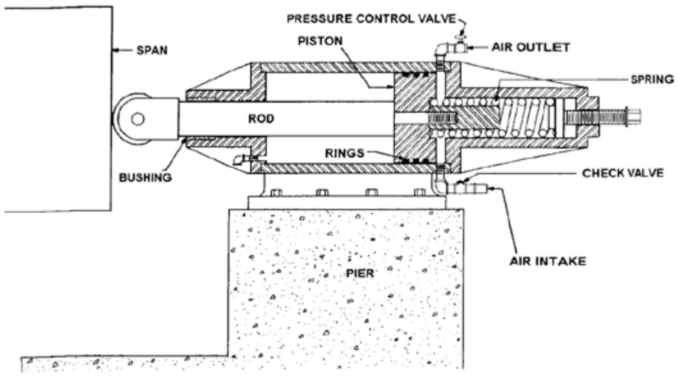



**Figure 2.8.2.5-2 –** Section of a horizontal buffer

### 2.8.2.5.1 Inspection

During routine inspections:

- Watch the buffers in operation during cycling of the leaf. The piston rod should withdraw smoothly to the fully extended position as the leaf opens. If it does not, it could indicate the inside of the cylinder is not properly lubricated, the guide bushing is binding the piston rod or is not lubricated, there is foreign material and/or wear that is causing the piston to hang up, the check valve is not permitting air to flow into the cylinder, or, in the case of horizontal buffers, the spring may be broken.
- When the leaf is closing, the piston rod should contact the strike plate somewhere near its center, Figure 2.8.2.5.l-1. As the piston is forced into the cylinder, air should escape only through the control valve on the outlet pipe. No air should escape through the inlet; if it does, the check valve is not functioning properly. This is important because if the inlet valve is faulty, the cylinder may appear to be working properly but will not be building up any pressure; hence, no retarding force and corrective action is required. Shock loading may, of course, result. Also, bridges with modern control systems may not require buffers.
- Check the air filter on the inlet pipe for cleanliness.
- Inspect the piston rod for scoring, rust, and lubrication. If it is rusty and has no lubricant coating the bushing is probably not being properly lubricated. Scoring of the rod can indicate bushing wear or the presence of grit, metal particles, or both in the lubricant.

**Figure 2.8.2.5.1-1 –** Buffer cylinder, and piston rod. Note that the buffer is heavily corroded and not functional.

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

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

During an in-depth inspection:

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

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

### 2.8.2.6 Live Load Shoes

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

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

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

*C2.8.2.6*

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

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

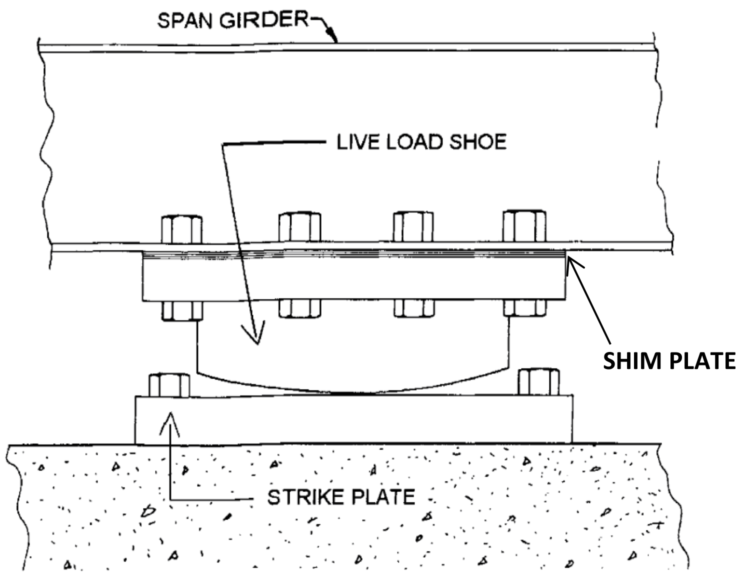



**Figure 2.8.2.6-1–** Live load shoe and strike plate

### 2.8.2.6.1 Inspection

During routine inspections:

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

### 2.8.2.7 Threaded Fasteners

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

### 2.8.2.7.1 Anchor Bolts

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

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

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

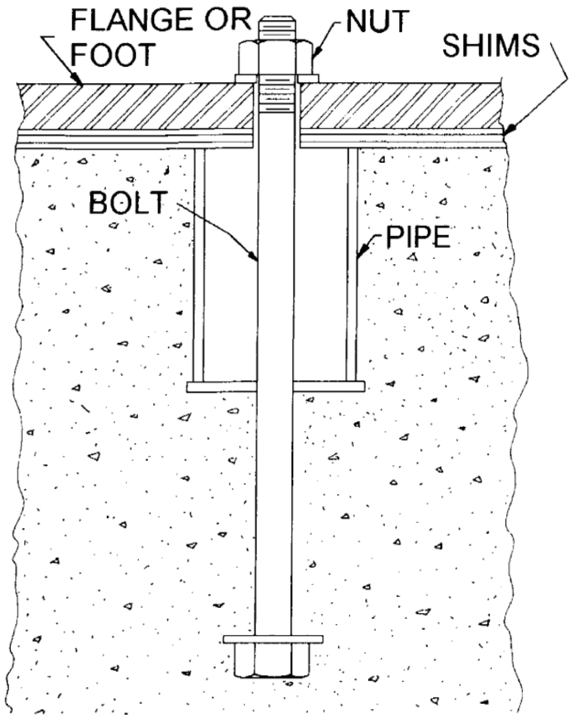



**Figure 2.8.2.7.1-1 –** Sleeved anchor bolt

### 2.8.2.7.2 Turned Bolts

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

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

*C2.8.2.7.2*

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

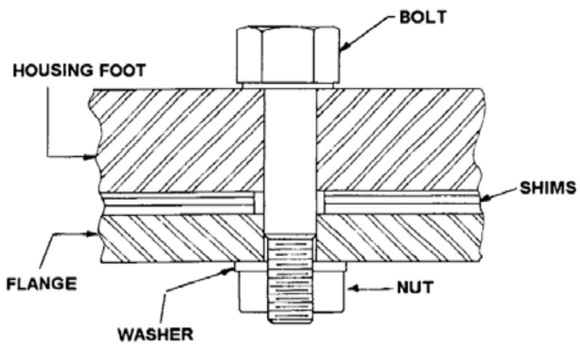



**Figure 2.8.2.7.2-1 –** Turned bolt

### 2.8.2.7.3 Inspection

During routine inspection, check the following:

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

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

### 2.8.2.8 Emergency and Manual Drives

### 2.8.2.8.1 Emergency Drive Engines

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

### 2.8.2.8.2 Manual Drives

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

**Figure 2.8.2.8.2-1 –** Manual drive on a swing bridge

### 2.8.2.8.3 Inspection

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

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

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

- Check each emergency drive for proper operation. The

*C2.8.2.8.3*

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

bridge operator should know the location of hand cranks, chains and other removable components of the system.

- Install them and confirm they fit.
- Engage and disengage all clutches and cutout couplings and make certain the system is capable of moving the leaf.
- Have the bridge operator start up the auxiliary engine and operate the bridge using emergency power. If the emergency system has recently been used, the inspector may review the associated operations log in lieu of performing an emergency test operation during the inspection.

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

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

### 2.8.2.8.4 Air Motors

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

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

2,000 rpm.

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

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

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

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

### 2.8.2.8.4.1 Inspection

During routine inspection, check the following:

- Check mounting bolts, structural supports, and base castings for looseness and cracks.
- Check the function of the system through one full operating cycle and monitor system pressure; check for leaks, unusual sounds or behavior. Verify that the system runs at an appropriate speed without major speed variations and that valves, filters, regulators, and oiler assemblies are present and functional per the system plans. Lubricators should always be present and are generally installed at the inlet side of the motor. Since it is undesirable for oil laden air to exit freely to the environment, it is generally necessary for a two stage liquid separator filter to be present on the motor outlet side. On reversible motors, these requirement lead to either duplicate lubricators and filters or a complex inlet/outlet piping configuration to run air in alternating directions through a single filter and lubricator.
- Check that hoses, fittings, valves, and piping are tight, free from deterioration that could lead to an air leak or a line failure during operation.

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

### 2.8.2.9 Shrink Fits With and Without Clamping Sleeves

Coupling attachments (and many other attachments to shafts) often include keyways machined in the shaft longitudinal dimension in the OD of the shaft and the ID of the fitted part hub. The usual design involves a key that is separate piece fitting into the longitudinal grooves machined into the shaft hub. The fit and finishing requirement of the hub, shaft slots and keys is as specified in the contract plans, but subject to recommended minimum requirements published in Reference 7 and also to manufacturers' recommendations that may at times exceed Reference 7 or contract plan requirements.

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

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

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

### 2.8.2.10 Machinery Coding Recommendations

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

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

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

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

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

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

If found by assessment to be “non-severe,” cracks should be closely monitored to determine the rate of crack propagation

*C2.8.2.10*

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

and the owner should prepare contingency plans to be implemented in the event of shaft failure. Such contingency plans should remain in force until the cracked shaft(s) are replaced or repaired.

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

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

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

**Fasteners** that show signs of movement should be checked for nut tightness, cracks or breaks. Loose fasteners that are on structural parts are less likely to be “severe” than if they are turned machinery bolts. Cracked, broken or loose fasteners should be coded “fair,” “poor,” or “severe” based upon the percentage of the fasteners that are not functional. If less than 10 percent of the number of fasteners are ineffective, the connection should be coded “fair.” If greater than 10 percent, but less than 20 percent of the fasteners are ineffective, the connection should be coded “poor.” Any questionable fasteners that comprise a percentage loss of connection effectiveness exceeding 20 percent should be coded “severe” until actual calculations are performed to rate the connection for imposed loads. Once calculations are made, the coding can be revised based upon engineering judgment.

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

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

## 2.8.2.11 Special Machinery

The inspection of mechanical components common to movable bridges is covered in Chapters 2.8.1 and 2.8.2.1–10 respectively. The inspection of special machinery and mechanical components that are unique, either in function, location or appearance, to one specific type of movable bridge, is covered in the following section. Section 2.8.2.11.1 addresses machinery specific to bascule bridges, Section 2.8.2.11.2 addresses machinery specific to swing bridges, Section 2.8.2.11.3 addresses machinery specific to vertical-lift bridges. In general, unique or uncommon movable bridge types, such as floating pontoon bridges, share machinery components addressed in the following sections.

### 2.8.2.11.1 Bascule Bridges

The following special machinery components are unique to bascule bridges:

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

*C2.8.2.11.1*

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

#### 2.8.2.11.1.1 Trunnions

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

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

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

The symmetric type of trunnion bascule has equal size trunnions mounted on fixed supports, which are typically piers or steel assemblies, such as A frames or rigidly framed towers. (see Figure 2.8.2.11.1.1-3).

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

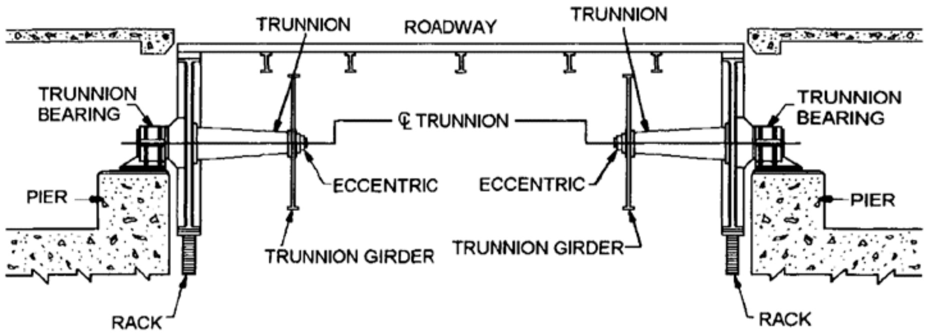



**Figure 2.8.2.11.1.1-1 –** Asymmetric trunnion assemblies

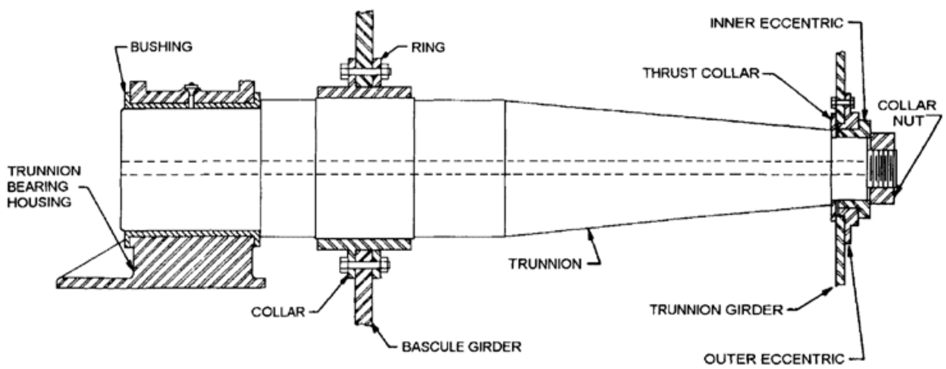



**Figure 2.8.2.11.1.1-2 –** Sectional detail of an asymmetric trunnion shaft assembly with an adjustable eccentric type inner bearing; the term “asymmetric” refers to a lack of symmetry about the centerline of the bascule girder

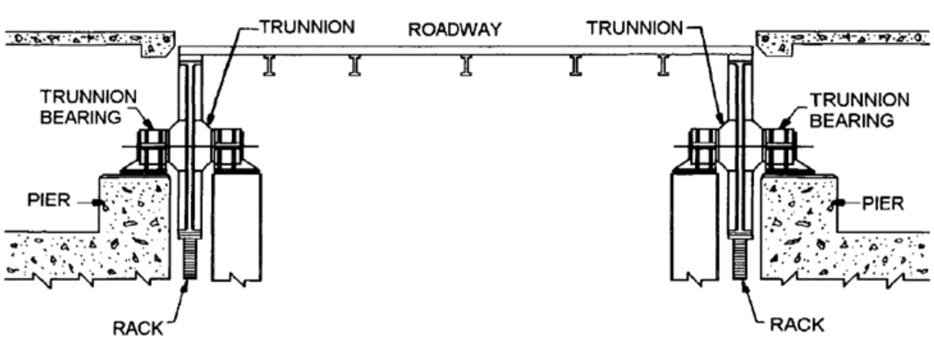



**Figure 2.8.2.11.1.1-3 –** Symmetric trunnion assemblies

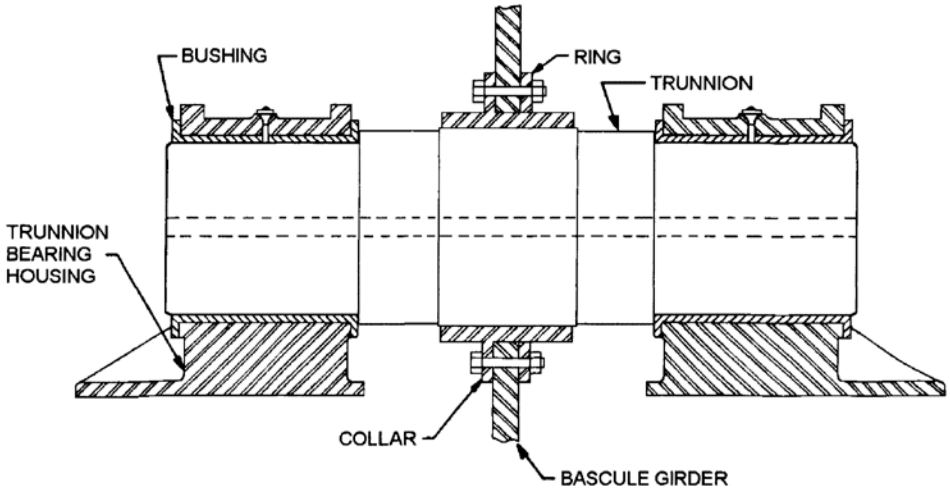



**Figure 2.8.2.11.1.1-4 –** Sectional detail of symmetric trunnion shaft assembly

### 2.8.2.11.1.1.1 Inspection

During routine inspections:

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

During in-depth inspections:

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

During special inspections:

- Current practice is to check the trunnion alignment using a laser based bore alignment system using the boreholes in the trunnions. An older method to check trunnion shaft alignment is to run a piano wire through the drill holes (if present) at the center of both trunnions (Figure 2.8.2.11.1.1.1-1). The wire must be tight to minimize sag. Attach one end of the wire to a bar, which should be held 1.0 in. (25.4mm) out from the end of the trunnion to allow centering of the wire. This can be accomplished by inserting 1.0 in. (25.4mm) blocks between the bar and the trunnion. Center the wire by measuring from it to the OD of the trunnion in several places, and adjust it until each measurement is the same.

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

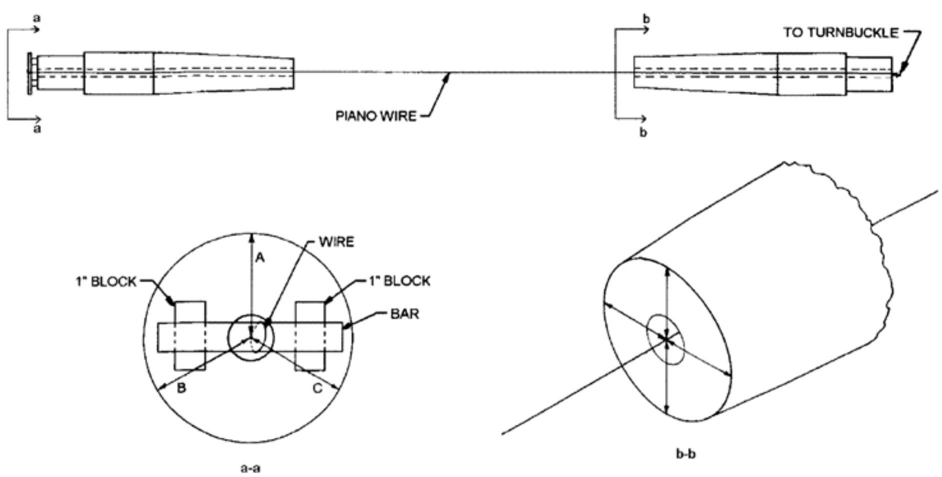



**Figure 2.8.2.11.1.1.1-1 –** At large end of the trunnion on side a-a, a piano wire is secured around a bar resting on 1.0 in. (25.4 mm) blocks. The other end of the wire is attached to a turnbuckle, which can be mounted on a railing or any other fixed point. Measure the horizontal and vertical dimensions,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

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

### 2.8.2.11.1.2 Segmental Girders and Tread Plates

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

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

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

### 2.8.2.11.1.2.1 Inspection

Routine inspection of these components should be performed as follows:

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

*C2.8.2.11.1.2.1*

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

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

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

### 2.8.2.11.1.3 Bascule Centering Devices

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

#### 2.8.2.11.1.3.1 Inspection

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

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

### 2.8.2.11.1.4 Span Locks

*C2.8.2.11.1.4*

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

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

Many rolling lift double-leaf bascules have rigid non-moving intermeshing jaw type span locks. These rigid span locks consist of a tongue and groove arrangement wherein tongues are provided on one leaf to intermesh with grooves provided on the other leaf. The bottom portion of the groove extends further than the top portion. When the leaves are lowered, the leaf with the grooves is lowered first and is stopped before it fully seats. The leaf with the tongue is lowered until it comes in contact with the projecting part of the groove. The locks intermesh as both the leaves are subsequently lowered further till both leaves are completely seated.

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

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

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

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

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

*On double-leaf bascules a loose lock bar fit can be discovered by closely observing the floor break between the two leaves on either side of the channel. Relative vertical motion of one leaf compared to the other will generally indicate loose fit. If the lock bar area is accessible, the mechanism can be operated and the bar and receiver measured with a vernier caliper with the span closed. If the structure is not accessible, then inspectors can sometimes use a manlift or ladder to climb the open structure and stand on the web of the end floorbeam to take measurements of the bar and receiver.*

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

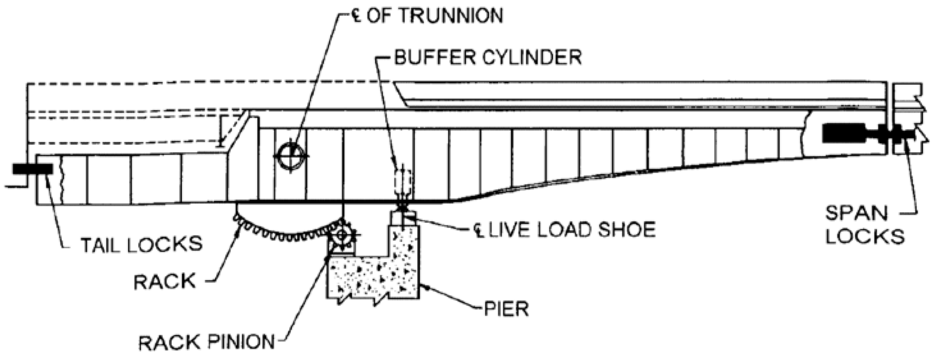



**Figure 2.8.2.11.1.4-1 –** Operating components of a double-leaf bascule bridge

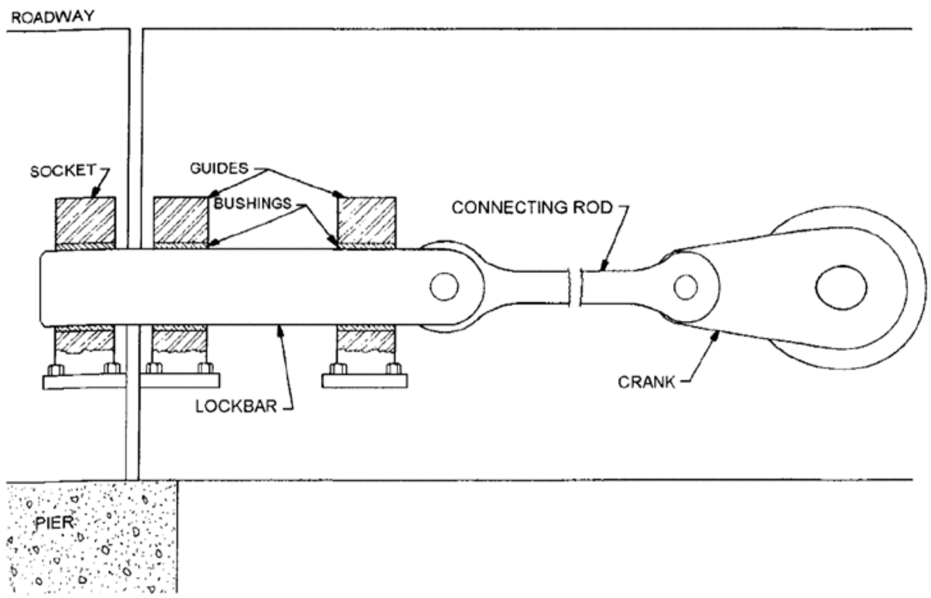



**Figure 2.8.2.11.1.4-2 –** A conventional lock bar assembly

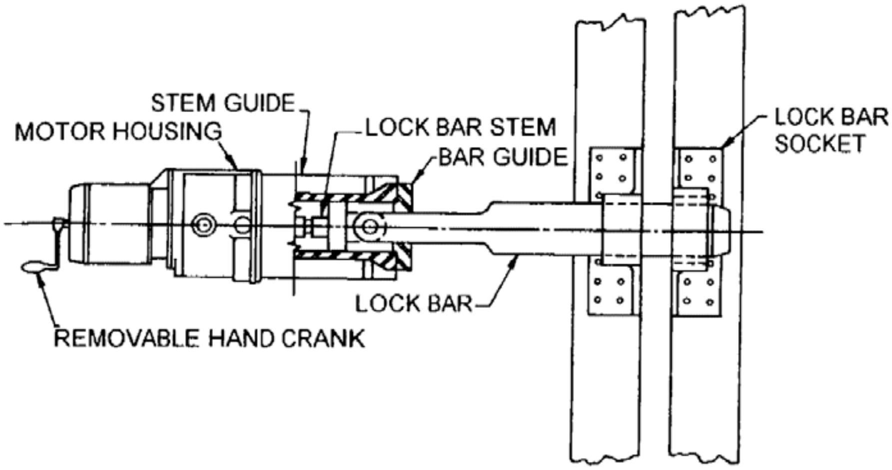



**Figure 2.8.2.11.1.4-3 –** A cutaway view of a self-contained lock bar operator

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

**Figure 2.8.2.11.1.4-4 –** Lock bar operator.

### 2.8.2.11.1.4.1 Inspection

During routine inspections, check the following:

- Observe the device during its complete operational cycle.
- Measure the clearances between the bar, the guides and the sockets. It may be necessary to have the bridge operator raise the leaf slightly to make these parts more accessible.
- Inspect individual drive components such as gears, bushings, motors, and hydraulic systems as per Chapter 2.8.2.1–10 and 2.8.2.12.
- For the self-contained operator, check the acme threads for wear and proper lubrication.
- For the rigid jaw type locks, check the jaws (tongue and groove) for wear, corrosion, and damage. Damage can occur while intermeshing the tongue into the groove. Also, observe the floor break between the two leaves for relative vertical motion under live load. A relative vertical motion

indicates a loose fit, and would require shimming during maintenance.

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

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

### 2.8.2.11.1.5 Hopkins Frame

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

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

**Figure 2.8.2.11.1.5-1** – Hopkins frame

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

- Check the frame for cracks, especially where gears, racks, and pinions are attached. Check for loose or missing bolts at these locations.
- Check to see that the frame is mounted securely, that all connections are tight into the pier, and that clevises are free of cracks.
- Observe the supports while the leaf is operating to see if movement occurs between the substructure or superstructure and the support or between the machinery component and support. Any movement could indicate loose fasteners, cracked concrete, or deteriorated steel members.
- Carefully watch for any apparent deflection of the support. Noticeable deflection can result from improper fit of the bolts in their bolt holes or cracks around the mounting flanges near bolt holes, fillets, welds, or "severe"ly deteriorated steel. If any of these conditions exist, they will be readily apparent during leaf operation. However, suspected cracks may require further investigation using dye penetrant or other nondestructive testing means.
- Supports which are partially embedded in concrete are particularly susceptible to "severe" corrosion at the concrete interface. Any corrosion of this type should be promptly treated and corrected to avoid substantial weakening from continued corrosion and deterioration.

### 2.8.2.11.2 Swing Span Bridges

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

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

*C2.8.2.11.2*

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

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

### 2.8.2.11.2.1 Center Bearings

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

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

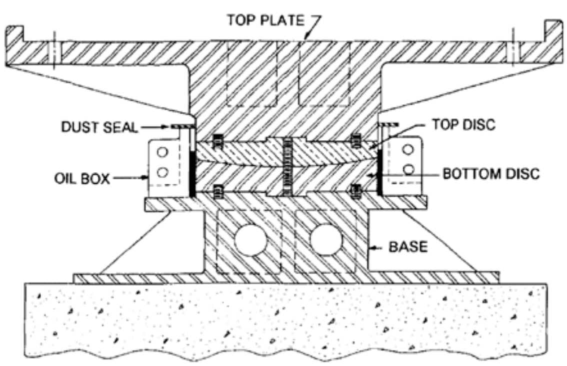



**Figure 2.8.2.11.2.1-1 –** Cross-sectional view of a center bearing; a split circular oil box surrounds bearing. Notice that none of the discs or plates are bolted together.

#### 2.8.2.11.2.1.1 Inspection

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

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

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

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

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

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

- Remove the top disc from the bearing.
- Check top of bronze disc for scoring, worn boss, enlarged dowel holes, and worn or sheared dowels. Worn dowels should be replaced. If the boss shows any wear, measure its outer diameter and the inner diameter of the counterbore of the top plate. There should be no clearance. Wear on boss

or dowels may indicate the bridge was operated with a dry or “poor”ly-lubricated bearing. If boss is egg shaped or out of round, bridge may be operating under excessive wind load.

- Check spherical bottom surface of disc. It should have a mirror finish, and oil grooves should be open and free from foreign matter. If bronze top disc or steel bottom disc have any score marks and no replacement is available, score marks should be polished out before returning the bridge to service.
- Clean all parts thoroughly before returning to operation. Be certain that no foreign matter enters the bearing prior to or during reassembly.

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

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

#### 2.8.2.11.2.2 Balance Wheels and Track

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

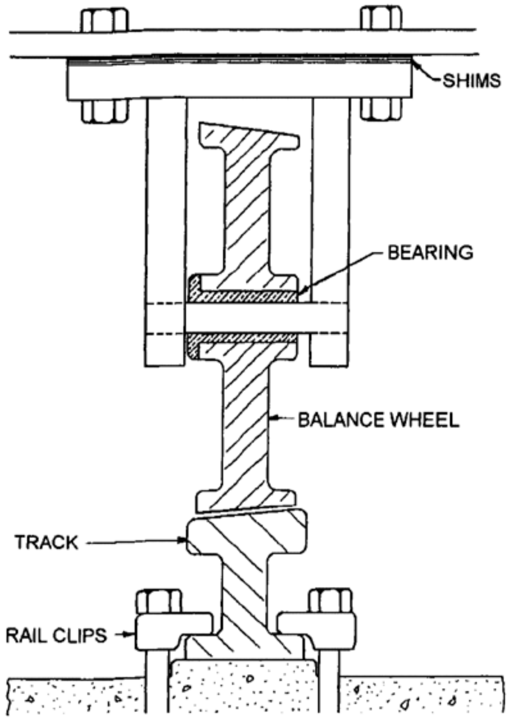



**Figure 2.8.2.11.2.2-1 –** A balance wheel assembly in which the wheel rotates on a stationary shaft

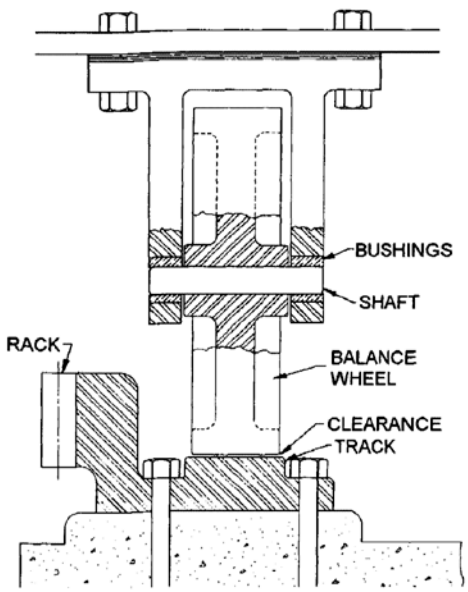



**Figure 2.8.2.11.2.2-2 –** A balance wheel assembly where the rack teeth have been machined into the curved track

### 2.8.2.11.2.2.1 Inspection

During routine inspections, check the following:

- When the wedges are driven, no balance wheel should be in contact with the rail. The distance between the rail and the wheels should be the same for each wheel. The drawings should indicate the design clearance. If no drawings are available, 0.050 in. (1.27 mm) can be used, Figure 2.8.2.11.2.2.1-1.
- If there is no wind when the wedges are withdrawn, the clearance under the wheels should remain until rotation begins. If the span tilts and brings some wheels into contact with the rail, it is probably unbalanced.
- Try to rotate balance wheels with the wedges driven. Check the clearance between wheel and rail.
- Check the bearing clearances on the wheel shaft. If the wheel shaft is stationary and the bearing is in the hub of the wheel, it is not possible to check the clearance with feeler gauges. A dial indicator can be mounted to check vertical movement of the wheel and a pry bar used to raise and lower the wheel. Any vertical movement greater than design clearance indicates wear in the bearing and or shaft.
- Check the outer diameter of the wheel and the track surface for irregularities.
- Check rail clips, foundation bolts, and set screws for tightness and corrosion.

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

### 2.8.2.11.2.3 Tapered Rollers

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

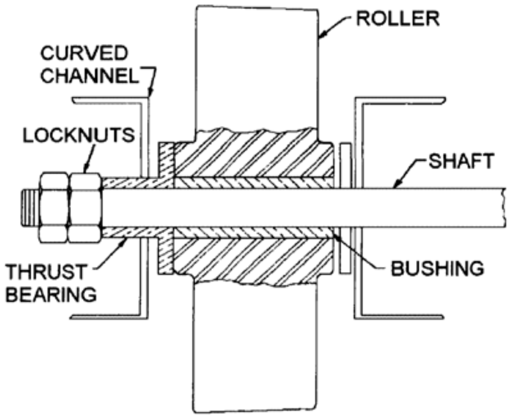



**Figure 2.8.2.11.2.3-1 –** A typical tapered roll. Lock nuts on shaft can be tightened to bring the roller into contact with both rails.


**Figure 2.8.2.11.2.3-2 –** Layout of rim bearing assembly

### 2.8.2.11.2.3.1 Inspection

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

- Observe the roller assemblies while the span rotates. See that rollers rotate properly, and that the center ring rotates smoothly.
- Listen for noise coming from the rollers, the center ring, or the center-pivot bearing. Watch to see if the rollers try to skew as

they roll.

- Check the outer diameter of the rollers and both upper and lower track surfaces for irregularities.
- Check radial rods and fasteners for tightness, corrosion, and deformation.

During in-depth inspections, check the following:

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

### 2.8.2.11.2.4 Wedges, End-lift Jacks, and Shoes

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

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

*C2.8.2.11.2.4*

*Wedges, end lifts, and shoes may be actuated by either mechanical (such as shaft or chain driven muscle powered), electromechanical, or hydraulic devices. The types discussed at length herein are electromechanical. Inspection of hydraulic systems is covered in Chapter 2.8.2.12. The components of the hydraulic drive of the wedge, shoes, or end lift should be inspected as described therein. The inspection of mechanical and electromechanical systems should be based upon the principles described in Chapters 2.8.1–10.*

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

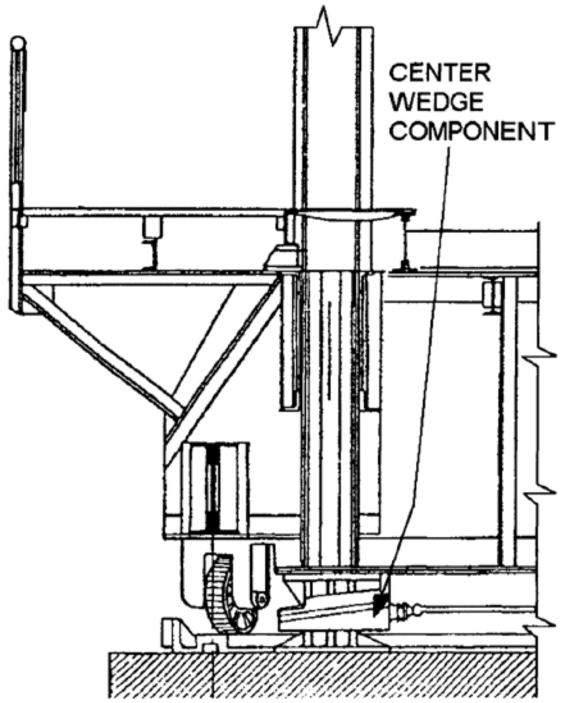



**Figure 2.8.2.11.2.4-1 –** Center wedge component

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

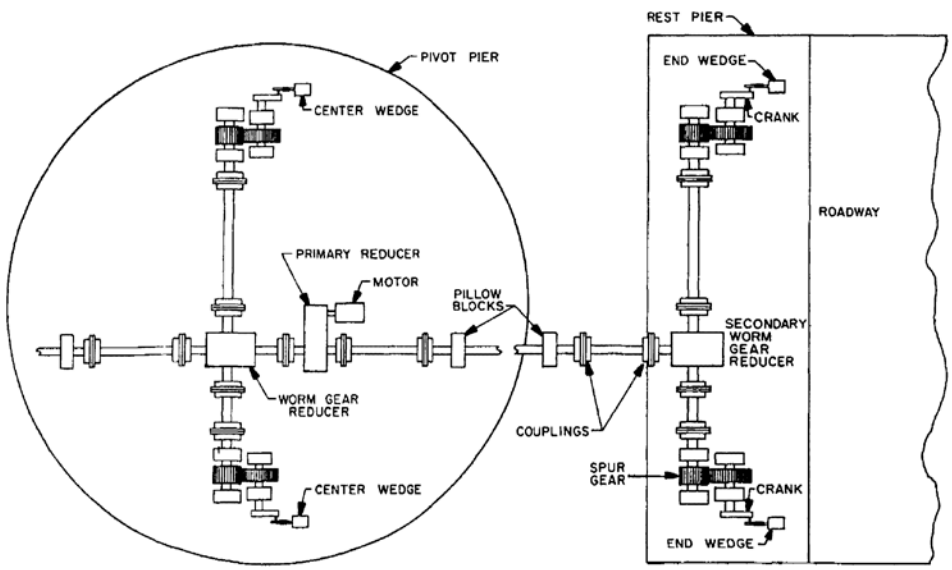



**Figure 2.8.2.11.2.4-3 –** Wedge drive machinery

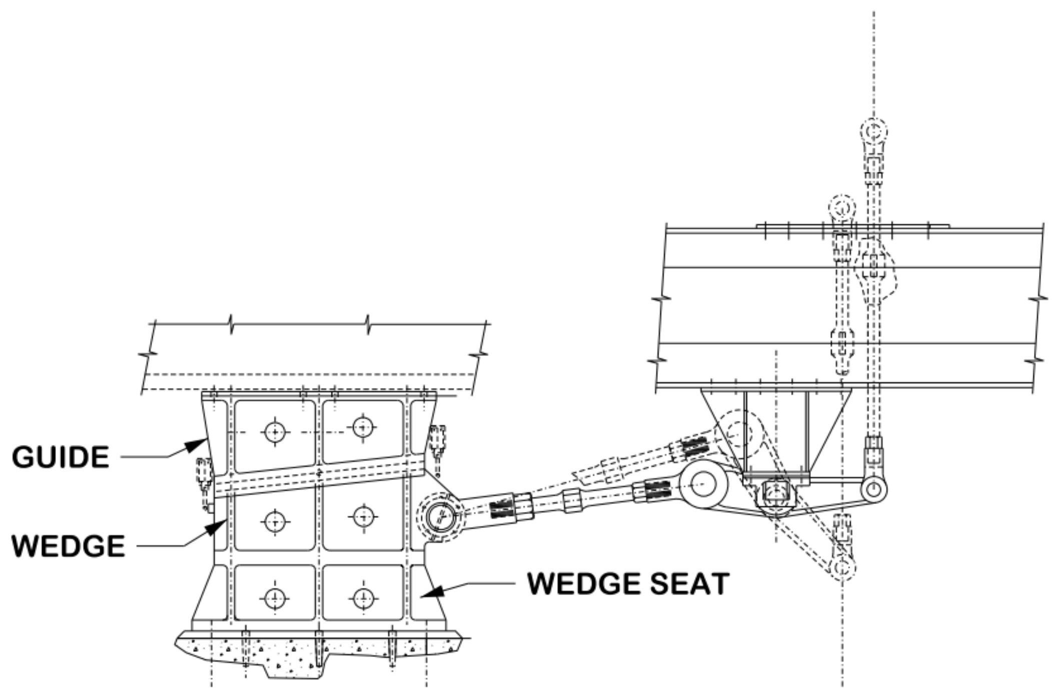



**Figure 2.8.2.11.2.4-4 –** Wedge components

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

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

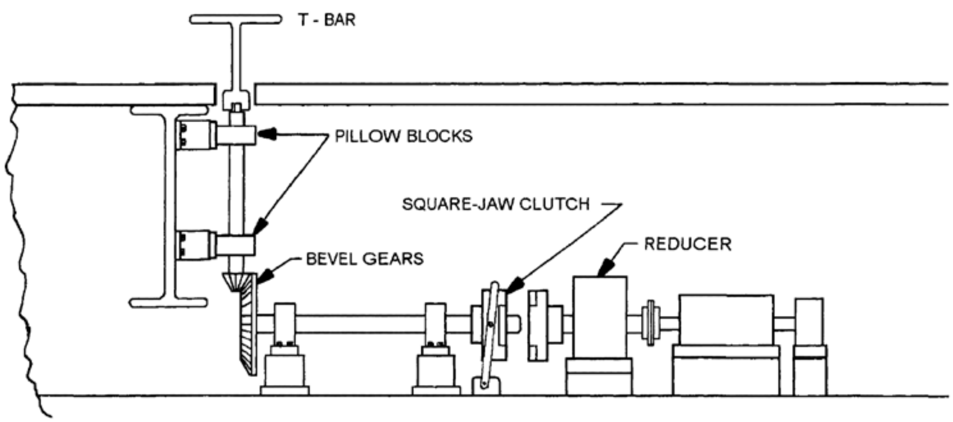



**Figure 2.8.2.11.2.4-5 –** Elevation of manual drive components.

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

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

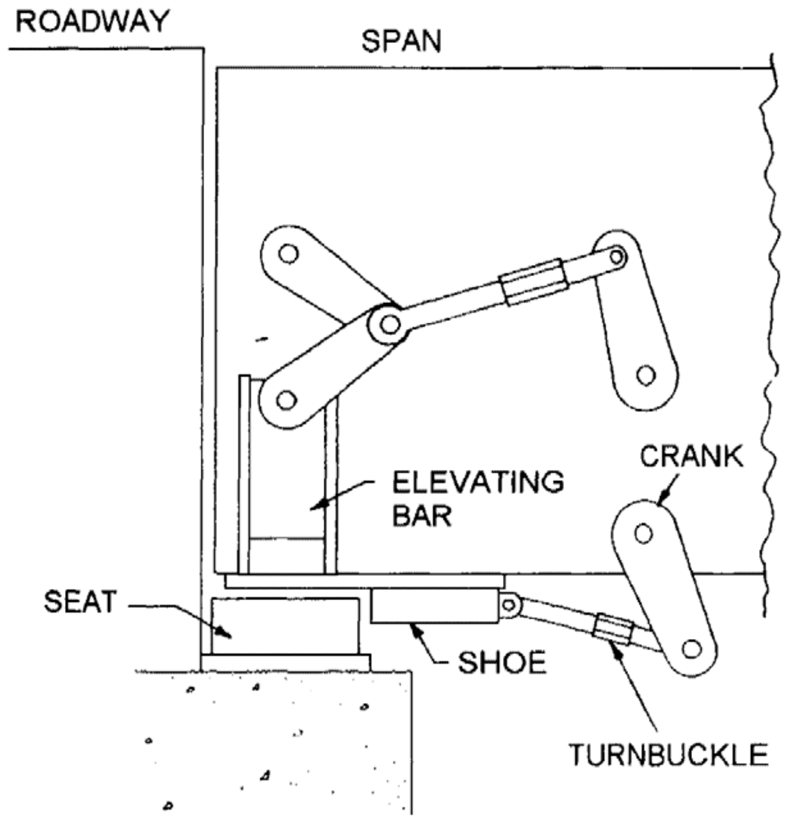



**Figure 2.8.2.11.2.4-7 –** Toggle elevating drive – bar is raised and shoe withdrawn; span is free to rotate

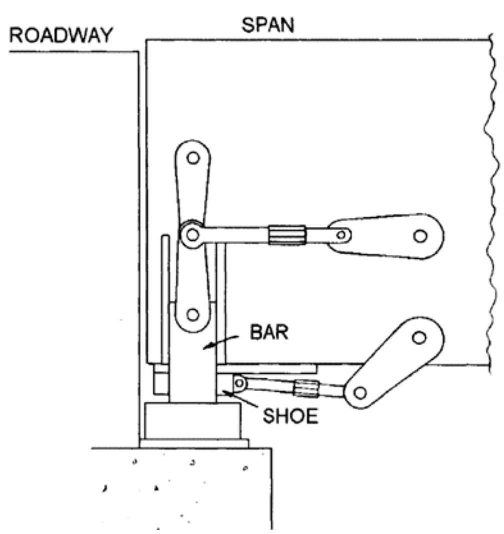



**Figure 2.8.2.11.2.4-8 –** Elevating bar fully extended and shoe in place; when the bar is raised, the span will rest on the shoe

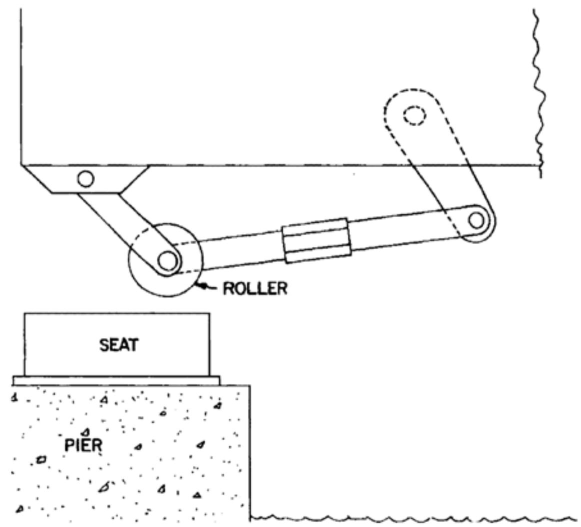



**Figure 2.8.2.11.2.4-9 –** Link-and-roller end lift (live load shoe not shown)

### 2.8.2.11.2.4.1 Inspection

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

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

**Figure 2.8.2.11.2.4.1-1 –** Improper bearing of live load shoe

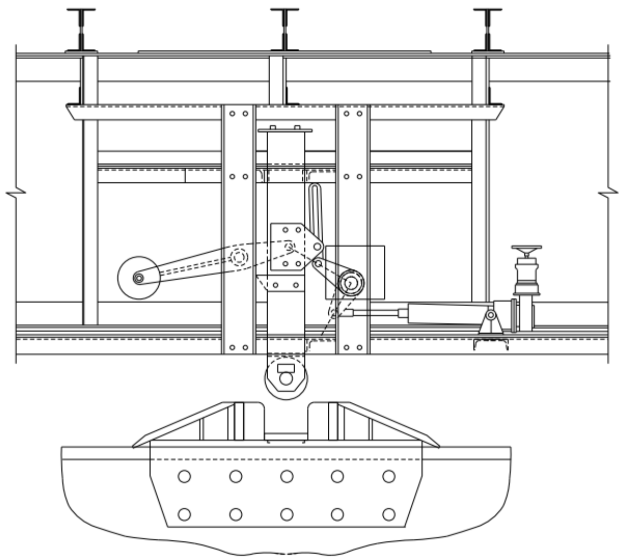
- During the inspection, check straightness of shafts and connecting rods. Be sure rotating and sliding parts are well-lubricated, and that bolts and fasteners are tight and free from corrosion and rust.
- Verify the amount of lift provided at the ends of the swing span. This amount should be that defined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

### 2.8.2.11.2.5 Swing Span Centering Latches

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

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

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



CENTERING DEVICE
FIGURE 2.8.2.11.2.5-1

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

### 2.8.2.11.2.5.1 Inspection

During routine inspections, check the following:

- Observe the operation of the latch bar during the opening and closing of the span. Check the height of the wheel when it is raised out of the recess in the pocket to be sure that it can roll up the ramp properly when the span begins to rotate. Make sure the latch bar pawl disengages the pin and allows the latch bar to drop to the lowered position as the wheel rolls down the ramp.
- Watch the latch bar operation as the span closes. The span should slow down and nearly stop before the latch bar drops into the pocket. Be sure the latch bar drops completely into the pocket (Figure 2.8.2.11.2.5.1-1).
- Look for movement between the pocket and the substructure. Check the bar and the guide for deformation due to over travel as the span closes.
- See that the pin that engages the pawl contacts it near the center of the curved end. Check the pawl, pawl support bracket, and pin for deformation and wear. Be sure the pawl

swings freely.

- Check system for proper lubrication. Inspect fasteners for tightness and corrosion, especially the bolts on the latch bar guide and pocket.

**Figure 2.8.2.11.2.5.1-1 –** Latch bar engaged in pocket

### 2.8.2.11.2.6 Drum Girder

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

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

- Inspect the drum girder as a whole for pitting, cracks, corrosion, and section loss, loose, missing or broken fasteners, and signs of buckling of the web plate.
- Inspect the drum girder bottom flange for fatigue cracks projecting from rivet or bolt holes in the horizontal leg at the flange angle fillet.
- Inspect the drum girder/distribution girder connection for impacted rust, loose, missing or broken fasteners, and section loss.
- Check for impacted rust between the horizontal leg of the bottom flange angle and the upper track.
- Check to make sure the drum girder is correctly aligned on the tapered rim bearing rollers.

- Observe the motion of the drum girder during opening and closing operations for smoothness of movement. Make note of and investigate any unexpected noises.
- Inspect the drum girder bracing for corrosion, loose connections, and proper alignment.
- Inspect the distribution girder/loading beam interface for loose, missing or broken fasteners, impacted rust and section loss.

### 2.8.2.11.3 Vertical-lift Bridges

The following special machinery components are usually found on vertical-lift bridges:
- Wire ropes and sockets
- Sheaves and drums
- Trunnions
- Tension adjusting devices
- Span guides
- Balance chains
- Span leveling devices
- Centering devices
- Span locks

#### 2.8.2.11.3.1 Wire Ropes and Sockets

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

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

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

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

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

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

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

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

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

**Figure 2.8.2.11.3.1-3 –** Broken wire on a wire rope

### 2.8.2.11.3.1.1 Inspection

During routine inspections, check the following:

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

*C2.8.2.11.3.1.1*

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

- Closely examine individual wires for cracks or breakage. List the number of broken wires in one rope lay for each strand. The number of broken wires is a significant factor in determining the remaining life of the rope.
- Look for flat areas on the rope. These are areas indicating abrasive wear. Also note the length along the wire of the flattened portion of the wire, as it is a significant factor in determining the remaining life (based on industry standard guidelines) of the rope. The criteria for determining the remaining life of a wire rope can be obtained from the wire rope manufacturers.
- Measure the diameter of the rope. Reduction of the diameter is an indication of problem within the interior of the rope.
- Check for dirt and foreign matter in the lubricant, and note the adequacy of the lubrication.
- Check the sheaves to be sure the rope is properly seated in the sheave groves.
- Observe the wire rope for any distortion such as kinking, crushing, main strand displacement or core protrusion.
- Check for corroded or broken wires at end connections.

During routine inspections, check the following:

- Measure and record the tension in all wire ropes. Tension values should to be compared with original and previous report values. Also, compare tension with wire rope ultimate tensile strength and confirm whether or not ultimate tensile strength / Loading ratio meet AASHTO 8:1 safety factor. The tension can be estimated by timing the natural frequency $f = \frac{1}{2L}\sqrt{T/m}$ or by the use of an electronic rope tension meter.

T = tension in rope (lbs.)

m = mass/unit length of rope = lbs/ft/32.2 ft/sec$^2$

F = frequency (cycles/second) that can be estimated or measured using an iPhone with a vibration app.

### 2.8.2.11.3.2 Sheaves and Drums

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

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

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

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

bearing material.

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

### 2.8.2.11.3.2.1 Inspection

During routine inspections, check the following:

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

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

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

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

## 2.8.2.11.3.3 Trunnions

Sheave and drum trunnions are similar in construction to the symmetric type trunnion assemblies described for trunnion bascules and should be inspected by the methods presented for trunnions and trunnion bearings in Sections 2.8.2.11.1.1.1 and 2.8.2.3.3.1. (See Figure 2.8.2.11.3.2-1.)

### 2.8.2.11.3.4 Tension Adjusting Devices

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

### 2.8.2.11.3.4.1 Inspection

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

### 2.8.2.11.3.5 Span Guides

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

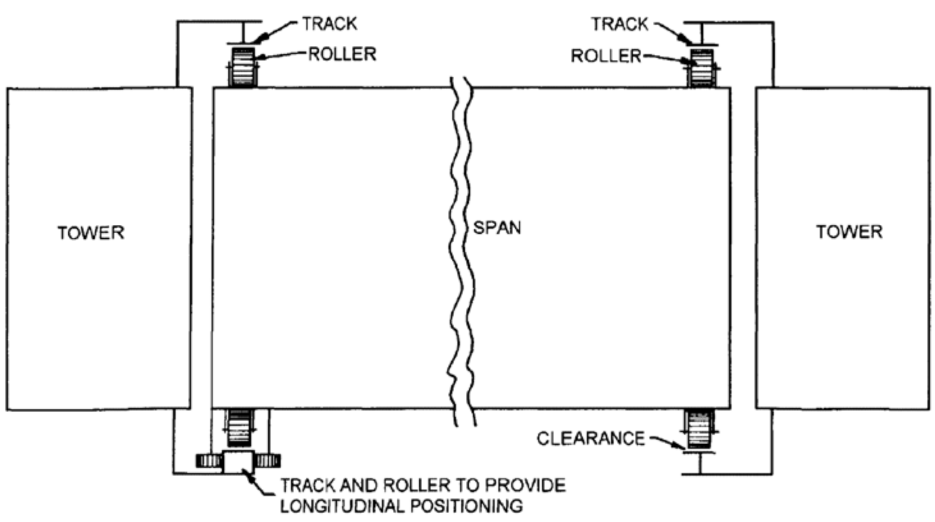



**Figure 2.8.2.11.3.5-1 –** Schematic of typical span-guide rollers; sliding-type guides are also used

### 2.8.2.11.3.5.1 Inspection

During routine inspections, check the following:

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

### 2.8.2.11.3.6 Auxilary Counterweights/Balance Chains

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

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

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

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

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

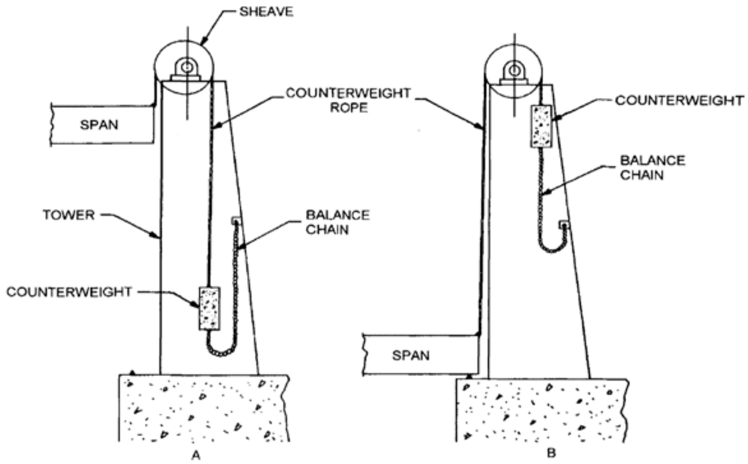



**Figure 2.8.2.11.3.6-2A & B –** Operation of balance chains

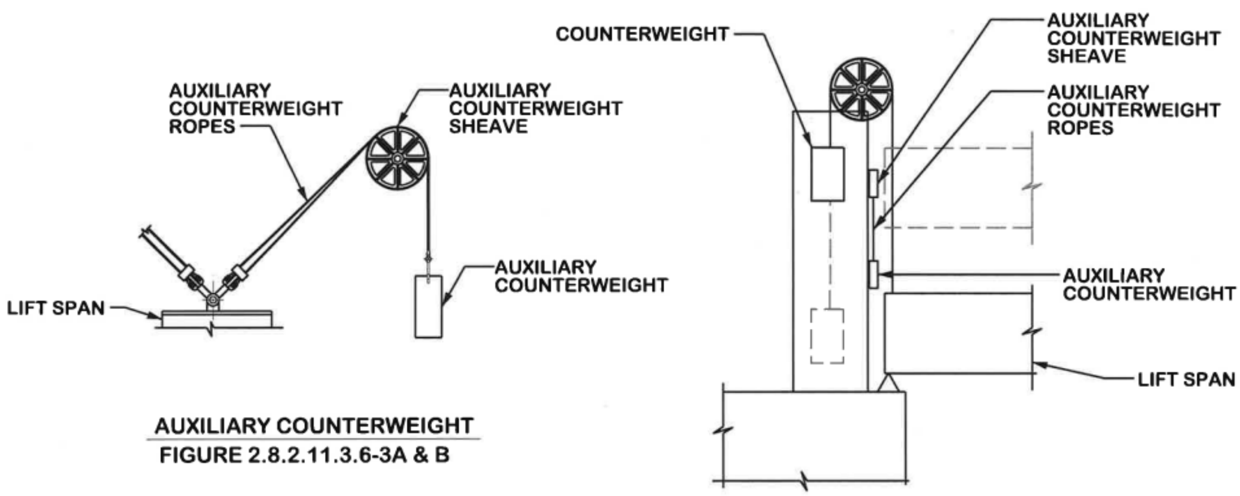



**Figure 2.8.2.11.3.6-3 A&B** – Operation of auxiliary counterweight

### 2.8.2.11.3.6.1 Inspection

During routine inspections, check the following:

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

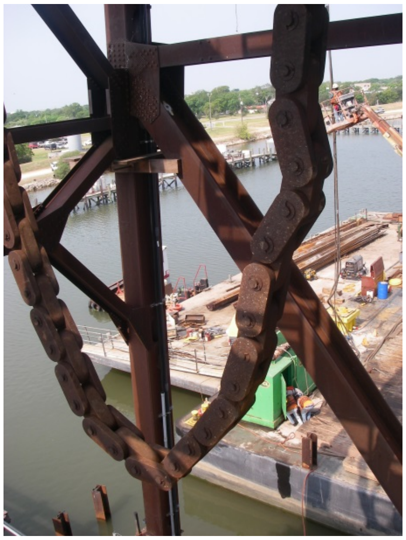


**Figure 2.8.2.11.3.6.1-1 –** Binding of links in balance chain

### 2.8.2.11.3.7 Span Leveling Devices

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

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

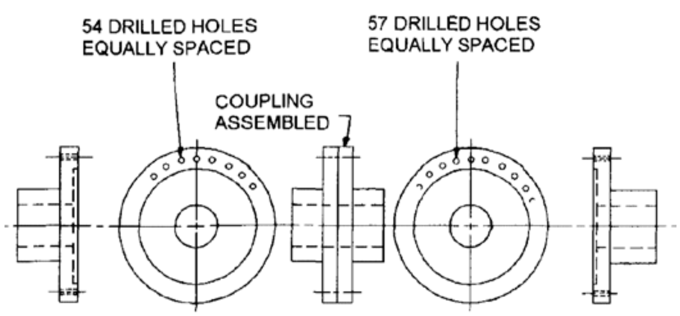



**Figure 2.8.2.11.3.7-1 –** An adjustable coupling for span leveling

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

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

### 2.8.2.11.3.7.1 Inspection

During routine inspections, check the following:

- The inspector should check the bolts to be sure they are tight, and free from corrosion.
- Since clutch mechanisms of this type are seldom used, wear is not a problem. However, the inspector should visually check the external condition of the clutch and associated machinery. If practical, have the bridge tender operate the clutch to check proper clutch function.

### 2.8.2.11.3.8 Lift Span Centering Devices

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

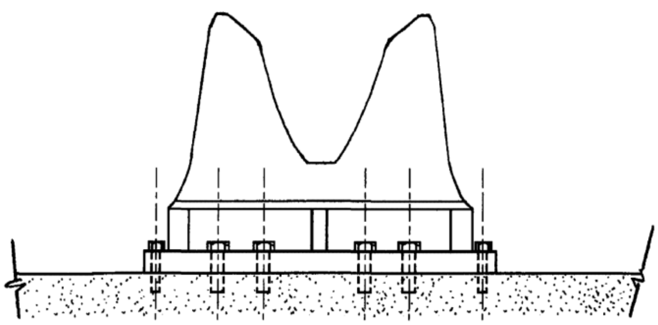


**Figure 2.8.2.11.3.8-1 –** Centering pocket for a vertical-lift bridge

### 2.8.2.11.3.8.1 Inspection

During routine inspections, check the following:

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

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

### 2.8.2.11.3.9 Span Locks

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

The span locks shown in Figures 2.8.11.3.9-1 and 2.8.11.3.9-2 are used only on vertical-lift bridges.

In the wedge shaped lock (Figure 2.8.11.3.9-1), a jacking mechanism delivers the thrust for the wedge to be driven through the guide, rigidly attached to the pier, and the socket, attached to the lift span. The jacking system may be either an electric motor driven mechanical jack or a hydraulic jack.

In the latch type of lock bar (Figure 2.8.11.3.9-2), an actuator moves the latch which engages a bracket attached to the movable span.

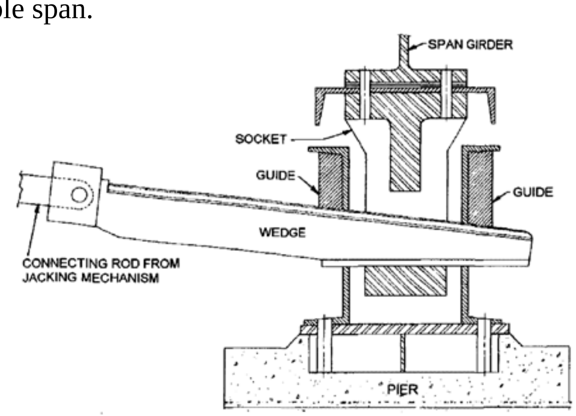



**Figure 2.8.2.11.3.9-1 –** A wedge shaped lock used to hold vertical-lift span rigidly in place

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*There are many types of devices used to lock the movable span in the open and closed positions. Most are mechanical, but some are hydraulic or spring-activated. Although more widely used on bascule bridges, self contained electric motor driven, dead-bolt type span locks are also used on vertical-lift bridges. The description and inspection of the self contained and the conventional lock bar machinery is covered in Sections 2.6.2.4 and 2.6.2.4.1.*

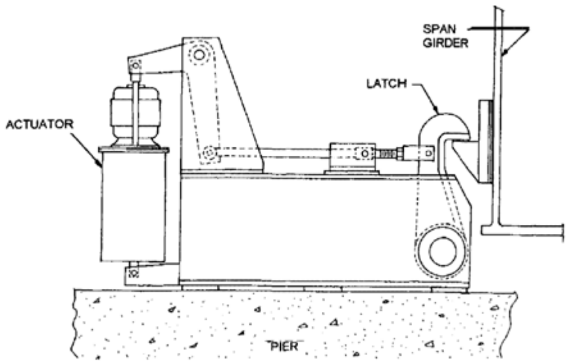


**Figure 2.8.2.11.3.9-2 –** A latch type lock used on vertical-lift bridges

### 2.8.2.11.3.9.1 Inspection

During routine inspections, check the following:

- Measure dimensions of the bronze liner in the socket, and inspect for wear. If it has excessive wear, it should be either adjusted or replaced. Make sure there is adequate lubrication and that fasteners on the sockets are secure.
- Measure bar dimensions and compare with the design dimensions.
- Check the bar closely for evidence of top, bottom, or side wear. If bar or socket exhibit an abnormal amount of wear, the span may be misaligned or the guides and sockets may have shifted.
- Measure the clearance between the bar and the guides, and the bar and the sockets. It may be necessary to have the bridge operator raise the span slightly to make these parts more accessible.
- Inspect individual drive components such as gears, bushings, motors, hydraulic systems etc. as per Chapters 2.8.2.1–10 and 2.8.2.12.

- Span lock hand cranking should be inspected and all necessary hand cranking tools.

### 2.8.2.11.4 Special Machinery Component Coding Guidelines

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

### 2.8.2.11.4.1 Bascule Components

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

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

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

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

**Bascule centering devices:** Centering devices on bascules are holdovers from design of railroad type bascules, where precise alignment of the rails is “severe” to safe operation. They are

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*Trunnions are vital components that can be “severe”ly damaged in a relatively short period of time by lack of lubrication. Owners should develop QC/QA procedures to verify that trunnions and other “severe” components are properly lubricated on the required schedule. The owner should assign the responsibility for verifying that lubrication logs are being maintained and that field observations are consistent with the log contents. The assigned inspectors or evaluators should regularly evaluate the lubrication record keeping. Is a lubrication chart present in the machinery space? Is a copy of the lubrication log present in the operator's house or machinery space?*

only necessary on highway bridges insofar as they may serve to provide proper alignment for live load shoes, rests and/or span locks. Wear and minor misalignment of centering devices on bascules should be coded ““poor,” not ““severe” unless the condition presents a hazard to the traffic safety or problems with the alignment of span locks, live load shoes, rests or other vital components are also present.

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

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

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

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

### 2.8.2.11.4.2 Swing Components

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

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

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

**Wedges, end lift jacks, and shoes:** Swing span wedges and end lift and support devices contain a number of unique mechanisms that are not typical to other types of movable bridges, but they are subject to the same coding guidelines presented in Section 2.8.10 for live load shoes or wedges. Wedges, jacks and shoes should be evaluated for percentage of full bearing of the bearing surfaces in contact when driven. Coding should be based on Table 2.8.2.11.4.2-1 unless calculations are performed to allow coding basing on engineering judgment.

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

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

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

| **Functioned properly during the stated percentage of opening** | **Condition Coding** |
|---|---|
| More than 90% | “Good” |
| Between 75% and 90% | “Fair” |
| Between 60% and 75% | “Poor” |
| Less than 60% | “Severe” |

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

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

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

### 2.8.2.11.4.3 Lift Span Components

**Wire ropes and sockets:** ANSI replacement standards have been developed on various types of cranes and hoists for running and standing wire rope fittings. The presence of wear and abrasion in running wire ropes and the presence of kinks, cracks in wires, and breaks in wires for running or standing wire ropes should be coded “poor” or “severe.” ANSI standards AIO.4 and AIO.5 for Hoists and B30.2 through B30.8 for various types of cranes, derricks and hoists indicate that a wire rope should be replaced based upon the number of broken wires and a number of other criteria. Wire rope that is crushed, flattened, shows evidence of jammed, high strands or unlaying of strands or wires, bird caging, kinks, bulges, gaps, or excessive clearance between strands or wire, “severe” internal corrosion, excessive stretching, core protrusion, heat damage, torch bum or arc strikes is also recommended therein for replacement. For movable bridges the presence of such conditions should be coded fair, “poor” or “severe” based upon the number of wires affected or as presented in Table 2.8.2.11.4.3-1.

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

**Table 2.8.2.11.4.3-1 –** Wire rope coding criteria

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

*based on ANSI replacement specifications

**developed from ANSI replacement data

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

### 2.8.2.12 Hydraulic Components

Some movable bridges functional systems may employ hydraulic components to create controlled appropriate motion. The purpose of this section is to discuss inspection of hydraulic components. It is intended for specially trained inspectors and maintainers. The coordination of inspection and maintenance efforts, as discussed in Section 2.8.2.1, is applicable to hydraulic components as well. Chapters 2.8.2.1–10 cover mechanical components and the general statements about the purposes of mechanical components therein also apply to hydraulic systems.

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

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*See Section 2.1.4 for inspector qualifications. Individuals who disassemble hydraulic system components should be properly trained as hydraulic specialists. Disassembly of hydraulic components can be hazardous.*

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

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

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

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

### 2.8.2.12.1 Hydraulic System Basic Principles

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

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

where:

F = Force, in any units (pounds, kips or kN)

P = Pressure, in units consistent with F and A, e.g., in psi (MPa) if F = lbs. (N) and A = in$^2$ (mm$^2$)

A = Area on which the pressure acts, in units consistent with pressure, e.g., A = in$^2$ (mm$^2$) if P = psi (MPa)

This static equation indicates how mechanical advantage is gained in a hydraulic system (more area = larger force). The

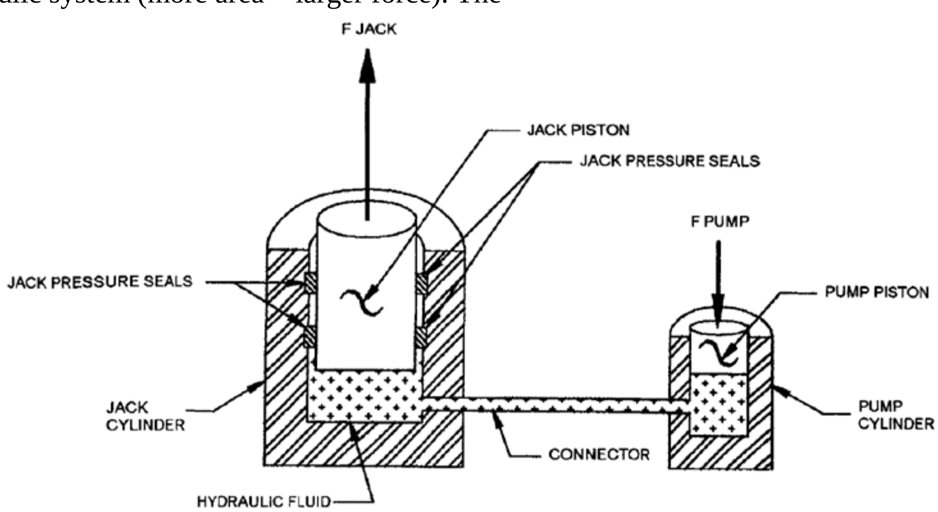


**Figure 2.8.2.12.1-1 –** Basic hydraulic principles

simplest form of a hydraulic system, a basic hydraulic jack, shown in Figure 2.8.2.12.1-1, can be used to illustrate the principle.

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

$$P_{pump} = \frac{F_{pump}}{A_{pump}} = \frac{F_{jack}}{A_{jack}}$$

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

Equation 2.8.2.12.2

Using Equation 2.8.2.12.2, the mechanical advantage between the force applied at the pump piston and the force developed by the jack is the ratio of the piston areas. If the area of the jack piston is ten times the area of the pump piston, then the hydraulic system mechanical advantage is ten to one. One pound (Newton) applied to the pump piston will provide ten pounds (Newtons) of force at the jack piston.

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

### 2.8.2.12.2 Hydraulic Components on Movable Bridges

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

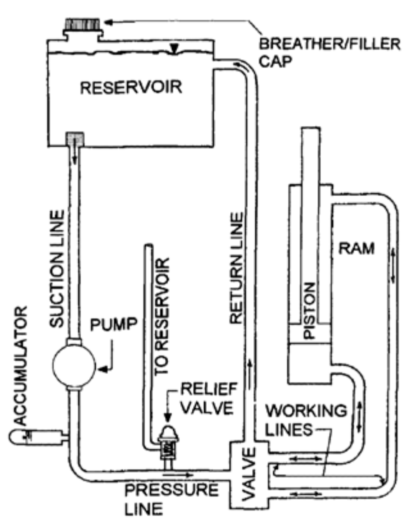


**Figure 2.8.2.12.2-1 –** Typical double-acting hydraulic system layout

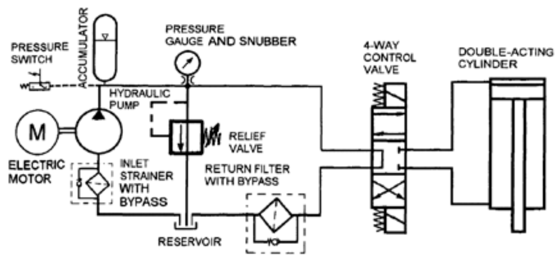


**Figure 2.8.2.12.2-2 –** Simplified hydraulic schematic circuit layout

### 2.8.2.12.3 Accumulators

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

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

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

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

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

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

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

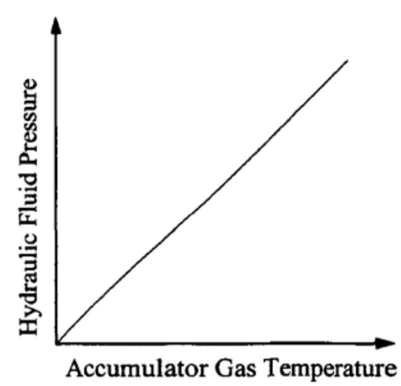


***Figure C2.8.2.12.3-1 –** Gay-Lussac's Law* set pressure switches, reduced actuator speeds) should be investigated prior to identifying the cause of rapid pump cycling as insufficient gas cushion in the accumulator.

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

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

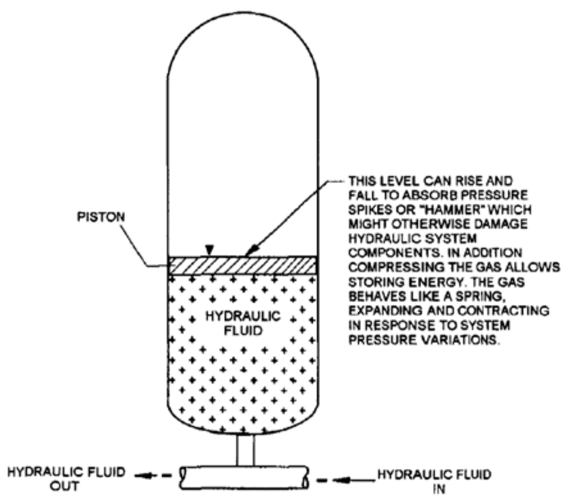


**Figure 2.8.2.12.3-1 –** Hydraulic piston type accumulator

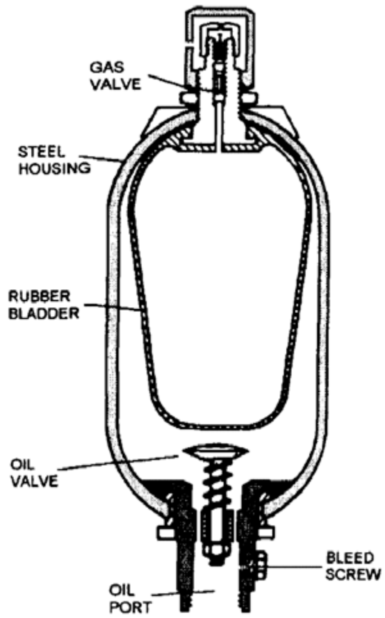


**Figure 2.8.2.12.3-2 –** Bladder type accumulator

### 2.8.2.12.4 Valves

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

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

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

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

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

Figure 2.8.2.12.4-1 shows a schematic of a basic pressure

*C2.8.2.12.4*

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

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

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

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

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

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

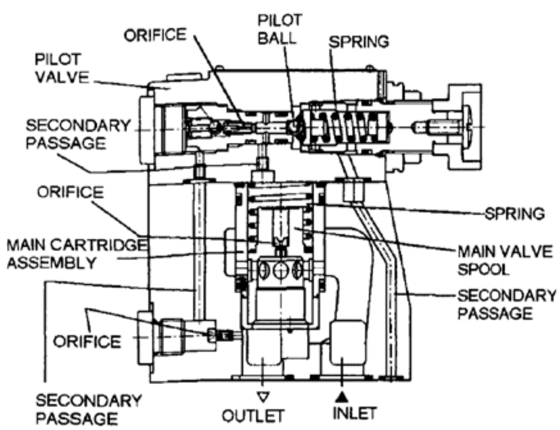


**Figure 2.8.2.12.4-1 –** Functional diagram of pressure reducing valve

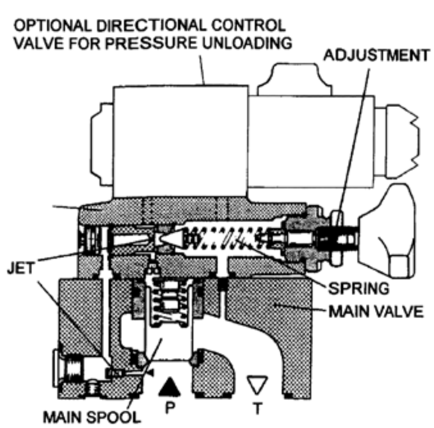


**Figure 2.8.2.12.4-2 –** Two stage pilot operated pressure relief valve

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

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

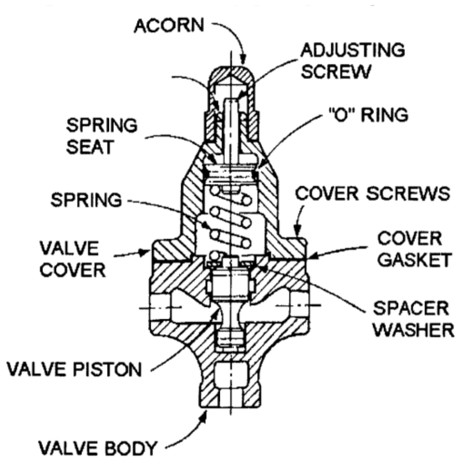


**Figure 2.8.2.12.4-3 –** Spool type pressure relief valve

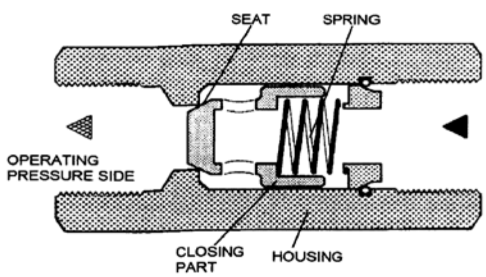


**Figure 2.8.2.12.4-4 –** Check valve

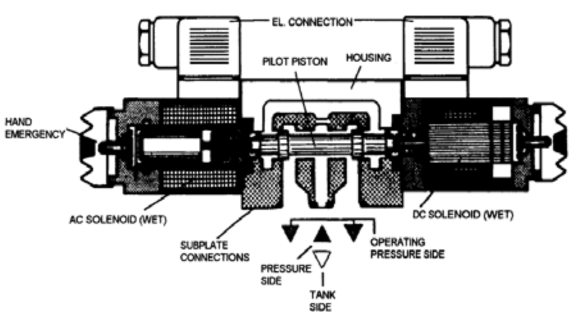


**Figure 2.8.2.12.4-5 –** Four-way, three-position (4/3) solenoid operated, directional control valve

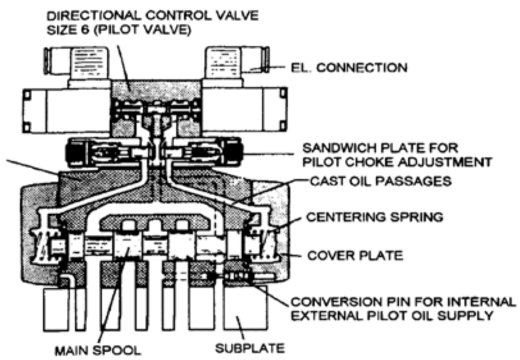


**Figure 2.8.2.12.4-6 –** Functional diagram of two-stage, 4/3 directional control valve.

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

**2.8.2.12.5 Hydraulic Cylinders**

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

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

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

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

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

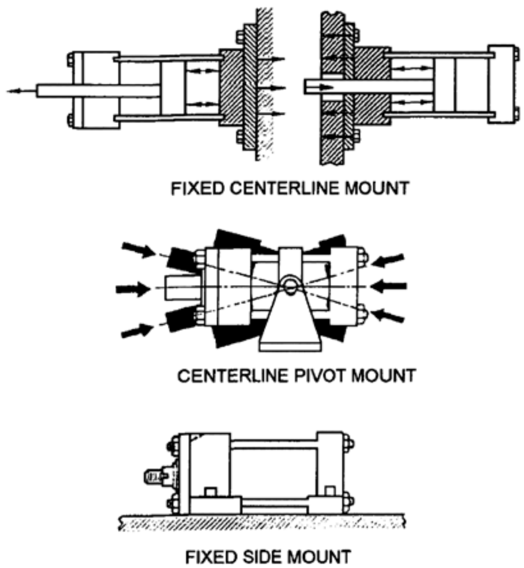


**Figure 2.8.2.12.5-1 –** Typical types of mounts

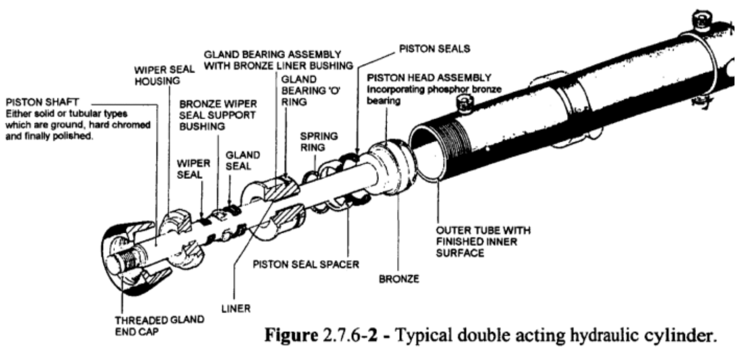


**Figure 2.8.2.12.5-2** – Typical double acting hydraulic cylinder

## 2.8.2.12.6 Hydraulic Pumps

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

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

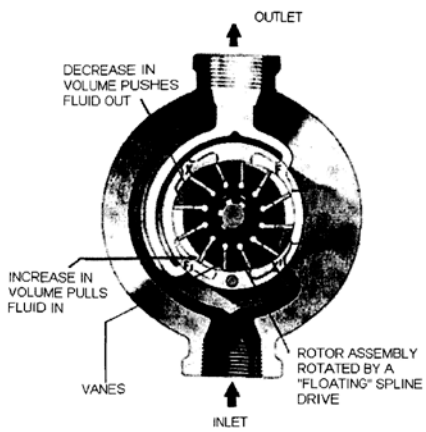


**Figure 2.8.2.12.6-1 –** Vane type fixed displacement pump

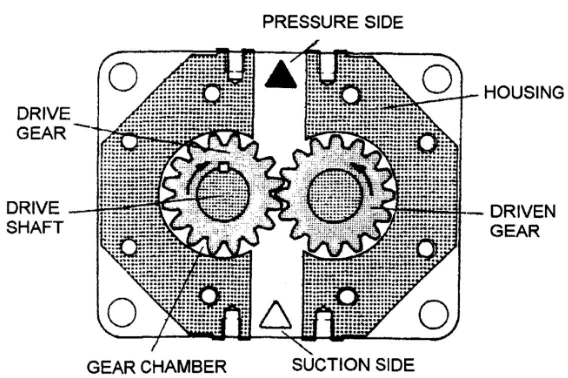


**Figure 2.8.2.12.6-2 –** Gear type pump

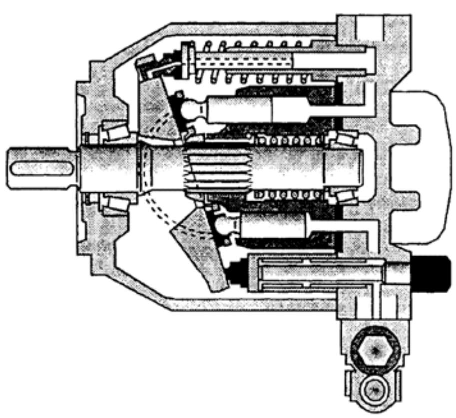

**Figure 2.8.2.12.6-3 –** Variable displacement axial piston pump (swash plate type)

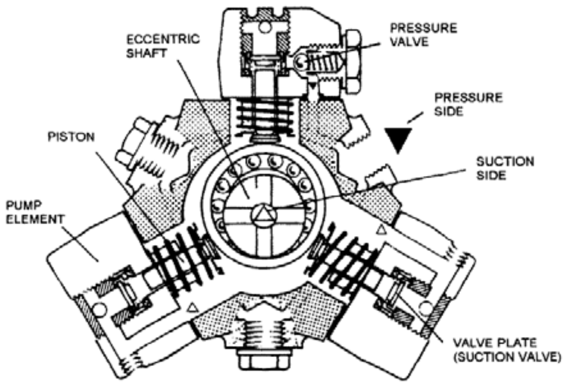


**Figure 2.8.2.12.6-4 –** Radial piston pump

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

Current AASHTO specifications (Reference 7) prefer that gear or piston type pumps be used in systems where operating pressure exceeds 2,000 psi (14 MPa).

**Table 2.8.2.12.6-1 –** Pump troubleshooting chart

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

### 2.8.2.12.7 Hydraulic Motors or Rotary Actuators

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

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

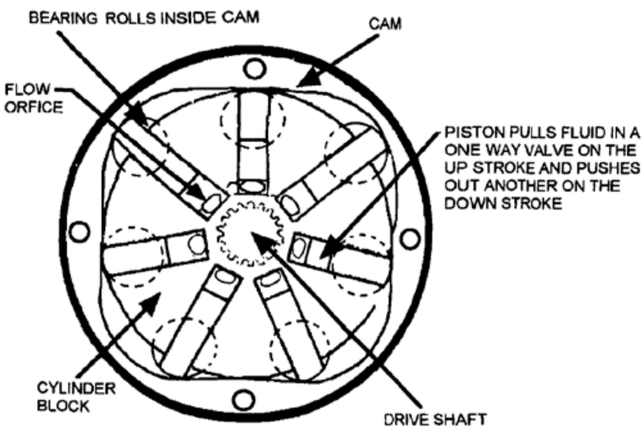


**Figure 2.8.2.12.7-1 –** Radial piston type hydraulic motor

### 2.8.2.12.8 Filters

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

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

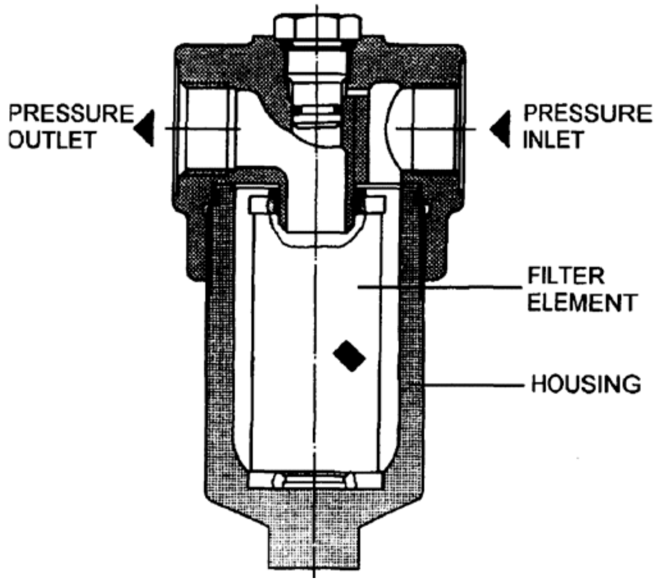


**Figure 2.8.2.12.8-1 –** Pressure line filter

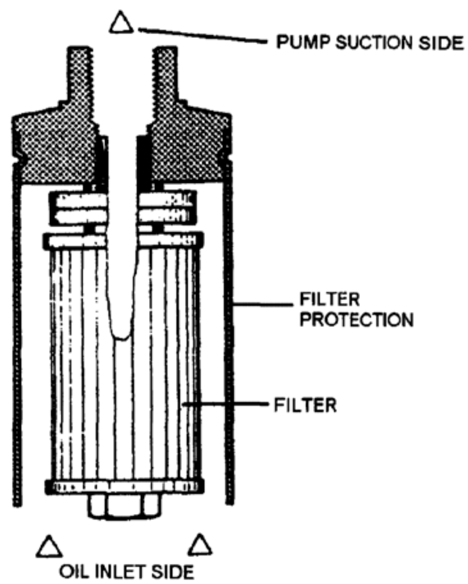


**Figure 2.8.2.12.8-2 –** Suction line filter

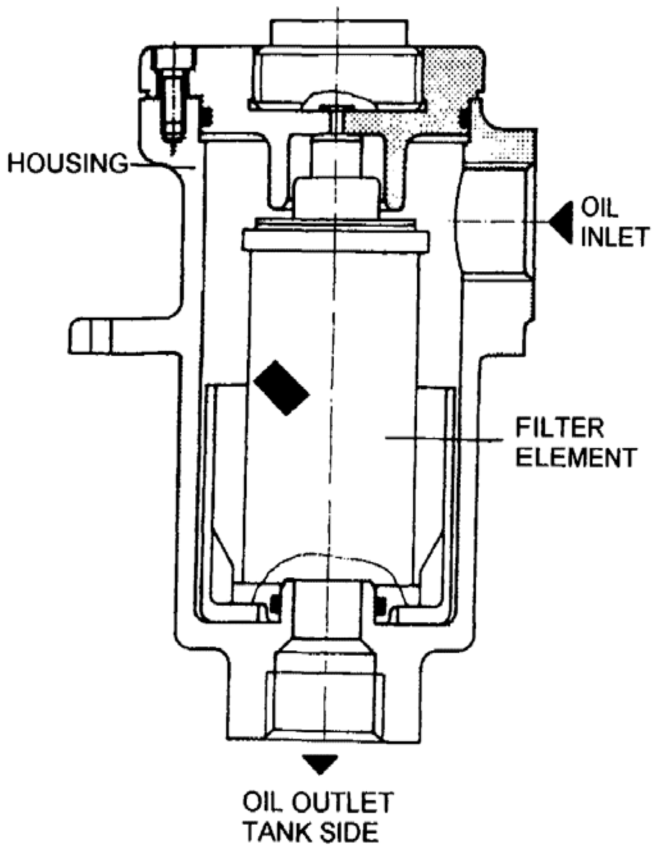


**Figure 2.8.2.12.8-3 –** Return line filter

### 2.8.2.12.9 Rigid Hydraulic Piping and Tubing

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

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

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

### 2.8.2.12.10 Hydraulic Hose

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

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

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

### 2.8.2.12.11 Reservoirs

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

During routine inspection, inspectors should check fluid level, and check for proper breather operation without opening the tank. Current AASHTO specifications (Reference 7) prefer the use of bladder type reservoirs in dusty environments, which may complicate inspection.

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

*C2.8.2.12.11*

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

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

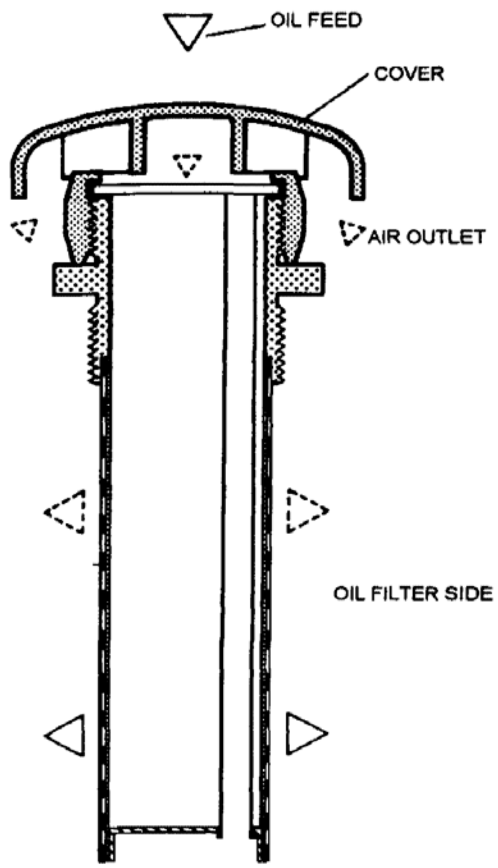


**Figure 2.8.2.12.11-1 –** Filter/breather unit

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

### 2.8.2.12.12 Hydraulic Fluid

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

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

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

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

Samples of fluid should be collected from the reservoir base and other areas during each routine inspection and inspected for the presence of particulates and other harmful substances. It is recommended that owners also consider routine testing of fluid samples to obtain chemical analysis and a particulate count. Testing allows predicting trends and may also provide early detection of a serious system defect such as pump cavitation, cylinder misalignment or formation of harmful acid in the fluid. See Chapter 2.10 for discussion of fluid sampling and testing. Fluid degrades over time due to heat, oxidation and other factors that vary with the application. Regularly scheduled fluid and filter changes are vital for reliable long-term system performance. Inspectors should inquire about the fluid replacement schedule and verify that it is being adhered to.

### 2.8.2.12.13 Hydraulic Systems Interlocking Sensors and Controls

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

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

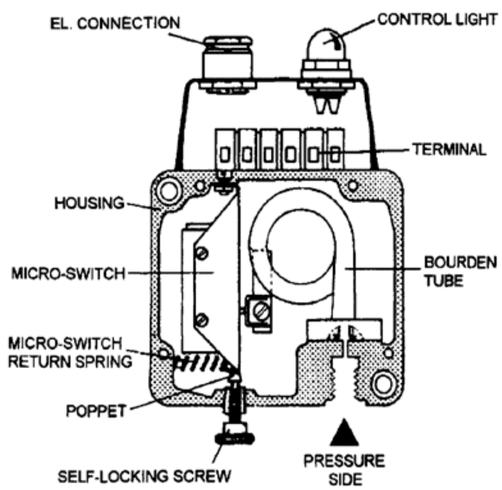


**Figure 2.8.2.12.13-1 –** Bourdon tube type pressure switch

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

### 2.8.2.12.14 Hydraulic Machinery Coding Recommendations

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

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

Components or systems that exhibit leakage of hydraulic fluid should generally be coded “poor” or “severe” based upon whether the inspector believes action is required in the near future or immediately. If the inspector believes that corrective action can be deferred for a short period of time, the component should be coded "poor" with clarifying documentation. Any hydraulic component observed to be leaking fluid to the waterway should be coded "severe." Components that exhibit no signs of problems or external evidence of defects or leaks should be coded based on engineering judgment or the component life table in Chapter 2.9

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

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

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

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

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

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

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

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

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

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

### 2.8.3 – ELECTRICAL INSPECTION PROCEDURES

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

The electric power supply for new movable bridges is currently recommended by Reference 7 to consist of a primary source from the local utility and a secondary or emergency source provided by an alternate method such as an engine driven emergency generator or auxiliary power feed from another electric power source. Some existing movable bridges do have an available secondary power source.

Control systems associated with electrically operated bridges typically consist of motor control equipment and either electric relay or electronic control logic, often with numerous interlocking and safety devices to verify that defined sequences of operation of the movable structure are followed and cannot be defeated in normal bridge operation. The inspector should familiarize himself with the typical bridge operating sequence outlined in Chapter 2.2 prior to performing any inspections.

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

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

- **Routine inspection**, which should not include major disassembly for inspections, performed by either the Engineering Evaluation or Predicted Life methods described in Chapter 2.9. The methods presented in the text of this Section and Section 2.8.2 apply primarily to routine inspections by the Engineering Evaluation method. Routine inspections by the Predicted Life method will generally consist of performance testing as described herein, visual inspection and component age based on condition ratings. Routine inspections using either method should include a check of span balance by the ammeter method (see Chapter 2.10) for bascules and lift spans and a check of swing span main drive loads by the same method.

*C2.8.3*

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

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

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

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

### 2.8.3.1 Electrical Systems for Movable Bridges

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

#### 2.8.3.1.1 Bascule Bridges

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

#### 2.8.3.1.2 Swing Bridges

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

### 2.8.3.1.3 Vertical-lift Bridges

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

### 2.8.3.1.3 Other Movable Bridge Types

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

### 2.8.3.1.4 Basic Electrical Equipment

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

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

Electrical controls and interlocking are covered in Chapter 2.8.3.13.

### 2.8.3.2 Inspection Scope

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

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

### 2.8.3.2.1 Routine Inspections

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

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

Following completion of the inspection, a report should be developed for record purposes to document the current status of the bridge and to prioritize any corrective action needed. The data base for the electrical systems associated with the bridge, in terms

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*The contents of Chapters 2.2 and, 2.3 of this Manual and the NBIS (Reference 8g) provide further guidance on frequency and definitions of the various types of inspections* of equipment, operating data and status of system insulation resistance, can be updated accordingly. The report should also include conclusions as to the status of the bridge's electrical systems in terms of age, safety, reliability, maintenance, and operating procedures.

#### 2.8.3.2.2 In-Depth Inspections

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

- A comprehensive visual inspection of the bridge and vehicular and marine traffic approaches to the bridge. The intent is to define, in specific terms, the physical condition of all electrical equipment and installation associated with the bridge. This definition will include the degree of corrosion and integrity of equipment enclosures, wireways, conduits, and submarine cables exposed to the prevailing environment, as well as completeness of the electrical system to operate safely and reliably.
- Testing of the complete electrical systems associated with the bridge and evaluation and analysis of the test results to determine the conditions and operating parameters of the system. The specific tests conducted are dependent on the types of electrical equipment and form of installation, but generally consist of:
- Insulation resistance testing of all motors, controllers, switchgear cables, and submarine cables, as given in Chapter 2.10. The condition of electrical insulation is a "good" indication of the service life that can be expected from aging equipment. Whenever an insulation resistance test is made, all pertinent data should be recorded, including the time of day, the date, the test voltage, temperature and humidity. Temperature and humidity influence test results. Because insulation resistance changes with age and operating environment, no specific resistance can be given for an absolute minimum value. The method adopted to evaluate insulation is to record the test results and plot this data on a curve from inspection to inspection. Normally, the

plotting of the test results produces a gradually changing line. When this line or curve deviates substantially from normal trend, the insulation is failing.

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

### 2.8.3.2.3 Inspector Safety

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

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

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

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

Inspectors and maintainers should always isolate and lockout equipment and check for the presence of voltage prior to removing equipment covers and enclosures for inspection and maintenance. Do not work on live parts. Make sure rotating machinery is deenergized and locked out prior to inspection or maintenance.

### 2.8.3.3 Motors

The three most common types of electric motors found on movable bridges are AC (alternating current) squirrel cage induction motors, AC wound-rotor induction motors and DC (direct current) motors. Occasionally, synchronous motors may be encountered on older bridges. Traffic gates, resistance gates, span locks and rear locks most often are driven by AC squirrel cage induction motors. Figure 2.8.3.3-1 shows a span lock motor for a mechanically operated lock. Main span drive motors are most often AC wound-rotor or DC motors. However, newer span drive motor designs may utilize vector variable frequency drives (VFDs) and inverter rated AC squirrel cage induction motors as an alternative to the traditional forms of span drive motor speed control.

**Figure 2.8.3.3-1 –** A span lock motor.

*C2.8.3.3*

*The span drive motors are usually arranged as variable speed units by interfacing with either a combination of drum controllers (or contactors) and resistors, silicon controlled rectifiers, primary or secondary voltage control, or by using variable frequency speed control with AC induction motors. The latter is becoming more common/or new movable bridge designs.*

### 2.8.3.3.1 AC Squirrel Cage Induction Motors

The squirrel cage induction motor is in common use throughout general industry. It is popular because it is simple, reliable and is generally less expensive than other motor types of the same horsepower.

The term "squirrel cage" is derived from the motor rotor (rotating element) construction, which resembles a squirrel cage. See Figure 2.8.3.3.1-1. The rotor employs solid bar copper or aluminum conductors that are soldered at each end to

*C2.8.3.3.1*

*Squirrel cage induction motors were previously single speed devices; speed remains almost constant from no load to full load in the absence of outside frequency control. However, with the development of the solid-state adjustable frequency motor controller, the squirrel cage motor can presently be used to provide variable speed* a shorting ring. The shorting ring actually short circuits the individual conductors of the rotor.

All induction motors have a stator (stationary) winding, called the primary, connected to the electrical power source. The rotor, also called the secondary, of a squirrel cage induction motor has no electrical connections. The magnetic field produced by the primary rotates the rotor due to the progression of AC current through the winding. The voltage induced in the secondary (rotor) is accompanied by a magnetic field. Because the rotor is free to rotate, motion is produced by the interaction of the magnetic fluxes.

**Figure 2.8.3.3.1-1 –** Squirrel cage induction motor

*and torque control over a wide range of load conditions.*

### 2.8.3.3.1.1 Inspection

Routine inspection should be performed with the motor running. The inspector should check the following performance criteria:

- Listen to the motor; check to determine if the bearings emit a squealing or grinding sound.
- Feel the motor casing for excessive vibration.
- Feel the motor in the bearing locations. If it is unusually hot to the touch, bearing trouble is indicated.
- Check to make sure all components are tight and all bolts are in place.
- Check bearing seals for signs of lubricant leakage.

*C2. 8.3.3.1.1*

*The squirrel cage motor is the easiest to inspect. Because of the frame construction, only the external components can be inspected. In-depth inspection of the motor should include insulation resistance testing using a megger as outlined in Chapter 2.10.*

### 2.8.3.3.2 AC Wound-Rotor Induction Motors

Wound-rotor motors (shown in Figure 2.8.3.3.2-1) operate on the same principle as the squirrel cage motor, current induced from the stator windings produces magnetic fields in the rotor. However, there is a significant difference between the two types. A wound-rotor motor, as the name implies, has several coils mounted on the rotor, instead of conducting bars found on the squirrel-cage type.

The windings are connected to collector rings, or "slip rings," mounted on the shaft. Brushes contact the slip rings, connecting them to external resistors in the motor controller. Figure 2.8.3.3.2-2 shows a view of collector rings and Figure 2.8.3.3.2-3 shows the rotor assembly.

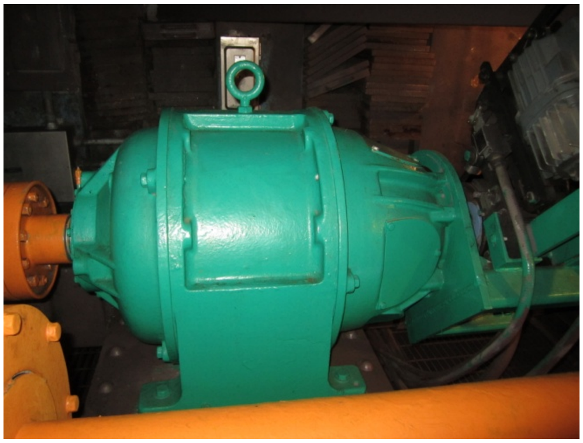

**Figure 2.8.3.3.2-1 –** A wound-rotor motor

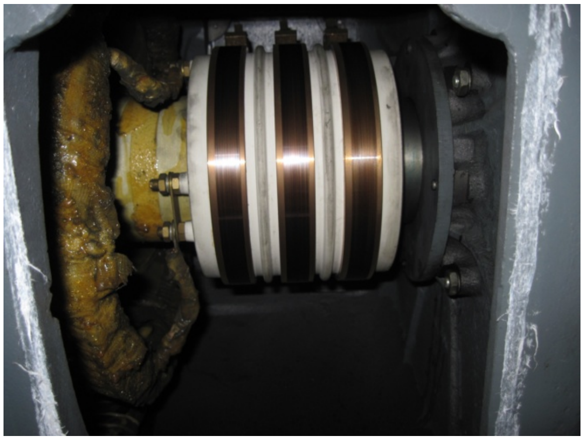

**Figure 2.8.3.3.2-2 –** Slip rings

**Figure 2.8.3.3.2-3 –** Wound-rotor motor assembly

When the rotor windings are shorted out, the motor operates much like a squirrel cage motor. However, by using the controller to insert a number of steps of secondary resistance across the windings, the speed and torque of the motor can be varied. This type of motor requires internal inspection to determine the condition of the rings during an in-depth inspection.

### 2.8.3.3.2.1 Inspection

The external inspection described in Section 2.8.3.3.1.1 for the squirrel cage induction motor should also be performed during the routine inspection of AC wound-rotor induction motors.

For the in-depth inspection, remove the inspection covers on the end of the motor frame to provide access to the inside of the motor. The brush assembly and slip rings are located behind these cover plates. The following outlines additional internal examination suggested during an in-depth inspection.

- Check the slip rings for signs of surface pitting, grooves and cracks.
- Check the insulation around the rings. It should be in “good” condition with no contamination, carbon build up, or arcing damage.
- Check the carbon brushes for length, freedom in the brush-holders, surface fit, and conduction.
- Check for oil and grease contamination of the winding. Buildup should be removed by maintainers using an approved solvent.

*C2.8.3.3.2.1*

*Chapter 2.10 describes brush inspection procedures that should be performed as part of an in-depth inspection.*

*The insulation resistance test and bearing inspection, outlined in Chapter 2.10, should be applied during an in-depth inspection. With the motor running, brush conduction should be checked and vibration levels observed. Bearing temperatures should be checked for high operating temperatures with an infrared non contact thermometer.*

- Check that the air passages between the windings are not plugged, preventing air circulation.
- Check the insulation for signs of overheating, cracking or short circuit possibilities.

The following other performance tests should be done during routine inspections:

- Observe the secondary controller during motor operation. The contactors should not chatter or bounce on their contacts. No sustained arcing should occur during any part of the control operation. Make certain the controller sequence is correct and that all components function properly. A schematic diagram of the controller will be required to perform this check.
- Visually check the controller components for wire and cable conditions. Cable connections should be tight. Look for broken conductors and signs of terminal cracking. Partially broken connectors can accelerate an insulation failure due to overheating.

Figure 2.8.3.3.2.1-1 shows the wound-rotor motor external resistors. The in-depth inspector should check for white discoloration (see arrow in Figure 2.8.3.3.2.1-2), which indicates possible trouble.

This white area could be a sign of “severe” overheating or an atmospheric corrosion of the metals. Overheating can be caused by broken resistor grids or “poor” contact between adjacent resistor grid plates. This condition should be corrected; Figure 2.8.3.3.2.1-2 shows broken grids. Discoloration around the break point will be apparent.

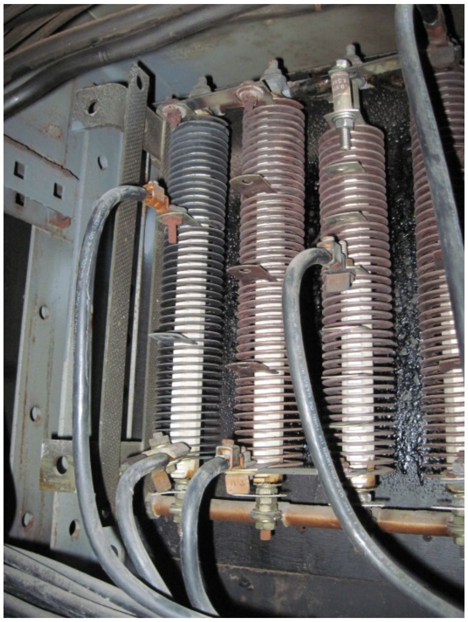

**Figure 2.8.3.3.2.1-1 –** Wound-rotor motor external grid type resistors

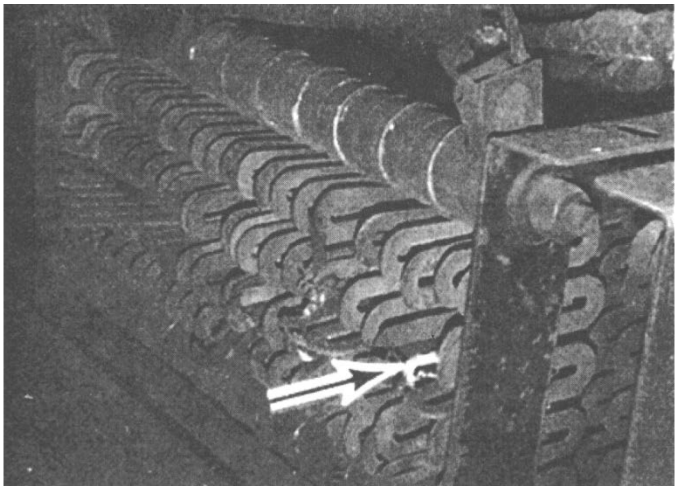

**Figure 2.8.3.3.2.1-2 –** Wound-rotor motor external resistors with broken grids

### 2.8.3.3.3 DC Motors

A shunt wound direct current (DC) motor is one in which the field windings and armature may be connected in parallel across a constant voltage supply. The speed of a DC motor is proportional to its armature voltage and the torque is proportional to its armature current.

Direct current motors provide a continuously variable speed range and have excellent speed control capability. Torque (load) variations do not affect the DC motor as much as the wound-rotor or the squirrel-cage motor. This permits better speed control of the

*C2.8.3.3.3*

*In adjustable speed applications, the field is connected across a constant voltage supply and the armature is connected across an independent adjustable voltage supply.*

DC motor than the wound-rotor motor. Figure 2.8.3.3.3-1 shows the construction of a DC motor.

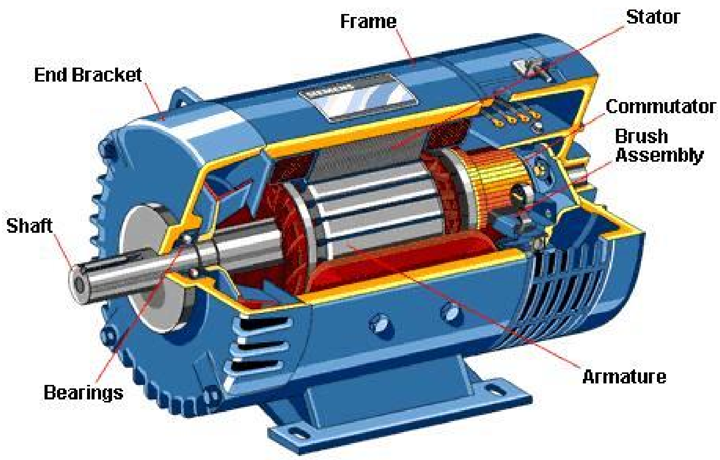


**Figure 2.8.3.3.3-1 –** Direct current motor

The armature (rotating member) is constructed with insulated copper formed coils positioned in slots in the laminated rotor body. The ends of these wire wound coils are connected to copper segments called commutator bars. The commutator bars are assembled on, and insulated from, the motor shaft and each other. To conduct current through the coils, the DC motor has one or more sets of carbon brushes that complete the electrical circuit from the power supply through the commutator and coils, and back to the supply. Each brush (one positive and one negative) makes contact with a coil in the armature through a commutator bar. DC voltage applied to the brushes produces a current flow in the armature coil, that in turn produces a magnetic field in the motor rotor. As the rotor turns, the next coil connected to the armature advances and makes contact with the brushes on the commutator and a new magnetic field is created. This change from one bar to the next on the commutator is referred to as "commutation."

### 2.8.3.3.3.1 Inspection

External inspection methods described in Section 2.8.3.3.1.1 are also applicable to the routine inspection of direct current motors.

During in-depth inspections, remove the cover plates on the end opposite the output shaft of the motor. The commutator and brush assembly are located immediately under the plates. The following outlines the internal in-depth inspection procedure:

- Check the commutator surface for smoothness. The

*C2.8.3.3.3.1*

*Grooves are caused by copper, abrasive particles, or foreign matter embedded in the brushes cutting into the soft copper as the commutator rotates.*

*If bridging is allowed to develop, short circuiting or "flashing" of the commutator will result.*

*The brushes should not project beyond the edge of the commutator, and brushes on multiple* commutator bars should be evenly glazed and free of grooves.

- Examine the slots between the bars for "bridging," i.e. copper spill-over from bar to bar.
- Check the mica insulation material between the bars. If the copper is worn below the mica, the brushes will not commutate properly and "brush chatter" will become noticeable.
- Check all brush holders for equal clearance from the commutator surface; ⅛ in. (3mm) is average but the equipment manual should be checked for specified clearances.

*brush-arm machines should be staggered and aligned so they do not ride in exactly the same position on the commutator. Some overlapping should occur to provide more even commutator wear. See the manufacturer's recommended procedures for proper brush installation, settings and spring pressure. In the absence of manufacturer's data, an approximate spring pressure of 2½ lbs (11 N) could be used.*

### 2.8.3.3.4 Synchronous Motors

A synchronous motor is similar to an AC induction motor, except that the rotor consists of a series of direct current field poles. These field poles are normally wired in series with their polarities alternating from north to south magnetic fields. The two connections to the DC field are wired to a pair of "slip rings" (collector rings) that are mounted on the shaft. DC voltage is applied through the brush assemblies on the collector rings from the controller.

The synchronous motor should be started just like an induction motor. Three-phase power is applied to the stator and the rotor connections are shorted through a small amount of external resistance. After the motor approaches rated speed, a DC voltage is applied to the field coils. The DC current in the rotor coils produces magnetic fields that interact with the stator produced magnetic fields. The stator coils alternate in magnetic polarity with the AC supply frequency each time the current reverses. The rotor poles should follow this alternating magnetic pole of the stator because like poles repel each other and unlike poles attract; i.e., the rotor coil (separated by the air gap from the stator coil) will be a magnetic north for one half cycle of the supply frequency and then change to magnetic south for the second half cycle. This means that the rotor coils will move past the stator coil at a rate of two poles per cycle, first a south, then a north magnetic pole. At running speed, the rotor is said to be synchronized (magnetically) with the stator frequency. This is the reason the name "synchronous" is given to this motor. If the rotor does not rotate at "synchronous speed," it is "not magnetically coupled" with the stator poles and slip will occur until the rotor poles synchronize with unlike poles on the stator.

The "slipping of poles" occurs only at start-up or from a high overloading of the motor, (usually above 160 percent) and occasionally from mechanical binding or friction. Normally, the synchronous motor does not slip during running operations, and the speed remains constant regardless of motor load change.

### 2.8.3.3.4.1 Inspection

The inspection of the stator is the same as for a squirrel-cage stator. The rotor should be checked somewhat differently. During in-depth inspections, the following procedure should be used:

- Check the two slip rings and brush assembly as though it were a wound-rotor motor.
- Inspect the rotor windings for insulation failure.

*C2.8.3.3.4.1*

*The damper winding is a weak point of the synchronous motor and particular attention should be focused on this area during indepth inspections to verify that the insulation has not been overheated.*

### 2.8.3.4 Motor Controls and Motor Control Centers

Main switchgear and motor control equipment is provided to power the bridge's electrical equipment. Older designs may consist of enclosed control equipment (Figure 2.8.3.4-1) mounted on a slate or synthetic compound board. Modern systems consist of enclosed main switchgear and motor control centers of modular metal construction (Figure 2.8.3.4-2).

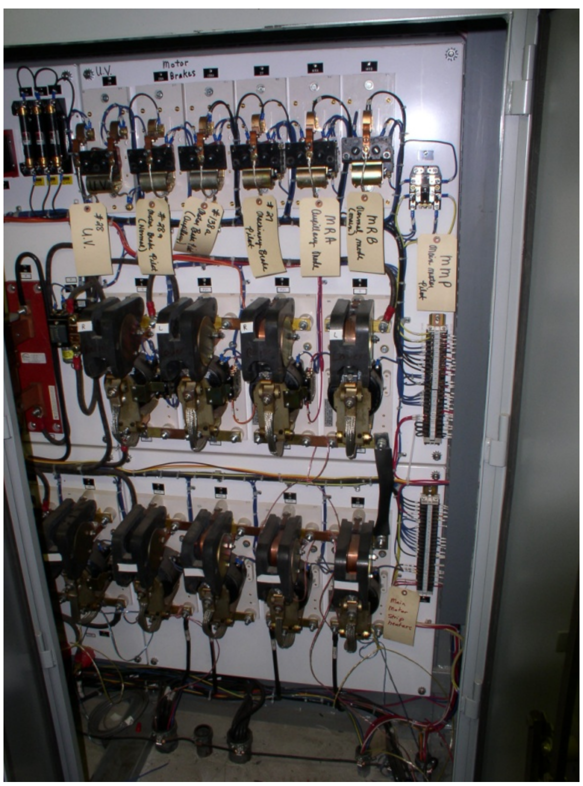

**Figure 2.8.3.4-1 –** Enclosed control equipment

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*The inspector should be sure to remove power feeding the starter before inspecting the starter cubicle. Do not operate starters or disconnect switches with contact arc covers removed.*

**Figure 2.8.3.4-2 –** Motor control center

Motor controls are electromechanical or solid-state devices used to control electric motors. Motor controls can be divided into two categories: starters and controllers. A starter is used to start, stop, and often reverse the direction of motor rotation, but not to control speed and the rate of acceleration and deceleration. A controller performs the functions of a starter and also controls speed, acceleration, and deceleration. If circuit breakers, fuses, disconnect switches, and overload relays are furnished with the starter unit the starter is called a "combination starter." On modern movable bridges, motor controls are grouped together in cabinets or enclosures. These cabinets or enclosures, along with the motor controls and associated control equipment, such as disconnect switches and circuit breakers, are called motor control centers. Motor control centers can be of standard manufacture or custom made for the particular application. Motor control centers have compartmentalized sections for motor starters, motor controllers (variable speed), incoming power, circuit breakers and other equipment.

Motor starters used to control AC motors are divided into two broad categories: full-voltage starters, also called across-the-line starters, and reduced voltage starters. A full-voltage or across-the-line starter is one that connects its controlled motor directly to full value of motor circuit voltage. Starters used in bridge control applications are typically magnetic type. In the magnetic starter, the contactor is operated by the contactor electromagnetic coil that is remotely controlled by push-button or selector switch located at the control console. The full voltage magnetic type starter is typically used to control movable bridge traffic gates and resistance gates and span and tail locks.

A reduced voltage starter, as the name implies, initially connects the motor to a value of the voltage less than that of the supply circuit and then increases the voltage gradually until the motor receives full circuit voltage. Reduced voltage starters are used to serve large motors, typically span drive motors.

During routine inspection the inspector should look inside each compartment for signs of rust and corrosion, dust, debris, and broken parts that may have fallen from equipment housed within the compartment. Wiring should be visually checked for deteriorating insulation and terminal connections should be tight. All wires should be properly. The exterior of the motor control center should be checked for rust and corrosion. Motor starters should be inspected for loose wires, missing or loose hardware, burned coil or wire insulation, worn and pitted contacts, and the presence of dust and debris. The inspector should also listen to motor starters during operation and note any unusual noises. In-depth inspection should consist of infrared monitoring of all cable connections and insulation resistance testing of all cabling connected to the line and load sides of all motor control center starters and circuits.

### 2.8.3.5 Brakes

Since brakes are composed of a linkage of moving parts and a friction member, normal wear is expected. Proper inspection and quality of maintenance directly contribute to the proper operation and life of the brake.

Braking systems usually consist of separate devices designed to perform two distinct braking functions: To decelerate and stop the moving span, and to hold the moving span in the fully closed position or the fully open position.

Brakes used to decelerate and stop the moving span are known as motor brakes and are normally connected directly to the drive motor shaft. They are arranged to operate in concert with the drive motors. The brakes used to hold the moving span are known as machinery or emergency span brakes and are connected within the machinery system, usually as close to the final machinery output shaft as possible. The machinery brakes are usually set after the motor brakes are applied and the moving span is stationary.

*C2.8.3.5*

*Brake shoe lining wear necessitates most frequent inspection, as it directly affects the brake adjustment. All bearings and pins should be kept lubricated with general purpose grease. All nuts and locking devices should be periodically inspected to verify that the brake is in proper operating condition.*

### 2.8.3.5.1 Thruster Brakes

The thruster brake is a motor operated hydraulic brake. The brake motor runs a pump that produces hydraulic pressure in the brake cylinder to release the brake shoes. Figure 2.8.3.5.1-1 shows a hydraulic thruster brake.

Brake torque is a function of the spring tension forcing the shoes onto the drum. By increasing the spring force, more brake torque is applied. However, the brake release mechanism should overcome this spring force to release the brake and correct adjustment is required at all times. The other adjustments compensate for shoe wear and alignment in the drum.

*C2.8.3.5.1*

*Most new motor and machine brakes are usually of the thruster operated shoe type, where the shoe applies the braking torque to the drive shaft when the thruster drive motor is deenergized. The thruster consists of an actuator, which obtains straight line motion by means of oil pressure generated under a piston by a motor driven impeller.*

*It is an important feature with motor and span brakes that power is used to release the brake rather than to apply the brake. If power*

A time delay feature in setting is usually supplied on thrusters and can be adjusted to provide a time of application of up to five seconds. This is usually by means of a controllable flow hydraulic orifice and allows the brakes to be applied gradually, lessening the stresses on the mechanical bridge components. Changing the setting time does not affect the releasing time. The time delay setting can generally be adjusted with a screwdriver. On thrusters having the adjustment screw and the nut on the outside of the tank cover, arrows indicate the direction of rotation for the desired time.

*fails, the brake will set and prevent uncontrolled span motion.*

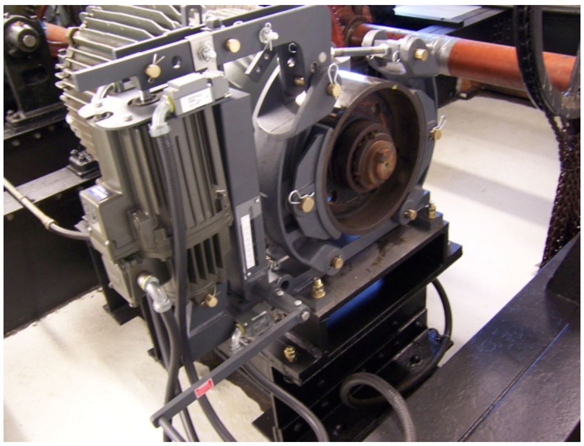

**Figure 2.8.3.5.1-1 –** Hydraulically operated thruster brake

### 2.8.3.5.2 Dual Magnet Clapper and Solenoid Brakes

On this design, electrically operated dual magnets operate the brake assembly that releases the brake shoes. The two magnets, called clappers, are shown in Figure 2.8.3.5.2-1. One magnet is wound to produce a north magnet pole at its face and the other is wound to produce a south magnetic pole face. When energized, the coils attract each other and press against the end of the brake rod on top of the frame; this compresses the spring and releases the brake.

Figure 2.8.3.5.2-2 shows a solenoid brake. The electrically operated solenoid coil magnetically draws the iron core into the solenoid. The iron core is attached to the operating arm assembly that releases the spring tension applied to the shoes.

*C2.8.3.5.2*

*Magnetic clapper and solenoid brakes are "instant on" types which can impose heavy braking torques on drive machinery. Systems with this type of brake or with thruster brakes that are set to engage instantly should be thoroughly investigated for signs of shaft or gear distress that sometimes may result from higher braking forces applied quickly to older systems. This is particularly true if the brake is a replacement component that was not part of the original design.*

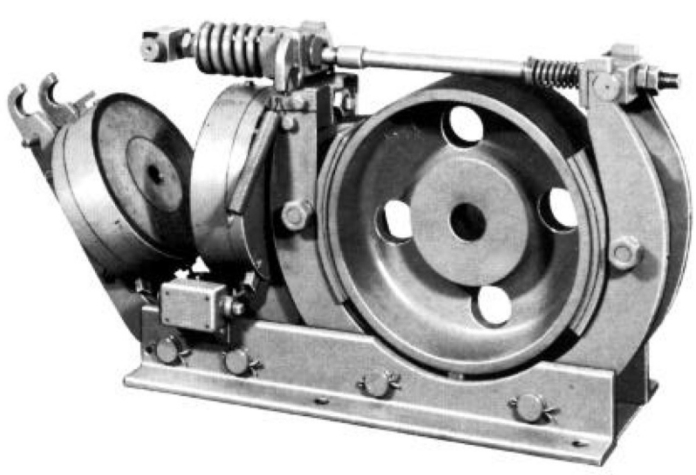

**Figure 2.8.3.5.2-1 –** Dual magnet clapper type brake

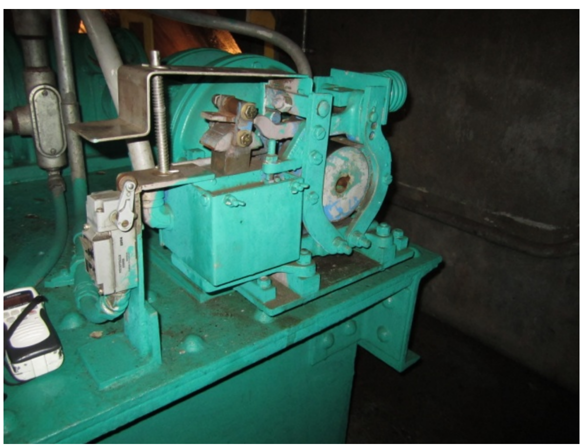

**Figure 2.8.3.5.2-2 –** Solenoid type brake

### 2.8.3.5.3 Disc Brakes

Disc brake lining is of the module type. The linings are the rotating portions of the brake and pressure is applied to both faces by a smooth finished cast iron pressure plate.

A lining wear indicator, which is an extension of the solenoid lever, gives an indication of lining wear. On standard brakes, the indicator is visible from the outside of the case. On watertight disc brakes, an inspection plate covers the indicator. When the indicator reaches the point marked "adjust," the wear adjustment nut should be adjusted to bring the indicator back to the "off" position. When the limit of the adjustment nut is reached and the indicator shows "adjust" relining of the brake is necessary.

*C2.8.3.5.3*

*There are several different types of disc brakes in use on movable bridges. One type is a disc rotor combination where the discs contact the rotating rotor to apply the braking torque. Another type is the enclosed multiple plate disc brake. Inspection procedure for the different types of disc brakes should be based on the manufacturers literature/or the particular type of brake.*

### 2.8.3.5.4 Brake Inspection

In-depth inspection of brakes should include visual inspection and performance testing. All electrical interlocking should be checked. Brake shoe clearance should be checked and the spring compression setting should be verified.

The electrical circuits and lead wires to solenoids should be inspected for signs of deteriorating insulation. Also check for signs of overheating and loose connections. Thruster motors can be overloaded and become overheated because of an improper torque spring adjustment. Check that the thruster motor air passages are clear and that the hydraulic piston is leak free.

### 2.8.3.6 Electric Cables

The various types of cables used on a movable bridge include:

**Power cables:** The power cable may have three or four insulated copper or aluminum wires that connect directly to a motor, generator or transformer. The applied voltage is usually 240 or 480 volts, but can be 2,400 to 4,160 or higher. The load currents are usually above five amps.

**Control cables:** The control cable contains insulated copper or aluminum conductors of low power capacity. They provide low voltage for the various control functions and bridge sensor devices. The wires in the control cables can be single conductor or stranded wire. Control cables can contain many color coded wires with a durable outer covering to protect and keep them together.

**Submarine Cables**: Submarine cables are used to carry power and control signals from one pier to another pier on a double-leaf bascule or to the central pier in the case of a swing bridge. The cables are designed and constructed for direct burial on the channel bottom.

The inspector should check system control voltage prior to inspection.

*C2.8.3.6*

*Control cables should be properly identified by a tagging system that is referenced to an as built wiring diagram. The inspector should note if existing cables cannot be properly identified during routine inspection.*

### 2.8.3.6.1 Cable Insulation Inspection

There are many types and classes of wire and cable available. In any type of cable, insulation failure results mainly from overloading, physical damage or deterioration with age. Dirt, moisture, oil, corrosive atmosphere, over voltage or over current can cause unexpected insulation failure.

Worn insulation can result in short circuits between the equipment and ground or between two or more cables. The inspector should carefully check the entire cable installation visually during a routine inspection. The following areas of

*C2.8.3.6.1*

*Control and power cables cannot tolerate continuous movement against another surface. Rubbing of cable insulation against any other surface results in the loss of small amounts of insulation. It does not matter whether the rubbing is against a solid surface or another wire. Eventually, the insulation will break down and a short circuit will develop.*

*Since a movable bridge has a number of wires and cables that are hung to provide control* concern should be noted on the inspection report:

- Wearing of insulation from rubbing or abrasion.
- Repeated bending of wires.
- Deterioration of insulation from age or atmospheric conditions. (See Figure 2.8.3.6.1-1.)
- Overheating (insulation discoloration).
- Cable insulation showing signs of “sweating.” This condition indicates cable insulation deterioration.

**Figure 2.8.3.6.1-1** – Deterioration of electrical cables

Flexible cables are frequently used to interconnect the power supply and controls that are located on the substructure elements with other electrical equipment (such as the drive motors) mounted on the moving span. Each opening and closing of the span causes the cables to bend and flex. Improper installation can result in a cable breakdown. The following routine inspection procedures should be performed:

- Check to make sure that the cables are supported at both ends of the loop. A loop is provided so that the movement of one end, during raising and lowering of the span, does not cause the cable to bend too sharply or twist while moving.
- Check to see if cable supports are provided. If not, cables may drag along the floor. This can cause a short circuit.
- Check for “severe” (short radius) bending. This can cause the wires to break at these points.
- Check for cracking or wearing of the insulation at stress locations.

In-depth inspections should determine how much insulation has been lost. Meggering of cables can be utilized to give an accurate cable insulation quality. Check for cracks that continue through the insulation to the conductor. These provide a short circuit path. If found, this condition should be corrected, especially if pieces of insulation are cracking away completely from the conductor. Insulation resistance testing with a megger and spot checking of wire resistance, circuit amperage and other

*and power, these wires and cables should be supported at each end so that they do not bend excessively. A careful inspection should be made for cracking or wearing of the insulation at support points and at locations where the cables are bent. Tight radius bends can damage cable insulation.*

*Cable insulation can deteriorate from atmospheric conditions. Moisture is usually present in the air and frequently contains contaminants such as salt from sea water. The effects of these contaminants reduce the expected life of the cables.*

*On swing spans, the submarine cables typically pass through the center casting at the center of span rotation. This area is usually difficult to access, but is also a likely spot for insulation and wire mechanical damage and deterioration resulting from repeated flexing during span rotation. It should be checked during routine inspection.*

*When system voltages exceed 600 volts, consideration should be given to hiring a specialist cable testing company to test the cables.*

vital system parameters should be performed during in-depth inspections.

Insulation overheating: The heating of insulation above a temperature for which it was designed will cause discoloration and may lead to failure. If overheating continues long enough, drying and cracking of the insulation results. The conductor metal will be "severe"ly discolored at this point. A thorough inspection of the cable insulation can reveal potential trouble spots before the wire is "severe"ly damaged and corrective action can be taken.

Localized overheating: Wires and cables carrying electrical current operate at a higher temperature than the ambient or surrounding temperature. Avoid contact between cables that are carrying heavy current since this creates an area where heat cannot be dissipated readily. This lack of heat dissipation can result in localized overheating of the insulation and soften insulation between the cables. The cable insulation will develop an indentation and have reduced insulation value at this point.

If localized overheating is suspected, carefully separate the cables and check for signs of overheating of the insulation. Cables will sometimes stick together due to fusing of the insulation or by contamination. Other types of insulation will dry up and crumble when overheated, rather than bond together. In either case, loss of insulation will result in short circuit failures.

Insulation contamination: Dirt and moisture cause a buildup of contamination, which reduces the heat transfer from a cable to the atmosphere and results in higher operating temperatures. The ambient effect of this temperature rise is an acceleration of normal insulation deterioration.

Grease and oil are very detrimental to insulation life because of their adherence to surfaces. The normal dirt in the air mixes with oil and grease and builds up very rapidly. Contamination from oil on any equipment presents a problem, not only for insulation, but also as a major fire hazard.

### 2.8.3.6.2 Terminal Connections of Wires and Cables

Terminal points provide increased stress on wires and insulation terminal connections frequently support some of the weight of the wires. Vibration and normal flexing of the cables should not break or crack these connections if they are properly designed and installed; however, loose connections frequently overheat and can cause insulation failures. Connections can become loose over time by repeated resistance heating and subsequent cooling of the connector metal parts, which can sometimes cause temporary thermal stresses that tend to loosen threaded fasteners. Inspection of connections for tightness and signs of insulation deterioration can prevent failures and unexpected equipment shutdowns.

*C2.8.3.6.2*

*Infrared heat temperature sensors provide a safe non-contact means of identifying loose wiring connections. Cable terminations should be "hot spot" tested by infrared testing equipment during an in-depth inspection.*

Wherever components are connected together, the surface contact area of wire terminals and equipment terminals are subject to corrosion and resistance buildup. Even newly made connections have a "junction resistance" and their contact surfaces develop some heat while conducting current across the junction. If the corrosion is excessive, overheating of the insulation and conductors results. Failure of the insulation will eventually lead to electrical failures.

### 2.8.3.6.2.1 Inspection

Routine inspections should include de-energizing circuits and spot checking threaded fasteners for tightness. In-depth inspections should include checking all threaded terminal connections for tightness and electrical resistance testing across the fastener to check for corrosion buildup.

Routine cable inspection should include the following:

- Check the wire terminations for tightness.
- Check cable insulation condition. An overheated connection will appear blue in color.
- Check control wire or power cable that passes through a wall or apparatus housing and check the condition of the insulation.
- Check for flat or worn spots and cuts in the insulation from support brackets or motor frames.

### 2.8.3.7 Power Source

Electrical power supplies commonly found on existing movable bridges consist of a service provided by the local utility and possibly a redundant supply line or backup standby generator. The local utility electric service can take a number of forms.

Primary service consists of a medium or high voltage connection from the utility, which is transformed down to the appropriate utilization voltage for the bridge (208/120 volts, 480/277 volts, etc.). The high voltage switchgear and transformation equipment is usually located in a vaulted area, secured by the utility, or on a power pole located at the bridge site. See Figure 2.8.3.7-1.

Overhead or underground secondary service is usually provided at the utilization voltage, with service from the utility system to the bridge structure and termination in the utility metering cabinet. The utility metering cabinet is normally found in the same room as the bridge main switchgear and motor control equipment.

*C2.8.3.7*

*Power company transformers normally mounted on top of the pole; step down the voltage to a level compatible with the bridge equipment. Electric power then enters the bridge house at a weather head type service or via conduit. The power then connects to the main motor control center and/or switchgear.*

The utilization voltage for movable bridges usually consists of a three-phase, 60 Hz service.

**Figure 2.8.3.7-1 –** Pole mounted transformers

The electric service is typically one of the following:

| Normal·Voltage | Phase | Wires |
|---|---|---|
| 120/240 | 1 | 3 |
| 120/208 | 1 | 3 |
| 208/120 | 3 | 4 |
| 240 | 3 | 3 |
| 480/277 | 3 | 4 |
| 480 | 3 | 3 |
| 600 | 3 | 3 |

### 2.8.3.7.1 Inspection (Incoming Power)

The following procedure should be used during routine inspection:

- Check for signs of rust, corrosion, oil leakage, or any condition at the power company transformer that may lead to failure of the incoming power.
- Check the line jacks. If any of the line jacks, which are fused elements, are hanging down, a blown fuse is indicated. A blown fuse will cause the bridge to operate on what is called a “single-phase” condition that can destroy equipment.
- Check for signs of loose hardware, supports, and conduits.
- Use of a voltmeter to monitor voltage fluctuations.

### 2.8.3.7.2 Electric Generator

Where provided, a backup standby generator maintains continued electric service for the movable bridge in the event of utility service failure. Usually, the standby system consists of an internal combustion engine driven synchronous generator with either an automatic or manual transfer system, to transfer from utility service to standby service in the event of utility failure. See Figure 2.8.3.7.2-1. The size of the standby generator is based on the starting requirements for the bridge drive motors and can be as much as twice the capacity of the utility service. Both AC and DC type generators are used on movable bridges.

**Figure 2.8.3.7.2-1 –** An automated generator

### 2.8.3.7.2.1 Inspection

AC generators are similar in construction to AC motors and similar inspection procedures should be followed.

Brushless exciter generators should be checked similarly to a squirrel cage motor. Caution should be observed to prevent damage to the diodes in the generator caused by testing equipment, and the manufacturer's equipment manual should be consulted before performing any testing.

DC generator inspection is similar to that of a DC motor. In addition, a self excited DC generator should be checked to verify that the generator comes up to voltage within five to ten seconds after the generator has reached rated speed.

Regulated DC generator supplies should be checked for stability (generator output) only when the generator load is stable. If the generator is unloaded the voltage should not be oscillating above or below the control voltage value. Similarly, when the generator has a constant load, the regulator should stabilize the output voltage after the first two or three transients caused by load change. If the voltage regulator tends to "hunt," the regulator may require calibration and a tune-up to improve its operation.

The engines on emergency generator sets should be started on a biweekly basis. This is necessary to push oil to the top of the engine and maintain proper lubrication. Also, the generator should be utilized to open the bridge once a month and during the routine inspection. The starting circuitry should be operated and checked at the same time. Vibration levels should not exceed the manufacturers' specification, and can be checked during testing of the generator. The generator room should be inspected to determine if adequate air flow is available for engine cooling and combustion. Engine exhausts should be properly ducted or piped outside of the generator room. If the generator is incapable of producing the necessary drive power to open the bridge, it should be listed as critical.

### 2.8.3.7.3 Transformers

The transformer is a relatively simple device that has made the economical transmission of electrical power over long distances practical. Its function is to transform, or change, AC power from one voltage and frequency to another voltage at the same frequency. There are many types of transformers. Two types will be discussed herein: dry transformers and liquid-filled transformers.

*C2.8.3.7.3*

*Transformers are used to reduce generated voltages to levels that the customer can use for his equipment. The primary voltage usually requires another transformer to reduce the voltage used on the customer level. The size of transformers depends upon, among other things, the load requirements of the customer.*

*In addition to the large transformers used on incoming service power, there are also numerous other applications for transformers within the bridge circuitry. Transformers are used to change power voltages to control voltages and to step down power to low voltage indicator lights and other devices within the bridge circuitry. The inspection methods for these devices will vary from manufacturer to manufacturer and should be developed based upon the latest available manufacturer's literature on the particular type of unit. The general concerns as discussed herein for larger transformers will in general also apply.*

### 2.8.3.7.3.1 Dry Transformers

The dry type, air-cooled transformer is constructed by winding coils around a laminated iron core. The coils are separated and have air spaces to enable air to circulate around the copper and between the iron core and windings. One advantage of the air cooled transformer is the accessibility of the windings for maintenance. The tap connections, used for changing voltage, are normally at the sides. The transformer can be inspected by removal of the cabinet panels. Figure 2.8.3.7.3.1-1 shows a view of the air-cooled transformer. The high voltage tap connections are not shown. They are located on the rear of the transformer.

Two advantages of this type construction are less weight and ease of tap changing.

**Figure 2.8.3.7.3.1-1 –** Air-cooled transformer

### 2.8.3.7.3.1.1 Inspection

The inspector should perform the following checks during a routine inspection:

- Check that supports are not bent and that bare conductors are not exposed to adjacent metal.
- Check the frame for signs of rust or metal cracking, especially around welds.
- Inspect the transformer primary disconnect switches (if furnished) for damage, loose materials, or contamination.
- Inspect installation location for any unfavorable environmental conditions.
- Visually check the equipment ground and record the number and size of ground bus and straps.

The inspector should perform the following checks during an in-depth inspection:

- Check the tightness of terminals at the high and low voltage connection points. The terminals should not show signs of breaking or overheating.

*C2.8.3.7.3.1.1*

*Sometimes the 60 Hz of the AC transformer winding creates mechanical vibration. Extreme vibration can cause frame cracking and contribute to an electrical failure of the limit. In-depth inspection should be designed to detect any such undesirable cracking conditions.*

- Check insulation for signs of cracking, overheating or breakdown indications. Make certain dirt has not accumulated to plug the air passages around the coils.
- Check insulators. They should be clean and intact without signs of cracking or chipping.
- Check high voltage switches (if furnished) for operation and adjustment. Check the insulation quality of switch phase-to-phase and phase-to-ground with megohmmeter.
- Check insulation of all control circuits to ground with a suitable megohmmeter.
- Check key interlocks (if present).

### 2.8.3.7.3.2 Liquid-filled Transformers

Better cooling capability is obtained by using liquid around the transformer core and coils because liquids conduct heat better than air. Liquid-filled transformers built today use two types of insulating fluids: mineral and synthetic oils. Figure 2.8.3.7.3.2-1 shows a liquid-filled transformer.

Mineral type insulating oil is degradable and can be handled in the normal manner. It is combustible and presents an explosion and fire hazard.

Synthetic insulating oils, called askarels (PCBs), are noncombustible, but toxic when absorbed through the skin. Special handling is therefore required, and stringent restrictions for use and disposal have been established. Askarel's do not present an explosion or fire hazard and have a higher insulation value than mineral oil.

*C2.8.3.7.3.2*

*Askarel (a generic name for PCBs) was widely used as a dielectric fluid for transformers manufactured from 1930 to 1976. In the 1970s, concerns about possible toxicity and environmental impact of PCBs came to the fore. Regulation of the use of these transformers began in 1978 with the EPA's Marking and Disposal Rule.*

*In 1982, The Electrical Use Rule introduced the concept of periodic leak inspections. Detailed records, as a minimum, are now required for any installation utilizing a PCB filled transformer.*

**Figure 2.8.3.7.3.2-1 –** A liquid-filled transformer.

Many liquid-filled transformers require cooling radiators to dissipate the heat generated internally. Usually mounted on the sides of the tanks, the radiators conduct heat from the liquid to the atmosphere. The radiators may be fan cooled to assist in conducting heat from the radiator surfaces. Sometimes oil circulating pumps are used to improve the thermal capability of the transformer.

### 2.8.3.7.3.2.1 Inspection

There are additional items to check on the liquid type transformer in addition to those items listed for inspection under dry transformers. The following additional areas should be checked during a routine inspection:

- Check for proper oil level inside the tank. Many transformers have dial type indicators for liquid level and temperature. The oil level of the transformer at the operating temperature can be determined on these gauges. The temperature indicator usually has a safe temperature point marking e.g., 70°F (21°C). If the oil level is correct, then the dial indicator should point to that mark.
- Check the tank and floor area for signs of oil leakage. Oil leakage indicates a potentially dangerous condition because the oil level is dropping inside the tank.

The following should be checked during in-depth inspections:

- Transformers without level indicators should be checked by removal of inspection covers on top of the transformers during in-depth inspections. This work should be done by personnel who have received safety training concerning proper methods to protect themselves against PCBs in the insulating oil.
- Check the insulating bushings for signs of cracking or chipping. Dirt build up should be noted.
- Check the radiators to make sure air passages are clear. If fans are used, they should be free from vibration and properly directed toward the radiators.
- Check the sudden pressure relay to be sure that it has not operated. This relay operates when a sudden pressure develops inside the transformer due to a fault condition. Normally it is wired into an alarm system to provide warning and shutdown functions. A small indicator located on the top of the relay will show operation.
- Check high voltage connections terminating inside a connection box to verify that the insulation on the pot head, cables and support is in “good” condition. Normally, the high voltage cable has a shielding wire. Be sure that these are properly connected to the grounding point.

*C2.8.3.7.3.2.1*

***Caution:*** *Unless absolutely sure that the transformer oil is not PCB contaminated, the inspector should not touch any of the oil if a leak is found. The inspector should call for immediate corrective action and file a deficiency report that should indicate the leak and request immediate investigation by an expert in liquid filled transformer evaluation.*

## 2.8.3.8 CIRCUIT BREAKERS

Circuit breakers are used both as protective devices and for switching electrical power. One of the main requirements of a circuit breaker is that it should be capable of carrying rated current continuously. If a short circuit or overload occurs, the circuit breaker must open the circuits.

The general classifications of circuit breakers are:

- Low or high voltage air circuit breakers (ACB).
- Molded case circuit breakers.
- Oil circuit breakers.

*C2.8.3.8*

*To isolate or open a circuit when no current is flowing is one thing, and to interrupt the flow of current and maintain the interruption is another. A simple knife switch may be quite adequate under no load conditions, but not for power interruption. Not too many years ago, breakers were merely manually operated switches with a tripping device and no electrical control. Some later designs were equipped with shunt tripping coils similar to those described in the air circuit breakers, while others used an undervoltage relay to operate the trip mechanism. An undervoltage relay trips the breaker when voltage dips below a safe level or if there is a power failure.*

### 2.8.3.8.1 Air Circuit Breakers

This type of breaker operates in air to extinguish the arc when a circuit is opened.

An air circuit breaker is generally used where the voltage is above 250 volts to ground. Figure 2.8.3.8.1-1 shows a three pole air circuit breaker. This breaker is of the open construction type and is normally part of a switchgear system. The main components are shown in Figure 2.8.3.8.1-1 and include the arc chutes pole contacts, trip and overload mechanisms. The overloads in this breaker are thermal/magnetic types and can be adjusted for a number of selected trip values.

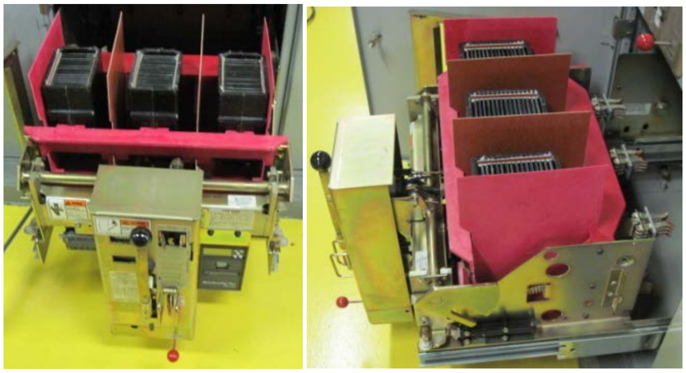

**Figure 2.8.3.8.1-1 –** Air circuit breaker

Some circuit breakers use spring charged operating mechanisms. These devices have manual or electric motor charging devices to compress the spring(s). When the breaker

*C2.8.3.8.1*

*In low voltage applications (120 volts to 277 volts to ground), typically molded case circuit breakers are used.*

is closed the "stored" energy snaps the breaker contacts closed maintaining a contact pressure. When the breaker is opened stored energy must open the contacts in a precise, fast operation to minimize contact wear due to electrical arcing.

In Figure 2.8.3.8.1-1, the air circuit breaker operating handle is used to close and trip the breaker. Some types of ACBs close with the handle mechanism, but trip with a push-button on the panel. Electrically operated shunt tripping coils can also be used to trip the breaker. These shunt trip coil units are mounted on the breaker frame, with the coil plunger operating the breaker tripping bar. The overload protection units shown in Figure 2.8.3.8.1-1 monitor the load current continuously for time over current conditions. The trip unit (one for each pole) will actuate the trip bar to open the breaker when an overload condition is detected.

Additional equipment can be mounted on the breaker, such as auxiliary contacts for the breaker indication. These contact blocks are mechanically coupled to the operating mechanism by link arms and close and open with the breaker main contacts. Other equipment might include electronic protection circuits with multiple monitoring functions. A check of equipment drawings will indicate the items supplied and the circuitry involved.

### 2.8.3.8.2 Molded Case Circuit Breakers

Another commonly used breaker is called a molded case circuit breaker. It is built with a complete enclosure of molded plastic. Its contacts operate in air with arc chutes around them to extinguish electrical arcing during contact opening. The breaker cases are factory sealed so that they cannot be tampered with. Figure 2.8.3.8.2-1 shows a molded case breaker used for motor circuit protection. The trip element in this type breaker can be changed to give a range from 7 to 4000 amperes. Current exceeding the set values causes the circuit breaker to trip.

On any adjustable breaker, the trip setting is normally calibrated at the time of installation to suit load requirements. The setting should be kept on record and checked by the inspector during inspection.


**Figure 2.8.3.8.2-1 –** Molded case circuit breaker

### 2.8.3.8.3 Oil Circuit Breakers

Oil filled circuit breakers are sometimes applied where large motors must be started and stopped. Oil provides increased insulation for high current interruption. Normally, this type of breaker will not be used on bridges, but older power circuit breakers were all oil immersed units

### 2.8.3.8.4 Inspection

The following outlines the routine inspection checks that should be performed for all breaker types:

- Check connection points to verify that overheating has not occurred. Cable connections should be tight.
- Check for stressing of the breaker terminals caused by unsupported cables.
- Check the trip settings on the front to make sure the proper trip settings are in use.

**Air circuit breakers**: The following tests should be performed during an in-depth inspection:

- Check the arc chutes for loose or missing hardware, foreign material, and the condition of ceramic insulation and arc interrupters. On most air circuit breakers, the arc chute can be removed for inspection.

*C2.8.3.8.4*

*The inspector should not attempt to restore the contact surface with a file or other abrasive device. Record the contact condition only. The proper testing of circuit breakers requires trained personnel with portable equipment. Except for small breaker testing (under 100 amps) special test equipment is required. Breaker testing will not be included in this discussion.*

*Some limited testing of breaker insulation to ground can be performed by using the megger test. Refer to Chapter 2.10 for a description of this test.* ***Caution:*** *Other equipment connected by cables to the breaker may have testing limitations; check the equipment before making any tests.*

- Check contact surfaces for arc damage, pitting and erosion. It should have at least 90 percent contact. Good contact operation requires a slight amount of "contact wipe" or overtravel after contact is made.
- Check to see that the contacts are clean and positively seated. Adjustable spring compression is normally provided.
- With the breaker in the test position and deenergized, check contact alignment and verify that they make simultaneous contact when closing.
- Check overload trip settings to make sure they have not been moved from their calibrated setting. Only authorized personnel should be permitted to change trip unit settings.
- Check the terminal connections where the line and load cables are connected to the breaker. Loose connections are a major cause of breaker failure. Loose connections produce heat resulting in insulation failure or breaker malfunction.

**Molded case breakers:** The molded case breaker requires little inspection because the case is sealed.

**Liquid-filled circuit breakers:** Routine inspections are similar to those described for molded case circuit breakers. When liquid filled circuit breakers are used, an in-depth inspection should include testing a sample of the insulating oil. This should be performed by a specialized testing company. A complete check of the breaker's oil immersed parts should be made at every in-depth inspection if the switching operation is very light, more often under frequent load interrupting conditions. If oil level indication is provided on the breaker, check the oil level every month or less depending upon operating conditions. Oil should be tested according to the test methods outlined in Chapter 2.10.

## 2.8.3.9 TRAFFIC CONTROL

Traffic control electrical systems operate traffic signals, traffic gates, and advance warning signs with flashing lights and message boards, and resistance or energy absorbing barriers located on bridge approaches open to the waterway crossing.

### 2.8.3.9.1 Warning Lights and Signals

The use of "drawbridge ahead" warning signs are required on all movable bridges to give advance warning to motorists, except in urban conditions where such signing would not be practicable (MUTCD, Reference 73). When physical conditions prevent a driver from having a continuous view of at least one signal indication, for approximately 10 seconds while travelling at 85

*C2.8.3.9.1*

*Any malfunctioning or missing warning lights, signals, or navigation lights should be reported immediately and recommended for immediate repair.*

percent of the posted approach speed, before reaching the stop line, an auxiliary yellow flashing light is required by the MUTCD on the warning sign. The inspector should check for proper installation of these warning signs and for proper operation of the flashing light if required. Any sign or warning light found to be missing or inoperative should be reported in a deficiency report.

### 2.8.3.9.2 Traffic Signals

Traffic signals should be checked for proper electrical connections, tightness of the bolts, corrosion of any metal parts, broken lines, and non-functioning lights. Any traffic lights found to be inoperative should be reported immediately.

### 2.8.3.9.3 Traffic and Resistance Gates

A typical gate arm motor is shown in Figure 2.8.9.3-1.

The following should be checked during a routine inspection of traffic and resistance gates:

- Check for traffic gates' smoothness of operation, tightness of the gate arm to the housing, and for proper lubrication of the gearing.
- Spot check electrical connections for tightness and signs of corrosion at the terminals.
- Check wiring for frayed, cracked, or deteriorated insulation.
- Check the gate housing for corroded or deteriorated metal parts.
- Check the service panels to verify that they fit tightly and the frames and gaskets are in good condition.
- Check the limit switch for proper operation.
- Check that all warning lights are operating properly and their associated wiring is in good condition. An installation using solid conductor wires is not acceptable on the electrical cable leading to warning lights on the moving gates. A stranded wire multi conductor cable should be used and protected against chafing at the point where it enters the gate housing.

*C2.8.3.9.3*

*The electrical inspection procedure for resistance gates is similar to that of traffic gates. Some types of traffic and resistance gates may utilize special mechanical linkages and/or hydraulic systems to actuate motion of some or all components. The inspection methods for such gates should be developed based upon the procedures described in Chapters 2.8.2.*

**Figure 2.8.3.9.3-1 –** A typical gate arm motor

### 2.8.3.10 NAVIGATIONAL LIGHTS

Navigational lights should be checked to confirm that they are present and operating properly in conformance with the bridge permit. Check to see that all globes are clean. Check the condition of the gaskets on the light covers. Check for corrosion on metal frame and support brackets. Any lights that may be inoperative or missing should be noted in a deficiency report.

*C2.8.3.l0*

*Any malfunctioning or missing warning lights, signals, or navigation lights should be reported immediately and recommended for immediate repair.*

### 2.8.3.11 LIGHTNING PROTECTION SYSTEM

The fundamental principle in the protection of life and property against lightning is to provide a means by which a lightning discharge can enter or leave the earth without resulting in damage or loss. A low-impedance path must be offered which the discharge current will follow in preference to alternative high-impedance paths offered by the bridge materials such as metal or concrete. When lightning follows the higher-impedance paths, damage may be caused by the heat and mechanical forces generated by the passage of the discharge. Most metals, being good electrical conductors, are virtually unaffected by either heat or the mechanical forces if they are of sufficient size to carry the current that can be expected. During the routine inspection the inspector should verify that:

- The metal path is continuous from the ground terminal to the air terminal.
- The conductors are either copper or aluminum, are free of the effects of rust or corrosion, and are attached to the structure at intervals not exceeding three feet.
- All connections are tight.

### 2.8.3.12 ELECTRICAL COMPONENT CODING GUIDELINES

Due to the proprietary nature and sealed “black box” appearance of electrical components, it is extremely difficult to quantify criteria for numeric condition evaluation coding without extensive testing by a qualified electrical engineer. There are, however, some general guidelines as follows:

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

Electrical components that are observed to be smoking, hot, or otherwise exhibiting signs of resistance heating should be coded “severe.” Sparking, melted or burned insulation, or black residue left by arcing or shorting of components should be cause to rate components “severe.” Components that create a potential shock hazard to the public or workers should be rated “severe.” Components with no external signs of distress should be coded based upon testing, engineering judgment and/or the component life table in Chapter 2.9. If an individual inspector cannot determine whether a component is “poor” or “severe,” he should code it “poor” and request additional investigation with an explanation of the reason and type of investigation needed.

**Motors** that are excessively hot to the touch or that smoke or emit smells of burning insulation should be rated “poor” or “severe” depending on the inspector's assessment of the likelihood of motor failure. Motors and associated motor controls, breakers and relays should be performance tested during in-depth inspections.

**Brakes** with damaged or excessively worn brake pads should be coded “poor” or “severe.” Brakes and other machinery not designed for cyclical loading, but subjected to cyclical loading due to span motion under live load, should be coded “fair,” “poor” or “severe” based upon the inspector's assessment of the

*C2.8.3.12*

*Motor resistors that have gotten a lot of dust or other debris on them can get permissibly hot during motor operation.*

*If sparking or arcing is observed in any electrical equipment, every effort should be made to deenergize the circuit to prevent further damage.*

likelihood of fatigue fracture of a nonredundant component. Motor and span machinery brakes should be internally inspected and performance tested during in-depth inspections.

**Electric cables and connections** that are not properly protected by enclosures or conduit; that show signs of corrosion, damaged insulation or other conditions that add electrical resistance to circuits; or that create risk of an electrical short circuit or shock hazard should be coded fair, “poor” or “severe” based upon the inspector's judgment of the probability of component or circuit failure.

**Transformers** that leak fluid or show signs of overheating should be coded “poor” or “severe” depending on the inspector's assessment of the likelihood of transformer failure, and whether the fluid is likely to contain PCBs. If a transformer is known to contain PCBs and is leaking, it should be coded “severe.”

**Backup generators** that are powered by gas (propane, etc.) or gasoline motors should be installed in adequately ventilated areas so that combustible gases do not accumulate and create a risk of explosion. Backup generators that fail performance tests and are incapable of producing the necessary drive power should be coded “poor” or “severe.”

**Breakers** that are excessively hot emit a smell of burned insulation during operation or that have a history of nuisance trips, should be coded “severe.”

**Contactors** with missing arc chutes that arc across to the adjacent contactor; or other components, or show carbon tracks due to arcing should be coded “poor” or “severe” based upon the inspector's assessment of the likelihood of component failure.

**Lock mechanisms** that are inoperative should be coded “severe” with an explanation. Those that exhibit signs of overheating or other distress should be coded “poor” or “severe” depending on the inspector's assessment of the likelihood component of failure.

### 2.8.3.13 Controls and Interlocking

#### 2.8.3.13.1 General

Bridge control systems play a vital role in the operation of every movable bridge. In Chapter 2.2, the inspector was provided with an introduction to bridge control system inspection. Subsections 2.2.2.3 through 2.2.2.7 and the "Movable Bridge Opening/Closing Operating Sequence" contained in Chapter 2.3 should be reviewed prior to reading and performing the inspection of control system components outlined in this chapter. This chapter addresses inspector preparation and outlines basic inspection criteria for discrete control system components, the control console system components and main drive motor controls. A control system inspection worksheet is provided in Chapter 2.7 and should be completed by the inspector at the conclusion of the inspection. A description on how to fill out the work sheet is provided.

The information presented in this chapter is intended for the inspector without a formal electrical engineering or electrical maintenance background. The inspector should be able to identify general deficiencies and unsafe conditions brought about by “poor” maintenance. The inspector should note any areas within the general bridge control system that require a more detailed inspection by a specialist with a background in control system design and maintenance.

#### 2.8.3.13.2 Bridge Operating Sequence

The inspector, through evaluation of as-built documentation and discussions with bridge operators, should understand the bridge control system being inspected. Each inspector should again review the bridge operating sequence described in Chapter 2.3 prior to proceeding with the detailed control system inspection.

*C2.8.3.13.2*

*The goal in control system inspection is to perform sufficient control tests to permit the inspector to verify that necessary controls and interlocking are present, functional and capable of being operated by a reasonable and prudent individual in a manner that is consistent with the safety of the structure, the public and workers.*

*The fact that a particular component or system is present in the control panel does not prove that it is functional. Performance testing of controls and interlocking by qualified engineers including verification a/the system's behavior in response to unusual control inputs or other possible errors is the most reliable method to determine that system function is reliable.*

### 2.8.3.13.3 Discrete Control System Component Inspection

Field-mounted discrete system components provide vital information to the bridge control system regarding the status of the bridge. Limit switches, selsyns, resolvers, encoders and tachometer feedback generators are the main components inspectors should focus on during their inspection. Inspectors should be familiar with these devices and their function in the control system being inspected.

#### 2.8.3.13.3.1 Limit Switches

A limit switch is a device that converts mechanical motion into an electrical control current by the closing or opening of a set of contacts at definite settings of the switch. The limit switch contact closures provided as a result of the mechanical movement are used to control the movement of the bridge or to make a change in its operating sequence. A limit switch provides feedback to the control system and can be called a sensor. (Figure 2.8.3.13.3.1-1)

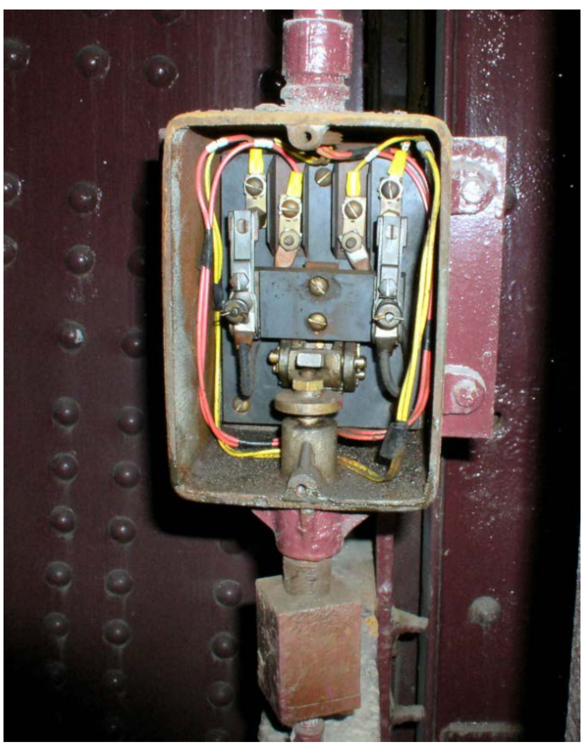

**Figure 2.8.3.13.3.1-1** – Dual contact limit switch

*C2.8.3.13.3.1*

*The limit switch is the most important control device utilized in modern or traditional automated bridge control systems. Each bridge component that would cause a safety hazard or operational component damage if operated out of sequence generally utilizes some type of limit switch to report the position or status of the device during operation.*

*The primary disadvantage for using a lever type limit switch is the limited travel of the limit switch operating arm. Forcing the lever arm past the end of travel point will destroy the limit switch. This is the most common cause of failure for this type of switch.*

The four most common limit switches found on movable bridges are the plunger, lever, rotating cam, and proximity types. Discussion in this Manual is limited to these types of limit switches.

Plunger type limit switches, Figure 2.8.3.13.3.1-2, are normally used to indicate when the movable span is fully closed or fully open. The switch housing is attached to either the movable or fixed part of the bridge and the plunger is depressed upon contact by a strike plate mounted to the span. As the plunger is pushed linearly into the housing, a spring is compressed, and the plunger rod forces two contacts to come together or pull apart. An electrical connection is made and/or broken as the case may be. There are various means for adjustment.

During routine inspections, check the following:

- Carefully examine the operation of the switches to make sure they are operating normally (the plunger is depressed or released at the appropriate time in the bridge operating sequence).
- Confirm the limit switch is functionally active in the control circuit.
- Carefully and safely push the rod and see if the bridge does not stop prematurely during the operation.
- Check wiring to and from each limit switch for looseness or deterioration.

During an in-depth inspection, check the following:

- Open the cover and check for water inside the housing. If water is present, check seal around the plunger for wear or damage.


**Figure 2.8.3.13.3.1-2 –** Plunger type limit switch

Lever type limit switches, Figure 2.8.3.13.3.1-3, are often attached to shoe brake operating linkages and indicate when the brake is set and released, additionally in the operating system to indicate when the movable span is fully closed or fully open, on the span locks and wedges to indicate their position. A roller is usually provided at the end of the limit switch lever arm. A moving object contacts the roller and causes the lever arm to rotate through a limited arc of travel, usually less than 90°. Lever arm movement causes cams to rotate within the housing and open and/or close contacts. The inspection of lever type limit switches is similar to plunger switch inspection. In addition to the previous steps, check the following during routine inspections:

- Check lever arm rollers to make sure they are free to rotate and make sure the limit switch housing is properly aligned with the contacting object.
- Check for excessive looseness of the lever arm assembly. Wiring should be checked for looseness or deterioration.

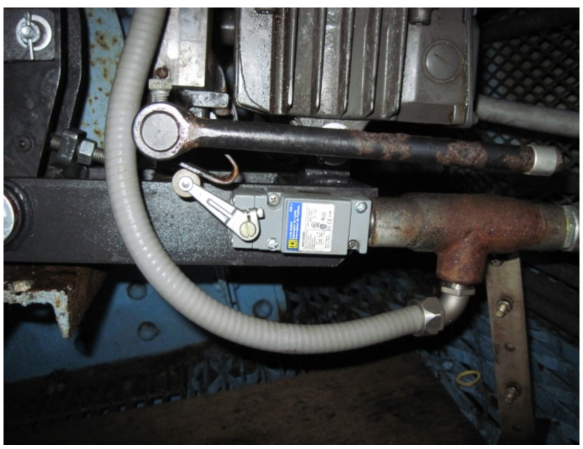

**Figure 2.8.3.13.3.1-3 –** Lever type limit switch

Rotating cam limit switches, Figure 2.8.3.13.3.l-4, are connected to the span drive machinery and typically are used to indicate critical points of span travel, such as the “nearly closed” and “nearly opened” positions. The limit switch shaft, which is coupled to the span drive machinery through reduction gearing, usually is designed to rotate less than 340°. Cams mounted on the shaft, within the housing, rotate with the shaft and open or close spring loaded contacts. Check the following during routine inspections:

- Check for any signs of looseness or deterioration of the wiring.
- Check the enclosure gasket for moisture seal.
- Check for moisture or signs of corrosion inside the switch enclosure.

Check the following during in-depth inspections:

- Check each of the contact surfaces, both the movable and stationary contacts, for any signs of wear or corrosion. Sometimes oxidation will take place creating a poor contact that results in an intermittent circuit.
- Check all bearings for lubrication and play.

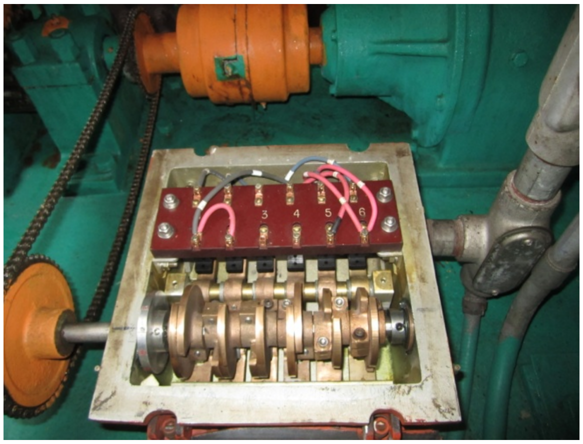

**Figure 2.8.3.13.3.1-4** – Rotary cam type limit switch

Proximity type limit switches, as seen in Figure 2.8.3.13.3.1-5, are often attached to the bridge structure to indicate the movable span position, such as fully closed, and fully open. Proximity switches, often magnetic, open or close an electric circuit when they make contact with or come within a certain distance of ferrous metal. Proximity switches do not have exposed moving parts. Check the following during routine inspections:

- Confirm the limit switch is functionally active in the control circuit.
- Check each of the contact surfaces, both the movable and stationary contacts, for any signs of wear or corrosion if accessible. Sometimes oxidation will take place creating a "poor" contact that results in an intermittent circuit.
- Check for any signs of looseness or deterioration of the wiring.
- Check that surfaces are free of metal filings, grease and other debris.


**Figure 2.8.3.13.3.1-5 –** A proximity limit switch

### 2.8.3.13.3.2 Selsyn Transmitters

Selsyn transmitters are rotary position sensors designed to convert mechanical input rotation to an electrical signal proportional to the input shaft position. The sensor may be equipped with a potentiometer and a two-wire transmitter that converts potentiometer movement to 4-20 mA signal.

Selsyn transmitters require no interior inspection. If the position indicators on the control console are functional then the selsyn transmitters, located in the machinery room, are functional. The selsyns should be inspected externally to detect signs of deterioration or misalignment. The inspector should check the selsyn for proper alignment with the span drive machinery. Check the condition of the flexible coupling that connects the selsyn drive shaft to the span drive machinery. The bolts that attach the selsyn to its support should be checked for tightness and corrosion. The selsyn housing should also be checked for corrosion. Check wiring for looseness and deterioration.

### 2.8.3.13.3.3 Resolvers and Optical Encoders

Resolvers and optical encoders, Figure 2.8.3.13.3.3-1, are rotary positional transducers, similar to selsyn transmitters, but are designed to interface with modern solid-state controls such as programmable controllers and digital panel meters. They provide greater positional accuracy than selsyn transmitters and for that reason are generally used in modern, automated bridge controls using programmable controllers requiring accurate position information for control algorithms.

Resolvers are rotary transformers having one rotor (rotating) winding and two stator (stationary) windings. The stator windings are located 90° apart. Output voltage indicates direction of rotation and the magnitude is a function of shaft displacement in degrees. Resolver output must be converted to a digital signal for proper interfacing with programmable controllers or other digital equipment.

Optical encoders consist of a rotating disc (rotor) with precisely located transparent sections. A stationary disc (stator) contains LEDs (light emitting diodes) arranged so their light shines through the transparent sections of the rotor. Photo transistors sense the LED light during rotor rotation and produce an output whose magnitude is a function of shaft displacement in degrees. Like the resolver, the output must be converted to a digital signal.

The inspection procedure for resolvers and encoders is similar to that of selsyn transmitters.


**Figure 2.8.3.13.3.3-1 –** Resolver type transducer

### 2.8.3.13.4 Control Console

The bridge is operated from a control console that contains the switches for the span operating motors; seating switches; bypass switches; instruments; position indicators or meters; indicating lights; and other control devices and apparatus necessary or pertinent to the proper operation and control of the span and its auxiliaries. Figure 2.8.3.13.3.4-1 shows a typical traditional control panel and Figure 2.8.3.13.3.4-2 shows a modern control panel. The bridge tender is responsible for operating the movable bridge. The push-buttons and switches on the control console are activated in the proper sequence to initiate and control span operation. The sequence is either performed manually by the operator or automatically by the control system. Sequence control and interlocking are accomplished through logic provided by relay panels and/or programmable controllers interfaced with or contained within the control console.

The inspector should note the location of the control console. The control console should be positioned in the operator's house so as to provide the operator a clear view in all directions. The console should be a cabinet-type console with a horizontal front section about 36 inches above the floor and an inclined rear instrument panel set at such a slope that all control devices are within easy reach of the operator. Specific dimension requirements have been intentionally omitted, following the example set in AASHTO's *LRFD Moveable Highway Bridge Design Manual*, to allow owners more leeway in choosing a control console design that best suits their particular needs.

Based upon current code requirements (Reference 7), there should be installed on the control console indicating lights of suitable colors that show to the operator the various positions of the bridge, especially the fully closed, fully open, nearly closed, and nearly open positions. Additionally, lights indicating the closed and open positions of the traffic gates, bridge locks and end lifting devices should also be present. The inspector should note in the report section if these are not provided. Indicating lights may also be provided to show when each span brake is released, and the status of other functions as required to alert the operator to emergency conditions. These items should be noted by the inspector.

The inspector should also note that if push button automatic sequence open/close controls are provided, then the control console should also be provided with additional controls for manual operation.

**Figure 2.8.3.13.3.4-1 –** Traditional control panel

**Figure 2.8.3.13.3.4-2 –** Modern control panel

The seating switches, if foot-operated, should be inspected to ensure they are operational.

All outgoing control connections from the console should be brought to suitably marked terminal strips supported on straps securely attached to the console frame. The terminal boards should be so located that they do not interfere with access to the inside of the console through the doors. All wires should be brought from the terminal boards to their respective terminals in a neat and orderly arrangement, properly bunched and tied. The inspector should note the presence or lack of the numbered wiring and the condition and/or neatness of the internal wiring.

The console interior should be suitably lighted and the lights controlled from a switch on the console. Each piece of equipment and each indicating light on the control console should be properly identified.

### 2.8.3.13.4.1 Metering Equipment

Operator panels are equipped with indicating meters to monitor the electric power circuits. Because current and voltage values are important to good operation, indicating instruments are provided for the operator's use. Only current (load) and voltage meters are required for the operator's use. The routine inspection procedure should include the following:

- Check for loose connections.
- Check for corrosion of metal parts.
- Check for cracks or broken cases in the cover glass.
- Check for collection of dirt or grease.

### 2.8.3.13.4.2 External Inspection of Control Console

The inspector should check overall console condition, looking for rust, corrosion, peeling paint, and the presence of objects on the console that interfere with bridge operation. Check all switches for proper operation and make sure bypass switches are properly locked or sealed to prevent inadvertent operation. The inspector should look for burned out pilot light lamps and missing or broken lamp lenses. Check all voltmeters, ammeters, and position indicators for proper operation as the span is operating. The inspector should record the voltmeter and ammeter readings during both opening and closing operations.

### 2.8.3.13.4.3 Internal Inspection of Control Console

The internal inspection of the control console consists of the following subsections.

### 2.8.3.13.4.3.1 Component Inspection

The inspector will note that no two bridge control systems are identical. For discrete or relay logic based control systems, check the following during routine inspections:

- **Internal temperatures of the enclosure:** The temperature should be between 32°F (0°C) and 104°F (40°C) for all control consoles.
- **Cleanliness of the enclosure:** The control consoles internally should be clean and dry.
- **Neatness of internal wiring:** The control wiring inside the console should be neatly arranged and run at 90 degree angles throughout the enclosure. Wiring should not run from field devices direct to relay or PLC inputs. Terminal blocks should be provided to terminate all field wiring.
- **Internal wiring** should be tagged and numbered
- **Plug in relays** should be checked. Relays should be firmly in their sockets or secured firmly to the backplane of the control console enclosure.
- **Modifications, add-ons, and extraneous equipment:** The only components inside the control console should be directly involved in the control circuitry. Compressors for the air horn or other extraneous systems should not be located within the console. Inspectors should spot check the control console wiring diagrams against the existing wiring during in-depth inspections and inventory inspections to detect modifications from design documents.

### 2.8.3.13.4.4 Bridge Control Interlocking

The following describes the basic interlocks that should be provided for in every bridge control system. By following the system tests outlined, the inspector should be able to assess the suitability of the control interlocking system. All tests should be performed with the bridge operating. The tests outlined are an attempt to determine lack of adequate bridge control interlocking. There is potential trouble for pedestrian, vehicular and marine traffic during any bridge opening/closing sequence. Steps should be taken to provide for the safety of the general public prior to initiating bridge testing.

*C2.8.3.13.4.4*

*For manually operated bridges, the inspector should confirm that a written sequence of operation exists within the bridge operator's house. The inspector should witness an opening/closing sequence and note adherence to and correctness of the written guidelines.*

### 2.8.3.13.4.4.1 Bridge Control Interlocking Tests

With the bridge in the closed position, the test sequencing during routine inspections is as follows:

- Prior to sounding warning lights and horn, attempt to lower the traffic gates. Traffic gates should not lower. Record results.
- With traffic gate up, insert gate arm hand crank (note if gate arm hand crank limit switch is present). Attempt to lower gate. Gate should not lower record results. Repeat test for all traffic gates.
- With traffic gates up attempt to lower resistance gate, if provided. Resistance gate should not be able to be lowered until its corresponding traffic gate is lowered.
- With resistance gate (if provided) or traffic gate raised, attempt to disengage the locks, centering devices, wedges, or jacks.
- With each resistance gate arm up, insert resistance arm hand crank (note if hand crank limit switch is present). Attempt to lower resistance gate. Resistance gate should not lower. Record results.
- With locks, centering devices, etc. engaged, attempt to raise the bridge span. Record results.

Confer with the operator and bridge inspection supervisor prior to performing the following tests. Once again, caution is emphasized.

- Confirm that if any hand crank device is inserted for the locks, centering devices, etc. that the corresponding motors are disabled.
- Confirm that the main drive motors cannot be started prior to all brakes being released. The inspector should manually set a brake and attempt to open the span. The main drive

*C2.8.3.13.4.4.1*

*Caution should be used during these tests. Vehicular and pedestrian traffic must be stopped during testing.*

*Test sequences are generic. The inspector is responsible for adjusting this sequence to fit the bridge being inspected.*

*During the bridge opening sequence, the inspector should note if span speed is controlled automatically or manually by the operator.*

motor starters should not engage -record the results.

- Test limit switches at full open.

### 2.8.3.13.5 Programmable Logic Controllers (PLCs)

A programmable logic controller (PLC), shown in Figure 2.8.3.13.5-1, is a general purpose industrial microprocessor based control system. The National Electrical Manufacturers Association (NEMA) defines a PLC as “a digital electronic device that uses a programmable memory to store instructions for implementing specific functions such as logic, sequencing, timing, counting and arithmetic to control machines and processes.” A PLC is designed to interface with industrial equipment and carry out a preprogrammed control scheme. The PLC checks the status of input devices such as push buttons, selector switches, limit switches, and pressure switches, and responds to these signals by activating the appropriate output devices such as motor starters, solenoids, indicators, as called for by the program.

*C2.8.3.13.5*

*It is recommended the inspector checks the PLC log or printout for faults or errors during previous bridge operation to alert them of possible problem areas.*

**Figure 2.8.3.13.5-1 –** A programmable logic controller (PLC)

PLCs are being used in ever increasing numbers by general industry to replace “hard-wired” (fixed operation) relay logic systems. The advantages offered by PLCs over hard-wired relay systems include greater reliability, less downtime due to built-in diagnostics, modular construction, and economical expansion. Many new bridges are equipped with PLCs and some older bridges are being retrofitted with them. The inspector should familiarize himself with this type of control component.

As a general guide, the inspector should check the following items during a routine inspection of the PLC. The inspector should refer to the manufacturer's manuals for specific maintenance information.

- Check the status of diagnostic indicator lights located on the CPU and I/O modules. Diagnostic lights will indicate equipment malfunction if present.
- PLCs are often installed in enclosures. The enclosures are equipped with air filters to provide clean air circulation over the PLC components. Make sure all air filters are clean.
- Check the accumulation of dirt and dust on PLC components. Components need to be clean for proper heat dissipation.
- Check wiring connections to all components for tightness. Check condition of wiring.
- Batteries, which provide backup power for program memory, should be inspected. Batteries usually have visual or audible alarms that become activated when battery power becomes low.
- Unnecessary articles should be kept away from the PLC equipment inside the enclosure. Drawings and manuals placed on or adjacent to equipment can obstruct air flow and create hot spots that can cause system malfunction. Paper materials can also burn if they become too hot.

Older movable bridge controls were designed prior to the advent of PLCs. The older bridges that were designed for semiautomatic operation often use relay logic systems and drum controllers to provide interlocking and control sequencing. In addition, some designs continue to prefer relay logic to PLCs.

### 2.8.3.13.6 Drum and Relay Logic Controllers

#### 2.8.3.13.6.1 Drum Controllers

Drum controllers are used for starting and reversing small AC and DC motors that can be started across the line without using accelerating resistors. They can be supplied as two pole or three pole switches also with or without limit switch connections. The drums are furnished with rotary operating handles. The drum contacts are usually hard drawn copper and are renewable. The contact fingers are mounted on finger boards. They are formed hard drawn copper with flexible shunts and are easily replaced. Contact pressure is maintained by means of special coiled compression springs.

Figure 2.8.3.13.6.1-1 shows a circuit diagram for a simple relay logic control system with sequential control of motor secondary resistance and interlocking with the span locks and other components. Relay logic is often designed using drum switches, as shown in Figures 2.8.3.13.6.1-2 through

*C2.8.3.13.6.1*

*If partial disassembly is required, the bridge owner may, at their option, move this part of the inspection to in-depth inspections.*

2.8.3.13.6.1-4. Manual rotation of the drum switch control by the bridge operator engages the various control circuits in order, but incorrect operation is disabled because limit switches must be in the required position in order for circuits to be completed. Older systems may have manual operation of circuits at the drum switch. Newer designs use the drum switch to actuate magnetic contactor relays that complete the various circuits. Drum switches should be checked as follows:

- Inspect the condition of the contactors and cams or contact segments. Also inspect the wiring and wiring contacts.
- Wiring should be clean, insulation should be in "good" condition, and wires should be labeled and routed clear of any moving parts.
- Contacts should be clean and tight. Inspector should de-energize the system and check a representative sample of contacts for tightness.
- Operate the span as described for other types of control systems and verify that the operation is as designed.

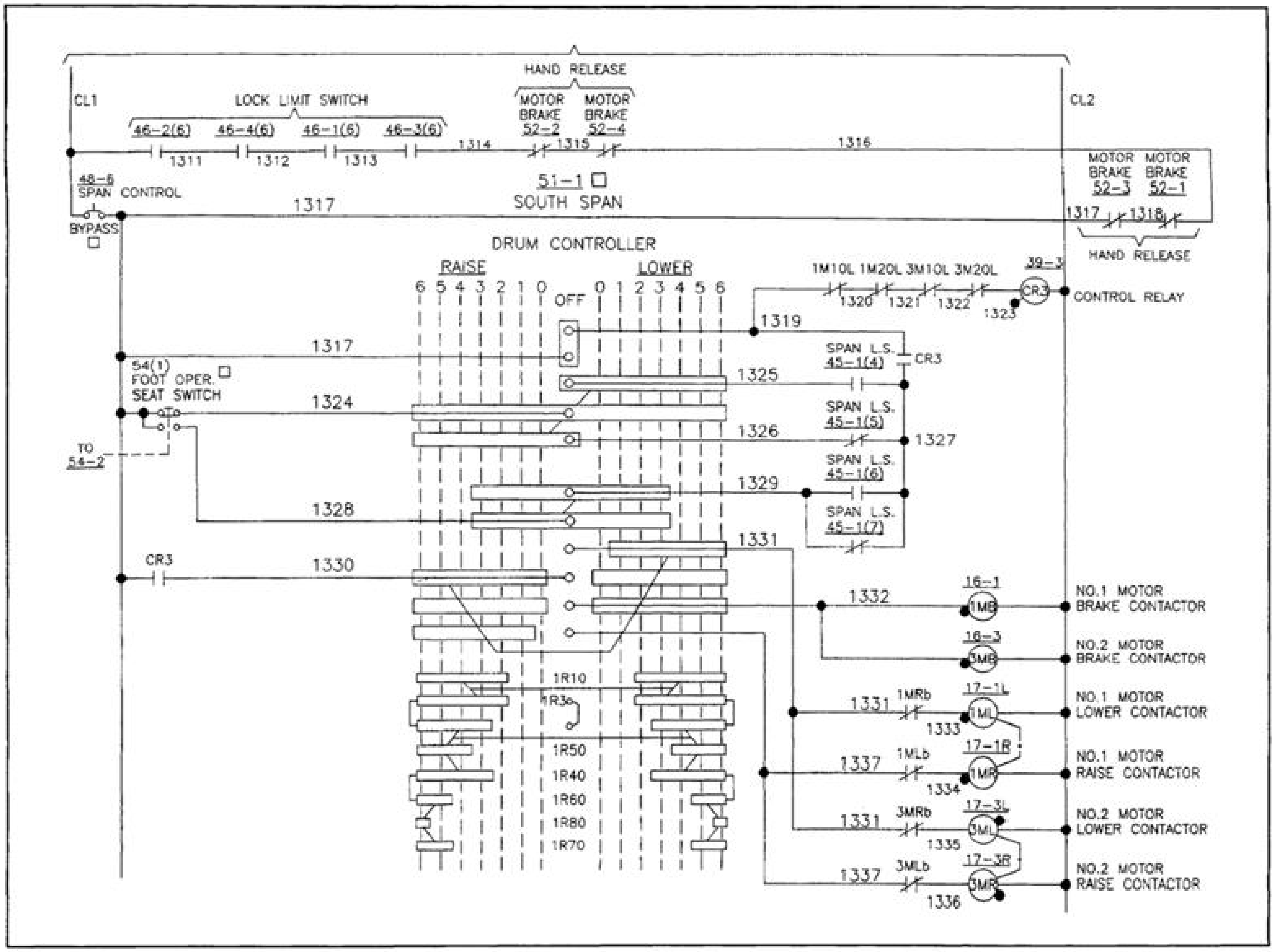


**Figure 2.8.3.13.6.1-1** – Circuit diagram for a relay logic control system.

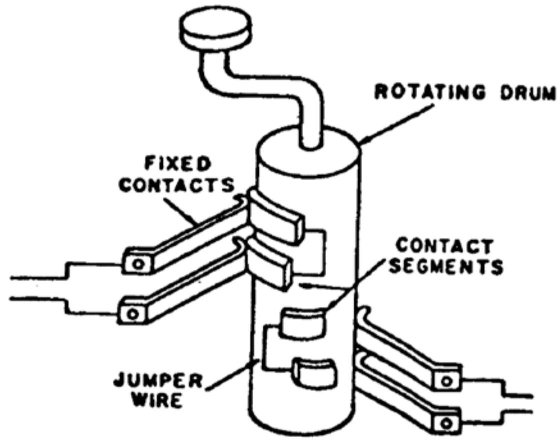


**Figure 2.8.3.13.6.1-2 –** Segment type drum switch

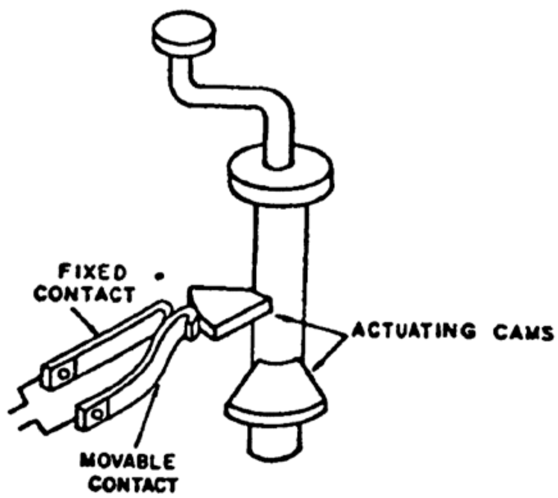


**Figure 2.8.3.13.6.1-3 –** Cam type drum switch

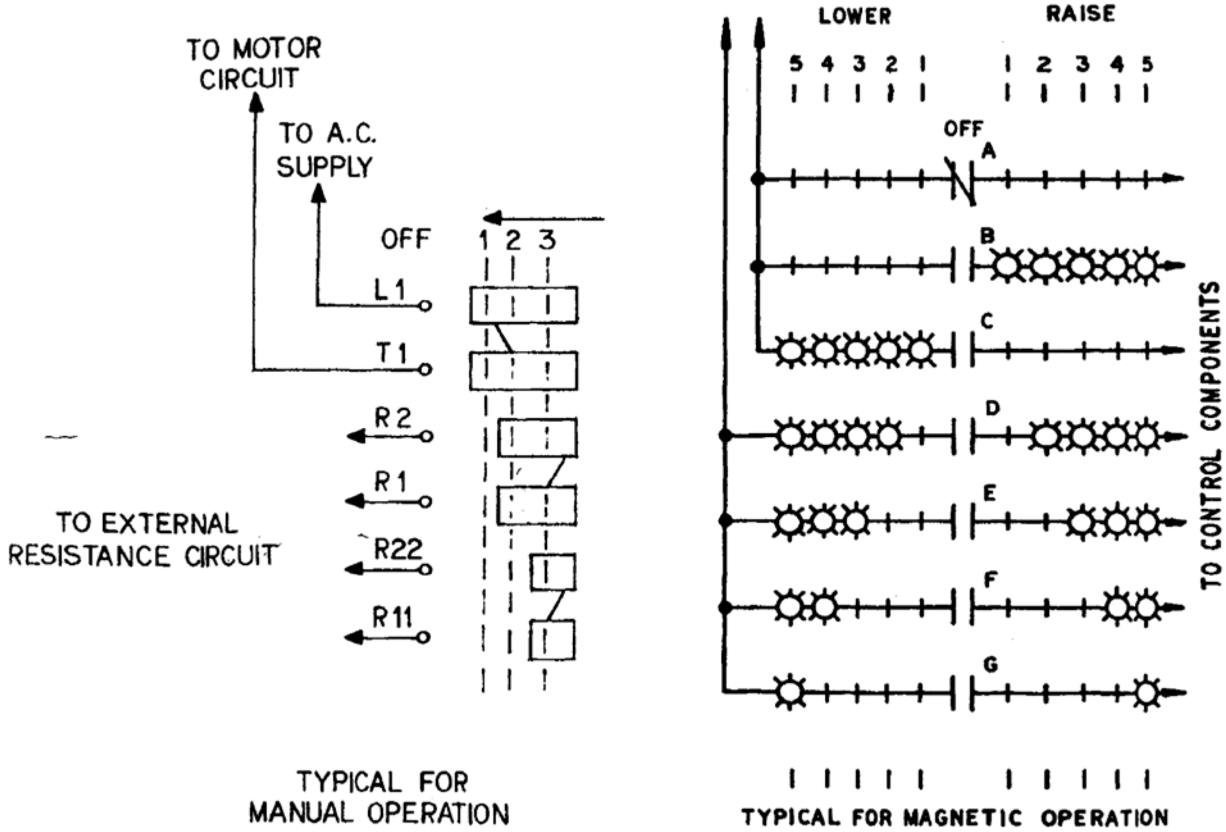


**Figure 2.8.3.13.6.1-4 –** Manual and magnetic drum switch control scheme

### 2.8.3.13.6.2 Relay Logic Controllers

Relays are devices that are generally operated by a variation in the conditions in one electric circuit that serve to make or break one or more connections in another electric circuit. A series of relays can thus be used to perform several related tasks sequentially in a logical order. For example, on a movable bridge, when the first function of lowering the traffic gates is completed, a limit switch will trip a relay that would energize the next circuit to perform the next sequential function and so on. A system that uses relays to perform a portion of the semiautomatic or automatic sequential tasks in controlling the operation of any machinery is called a relay logic system.

There are a number of types of relays used in relay logic systems. In general, the relay contactors should be checked for burning or contamination. Timers, coils, and other mechanisms should be verified to be functioning properly as per the original design parameters. Specific inspection procedures should be developed based upon manufacturer's literature for the particular type of relay. Inspectors should consider the following while performing routine inspections:

- The typical motor usually draws five to ten times the normal current at start-up. High starting current is normal and the motors are built to handle these loads for a brief period of time. As the motor accelerates, this current decreases to the normal running values. Mechanical binding of the drive will cause the starting current to remain high. For example, when the motor stalls against the mechanical stop, the operating current immediately goes up. This indicates that the limit switch is not set correctly or is not operating and the motor overloads will have to protect the motor against burnout. . It is a different case for some bridge drive motors when stalled drive motor seating is the recommended method of seating bascule and vertical-lift bridges, or swing bridges that close against a stop bumper. In these cases, the stalled drive motor is required to be in a reduced torque mode for 2 to 3 seconds while setting the brakes. Extended stalled motor conditions can indicate a failed limit switch, failed time delay relay or other electrical or electronic interlock failure.
- If the overload relay contacts are visible, the inspector should observe the relays to determine if they operate during motor operation. Overload relays usually operate when there is some problem. Repeated reset operations can result in a motor failure.

Performance inspection of relay logic:

- Observe the motor; starting the motor will produce a sequence of distinct sounds. When coming up to speed, the motor may vibrate noticeably. If there is mechanical binding in the equipment, or if the equipment runs into a mechanical stop, the motor will show an immediate current increase and will “hum” or vibrate.
- Occasionally, trouble situations are bypassed by use of an electric jumper. This means of temporary repair to allow operation should not be continued for very long. The application of the jumper can eliminate the overload protection or even the interlocking incorporated in the circuit. Check for wire jumpers in the control circuits. If found, inspectors should file a deficiency report and rate the controls as “poor.” As a motor ages, it starts to deteriorate. Torque output may decrease and the running load will increase.

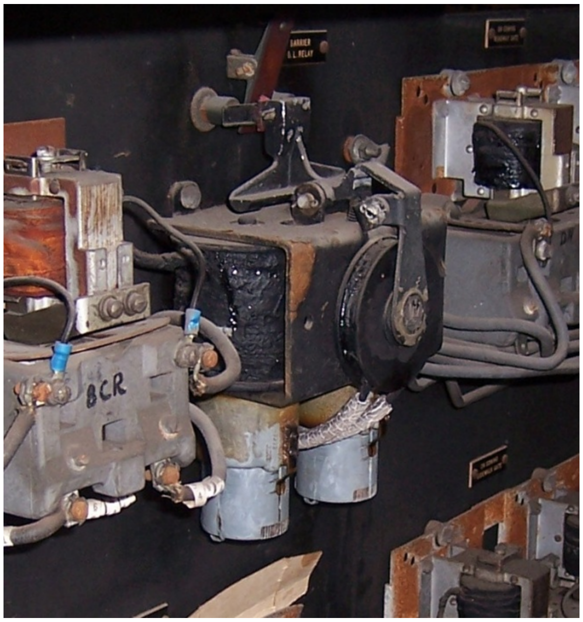

**Figure 2.8.3.13.6.2-1 –** Dash pot overload relay

This can result in intermittent overload operation. Visual inspection will not usually show the motor deterioration but the motor controller may show trouble starting by occasional nuisance tripping. If a jumper is applied around the overload contact, the nuisance tripping will be eliminated. The motor overload protection will also be eliminated. The probable result will be a failure in the motor or the cabling to the motor.

- Overload relays on early design contactors were built with "dash pots." Figure 2.8.3.13.6.2-1 shows this type of overload relay used on the wound-rotor span motors. Note that the cups on the bottom are calibrated for load settings. These calibrations are normally specified and set during the initial start-up of the equipment. In the illustration, only two dash pots are shown. The older controls used two overloads for protection of a three phase motor.

During an in-depth inspection, check the following:

- Remove the cups carefully from the dash pots and check for the proper dash pot oil level in the cups. There is usually a line indicator to show the proper oil level inside the cup.
- Check the oil in the cup for sediment. The oil should be renewed at least every two or three years and the cups thoroughly cleaned each time. Only approved dash pot oil

should be used. Operate the plunger with the cup in place. There should be no metal to metal interference and the plunger should move freely to the trip position.

- Visually check the arc chutes on the contactors. Excessive erosion of the inside surfaces is the result of heavy current interruption. Arc chutes that are readily accessible should be removed for inspection. Check for missing baffles and for uniform separation of plates. The areas in the path of the arc will deteriorate during interruption. When very little material is left at the supports, or if parts are missing, cracked or badly burned, the arc chute needs to be replaced. The arc chutes should be coded "poor."

### 2.8.3.13.7 Motor Speed Controller

There are a number of types of motor control systems commonly used on movable bridges to control span driving motors. The following discusses the most common types.

### 2.8.3.13.7.1 AC Wound-rotor Manual Control

Manual speed control utilizing the AC wound-rotor motor is the oldest method for controlling span speed. A master switch or drum controller mounted on the control console is controlled by position switches. The changing switch position varies the secondary resistance seen by the wound-rotor motor.

Although often regarded as a speed control system, the AC wound-rotor manual control does not truly control speed. The secondary resistance varies the torque producing capability of the motor and in so doing, depending on the magnitude of span loads, causes the motor to speed up or slow down in response to span loads. The system will provide moderately reduced speed operating with loads of 50 percent of full load motor torque or greater. It will also provide maximum starting torque with minimum starting current. However, it will not provide for reduced speed operation with light loads, unless some means of mechanical braking is provided. In addition, it will not provide the desired low speed, usually 10 percent to 20 percent of full load speed, when the movable span is approaching the fully open or fully closed positions.

AC wound-rotor motor manual controllers require more maintenance than the other (solid-state) controllers and for this reason need to be carefully inspected.

The inspector should observe the drum (or master switch) controller during motor operation. Stationary contacts are mounted on the side of the drum frame. A movable cam rotates

*C2.8.3.13.7.1*

*Nearly all older bridge control systems utilize this type of bridge control system or a slight variation thereof.*

with the drum and activates the movable contacts. No sustained contact arcing should occur during any part of the control operation.

Make certain the controller sequence is correct and that all components function properly. If a schematic of the controller is available, this can be used to properly inspect this sequence. If the schematic of the controller is not available, the inspector should observe the drive motor amps as the bridge is stepped through the sequence, and watch for fairly consistent jumps in amperes with every new step, this will help the inspector determine if the operation of the stepped resistance system is correct.

Visually check the controller components for wire and cable conditions. Cable connections must be tight. Look for broken conductors and signs of terminal cracking. Partially broken connectors can accelerate an insulation failure due to overheating.

Resistor grid banks should be inspected. A white area could be a sign of "severe" overheating or an atmospheric corrosion of the metals. Overheating can be caused by broken resistor grids of "poor" contact between adjacent resistor grid plates.

### 2.8.3.13.7.2 Variable Speed Controllers

Motor controls that provide true speed and acceleration control are becoming more common on movable bridges, both on new structures and as retrofits to old ones. The AC wound-rotor motor thyristor control, AC adjustable frequency (inverter) control, and the digital DC drive are such systems. These variable speed drives, as they are called by general industry, are solid-state and can be easily interfaced with programmable controllers or relay operated systems. In addition, they can provide electronic dynamic braking capabilities to reduce the dependence on mechanical motor brakes and can provide regenerative braking for true four-quadrant control when operating against overhauling loads.

During routine inspections the controllers should be inspected by the same methods listed for control consoles and PLCs.

### 2.8.3.13.7.3 AC Adjustable Voltage Controller

The AC wound-rotor motor thyristor controller was the first solid-state variable speed drive to be used on movable bridges. Thyristors are also known as silicon controlled rectifiers (SCRs). In this type of controller the thyristors are controlled by either a master switch located on the control console or discrete bridge position input. The thyristors vary the amount of voltage to the

AC wound-rotor motor primary from zero to full line voltage that controls the shape of the RPM/torque curve of the particular motor, and thereby controls the torque the motor applies at a given motor speed. The ability to change the shape of the RPM/torque curve provides the capability to alter speed at a given motor load.

The adjustable voltage controller uses SCRs connected opposite of each other to control the average voltage applied to the motor. This is called “phase angle control.” The average voltage supplied to the motor is adjusted by controlling the phase angle signal gating of the SCRs. The motor speed is controlled by varying the motor primary voltage. The direction of the motor rotation is controlled by selecting the appropriate SCRs. During a “span open,” the motor will be “driving” the load. In this case, the motor is doing the work. Typically, the bridge spans are balanced, requiring the motor to be overcome only frictional, inertial, and wind loads. Under this scenario, the voltage controller will gradually increase the applied voltage until the preset speed is maintained and the bridge opening completed.

During a “span close,” the voltage controller will accelerate and control an overhauling load by operating the motor in a counter torque mode. The controller is actually producing a controlled raising torque to control the descending span.

During a “span seating,” the motor must supply a controlled limited stall torque. Voltage controllers allow one to simply reduce the current limit operation at minimum speed thereby reducing the stall torque requirements by controlling stall currents.

### 2.8.3.13.7.4 AC Adjustable Frequency Controllers

The VFD, shown in Figure 2.8.3.13.7.4-1, varies the speed of the induction motor by varying the frequency applied to the motor. To produce rated torque, the relationship between voltage and frequency must be maintained at a constant ratio. Therefore, the VFD's output voltage varies directly with output frequency. During a “span open” operation, the adjustable voltage controller and VFD work similarly. The VFD gradually increases the applied voltage and frequency to the motor in response to a ramped speed signal. The VFD current limit operation will also occur when additional acceleration, wind or other unknown loading is present.

During a “span lower,” the VFD accelerates and controls an overhauling load in motor regeneration, but cannot pass this energy back to the power system. Braking resistors are required to dissipate the energy.

During a "span seating" the motor must supply a controlled

*C2.8.3.13.7.4*

*AC adjustable frequency controllers are used to control the speed of AC squirrel cage motors. The squirrel cage motor has long been the workhorse of general industry but until fairly recently there has been no economical and reliable way to provide true speed control using these motors.*

limited stall torque. For a VFD, lower torque limit should be utilized at seating for stalled seating. Wound-rotor motors could be used with switched secondary impedance to control stall torque. However, the adjustable voltage controller is more suited for operation with wound-rotor motors.


**Figure 2.8.3.13.7.4-1 –** A motor control center with integral VFD controller

### 2.8.3.13.7.4.1 AC Flux Vector Controller

The flux vector controller (FVC) utilizes the same basic power devices as the VFD. However, instead of controlling the voltage and frequency magnitude, which yields very "poor" performance at low speeds or under dynamic conditions, the FVC regulates the flux and torque producing components of current. The FVC operates with rotor position feedback from an encoder that is connected to the motor shaft. This position information is then used to control the flux and load current. These components are added to develop the controlled stator current that produces the optimum speed torque control of the load.

The "span open" and "span close" operation are similar to the VFD. However, during "span seating" precise torque control is

*C2.8.3.13.7.4.1*

*The AC flux vector adjustable frequency controller has grown in popularity and is used predominately over VFD wound-rotor drives and DC drives in movable bridge applications.*

easily achieved. The FVC provides continuous full rated torque from base speed down to and including zero speed.

### 2.8.3.13.7.6 DC Static Drive Controllers

DC drives are currently being used by many highway departments. The inspector should be aware of this type of drive. The static (solid-state) DC drive rendered the DC motor-generator set and the mercury-arc rectifier obsolete. For many years either a DC motor-generator set or a mercury-arc rectifier was needed to supply DC power in applications where the advantages of the DC motor were needed. Both these methods of furnishing DC power were inefficient and maintenance prone. The DC drive was a breakthrough and quickly became popular in general industry. The DC drive combines the rectifier power supply and all required speed controls in a single package (See Figure 2.8.3.13.7.6-1).


**Figure 2.8.3.13.7.6-1 –** DC drive controller

### 2.8.3.13.8 Surge Protection

Until the use of solid-state devices, most AC-powered equipment found on movable bridges was too insensitive to be upset by “dirty” or surging power. However, electrical power surges, and the damage they can cause, are commonplace today. Many movable bridge control consoles are comprised of solid-state devices and are vulnerable to surges.

These solid-state devices depend on consistent, “good”-quality power. A single powerful surge can literally melt, weld, pit, or burn its way through solid-state circuits and components.

Solid-state device failure is often the result of surges and the cause is typically not detected by the repairing technician. In addition to crippling the bridge control system, any stored data is lost and input or output information is meaningless. It is imperative that a bridge designed to be served from a grounded electrical system be maintained so that it remains adequately grounded. If the grounding system is allowed to deteriorate, the surge suppression system will not function properly and an electric shock hazard may exist.

*C2.8.3.13.8*

*It is a misconception to think of surge damage as being caused by a single, catastrophic event such as a lightning strike. While lightning is one of the most powerful and destructive surges, it is not always the cause of most of the surge damage.*

*Powerful, random surges result from the switching of an inductive load such as a main drive motor starter, arc welder, furnace ignition, compressor, etc. These momentary surge sources range from 250 to over 3,000 volts.*

*If a particular bridge has reported electronic device failures since the previous inspection and if the bridge is not provided with an electrical surge suppression system, then the inspector should note this condition as a deficiency.*

*Older electrical designs utilize ungrounded systems due their ability to maintain service to the faulted electrical system. These systems were prevalent in locations where down time costs outweighed other significant factors. However, any fault should be located immediately upon occurrence and the necessary action taken to safely reenergize the electrical system. It is recommended that ungrounded systems be noted on the inspection deficiency reports and the system subsequently replaced with a grounded system during any upcoming bridge rehabilitation.*

### 2.8.3.13.8.1 Inspection

The inspector should thoroughly survey the bridge and its power supply, an examination of electrical layout, circuit plans and inventory of electric loads (present and future) connected to all circuits can provide the information to form a recommended plan of protection. The following items should be thoroughly checked during routine inspections of grounded electrical systems:

- Verify that all electrical and system grounds are bonded together. Confirm the neutral is bonded properly to ground at the service. Verify that there is no bonding of the AC neutral and ground at electrical sub panels.

- Verify that the bridge span and other metallic structures are bonded to ground. Make sure all steel reinforcement and framing of the structure is bonded to your common ground.
- Verify whether or not the main electrical service panel is equipped with a surge protector on the load side of the main breaker. All sub panels should be so inspected. Verify if surge suppression is present on incoming electric service panel and record the finding.
- Inspect the control console. Verify if surge suppressors are installed on the input power line and record the finding.

  The following items should be thoroughly checked during in depth inspections of grounded electrical systems:
- If possible, verify the resistivity of the ground system. The resistance of the ground system should be 10 Ohms or less. If this measurement cannot be performed, it should be so indicated on the report form.

  Figure 2.8.3.13.8.1-1 illustrates an incoming surge suppressor and Figure 2.8.3.13.8.1-2 shows a typical control console surge suppressor.

For ungrounded systems, the inspector should verify that ground fault indicating lights are provided and functional. Also, the inspector should verify whether or not surge protection is provided for the ungrounded electrical systems at the main and sub panel locations.

**Figure 2.8.3.13.8.1-1 –** Incoming power surge suppressor


Figure 2.8.3.13.8.1-2 – PLC power surge suppressor

### 2.8.3.13.9 Controls and Interlocking Coding Guidelines

Due to the proprietary nature and sealed "black box" appearance of control and interlocking components, it is extremely difficult to quantify criteria for numeric condition evaluation coding without extensive testing by a qualified electrical engineer. There are, however, some general guidelines as follows:

*C2.8.3.13.9*

*Inspectors should be knowledgeable as to whether the control system is designed to be grounded or ungrounded. Ungrounded systems that are properly designed and are*

**General Recommendations**
**Excellent:** the system and components are well connected and grounded, protected, secured, safely operating, and functioning as intended (recently installed, no defects).
**Good:** minor deterioration or wear.
**Fair:** functional, but with obvious deterioration or wear.
**Poor or Critical:** Components are observed to be smoking, hot, or otherwise exhibiting signs of resistance coding depends on the inspector's assessment of the likelihood of an electrical failure or fire.
**Critical:** Sparking, melted or burned insulation, or black residue left by arcing or shorting of components. Components that create a potential shock hazard to the public or workers.

Components with no external signs of distress should be coded based upon testing, engineering judgment and/or the component life table in Chapter 2.9. If an individual inspector cannot determine whether a component is “poor” or “critical,” he should code it “poor” and request additional investigation with an explanation of the reason and type of investigation needed.

**Control, Interlocking and Sensor Devices (e.g., limit switches)** should be performance tested during in-depth inspections. Controls, interlock of sensor devices that fail to actuate span motion and proper sequential control of the various functional control systems should be investigated fully and coded ”poor” or “critical” based upon the results of the investigation. Limit switches that are functionally inactive should be coded critical and should cause immediate filing of a deficiency report. Limit switches that are not functioning smoothly, or that show evidence of significant corrosion or wear of operating parts or other defects that could interfere with reliability should be coded “poor” and should also cause filing of a deficiency report.

**Control Consoles** with inoperative indicators and/or gages should be coded “poor” with a deficiency report. Interlocking systems, which permit unsafe modes of operation, which might endanger (based on performance tests) the functional systems of the bridge, workers and the public should be coded critical, and a deficiency report should be filed immediately. If reliable written operating procedures are in place to prevent such unsafe modes, then such conditions may be rated “poor.”

The overall rating of the bridge controls and interlocking should be based on the results of performance tests. A system that performs adequately but that contains individual vital components that are ”poor” or “critical” should generally not receive a rating exceeding that of the worst vital component, since the reliable operation of the entire system is compromised by the questionable component.

*safely functioning may exist without the presence of grounding.*

*Systems which do not have surge protection or which do not meet the criteria given in Section 2.8.3.13.8 should be not be rated “poor” if it was designed under a standard that did not require surge suppression, but it should be noted in the report.*

**Controllers** should be rated based on performance tests, but the presence of wires or contacts that are loose and/or deteriorated should also cause a lower condition rating of the controller.

**Wires or Contacts** that show signs of overheating should be rated "poor" or "critical," as discussed in Chapter 2.8.

**Surge Protection** that is inactive or systems which do not have surge protection or which do not meet the criteria given in Section 2.8.3.13.8 should be rated "poor" or "critical" based upon the likelihood of a lightning strike or power surge at the particular site.