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Complex Bridges

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Complex Bridges

Topic 16.1 Cable-Supported Bridges

16.1.1 Introduction

There are several bridge types which feature elements which require special inspection procedures. The most notable bridge types are:

- Suspension bridges (see Figure 16.1.1)
- Cable-stayed bridges (see Figure 16.1.2)

Figure 16.1.1 Golden Gate Bridge

This topic is limited to the cable and its elements. All other members of a cable-supported bridge have been described in earlier topics and are to be referred to for the appropriate information. For each of the above bridge types, this topic provides:

- A general description
- Identification of special elements
- An inspection procedure for special elements
- Methods of recordkeeping and documentation

Figure 16.1.2 Maysville Cable-Stay Bridge

16.1.2 Design Characteristics

A cable-supported bridge is a bridge that is supported by or "suspended from" cables.

Suspension Bridges

A suspension bridge has a deck, which is supported by vertical suspender cables that are in turn supported by main suspension cables. The suspension cables can be supported by saddles atop towers and are anchored at their ends or self-anchored to the bridge superstructure. Suspension bridges are normally constructed when intermediate piers are not feasible because of long span requirements (see Figure 16.1.3). Modern suspension bridge spans are generally longer than 1400 feet.

Cable-Stayed Bridges

A cable-stayed bridge is another long span cable-supported bridge where the superstructure is supported by cables, or stays, passing over or anchored to towers located at the main piers. Cable-stayed bridges are the more modern version of cable-supported bridges. Spans generally range from 700 to 1400 feet (see Figure 16.1.4). Evolving for approximately 400 years, the first vehicular cable-stayed bridge in the United States was constructed in Alaska in 1972 (John O'Connell Memorial Bridge at Sitka, Alaska).

In suspension bridges, vertical suspender cables attach the deck and floor system to the main suspension cables. Cable-stayed bridges are much stiffer than suspension bridges. In cable-stayed bridges, the deck and floor system is supported directly from the tower with fairly taut stay cables.

Figure 16.1.3 Roebling Bridge

Figure 16.1.4 Sunshine Skyway Cable-Stayed Bridge in Tampa Bay, Florida

Types of Cables

A cable may be composed of one or more structural wire ropes, structural wire strands, locked coil strands, parallel wire strands, or parallel wires.

Parallel Wire Cable

Parallel wire cable consists of a number of parallel wires (see Figure 16.1.5 and Figure 16.1.10). The diameter varies depending on the span length and design loads. Parallel wire cables used in cable-stayed bridges conforms to ASTM A421, Type BA, low relaxation. It is basically stress-relieved wire used for prestressed concrete.

Structural Wire Strand

Structural wire strand is an assembly of wires formed helically around a center wire in one or more symmetrical layers. Sizes normally range from 2 to 4 inches in total diameter (see Figure 16.1.6).

Structural Wire Rope

Structural wire rope is an assembly of strands formed helically around a center strand (see Figure 16.1.7).

Parallel Strand Cable

Parallel strand cable is a parallel group of strands (see Figure 16.1.8). Seven-wire strand commonly used for cable-stayed bridges conforms to ASTM A416, low relaxation steel (see Figure 16.1.11). It is basically seven-wire stress-relieved strand for prestressed concrete.

Locked Coil Strand

Locked coil strand is a helical type strand composed of a number of round wires, and then several layers of wedge or keystone shaped wires and finally several layers of Z- or S-shaped wires (see Figure 16.1.9). Locked coil strand has not been used for cable-stayed bridges in this country, but it is commonly used for cable-stayed bridges in Europe.

Several types of cables have been used for cable-stayed bridges. The three most common are locked-coil strand, parallel wire, and parallel seven-wire strand. The majority of existing cable-stayed bridges in the world, other than the United States, use preformed prestretched galvanized locked-coil strand. The cable-stayed bridges in the United States incorporate parallel wire or seven-wire prestressing strand in the cables.

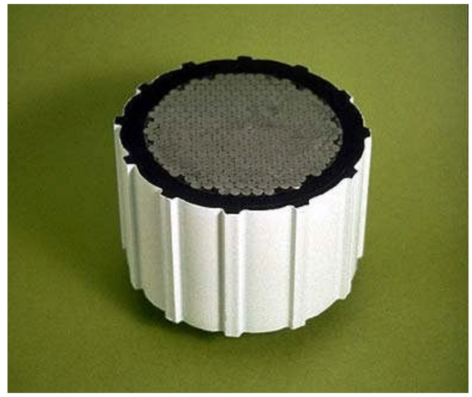

Figure 16.1.5 Parallel Wire

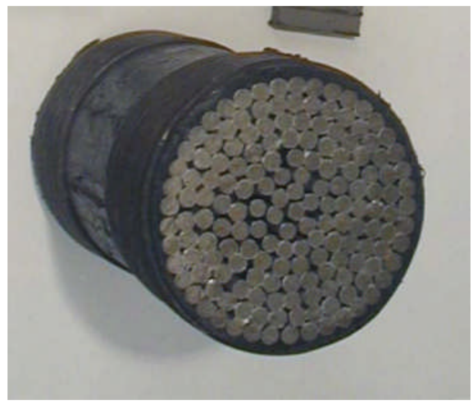

Figure 16.1.6 Structural Wire Strand

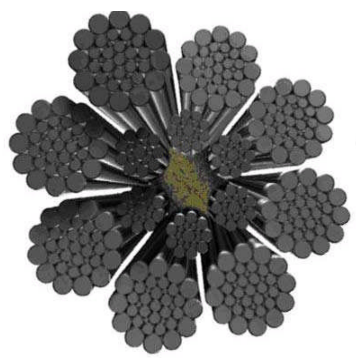

Figure 16.1.7 Structural Wire Rope

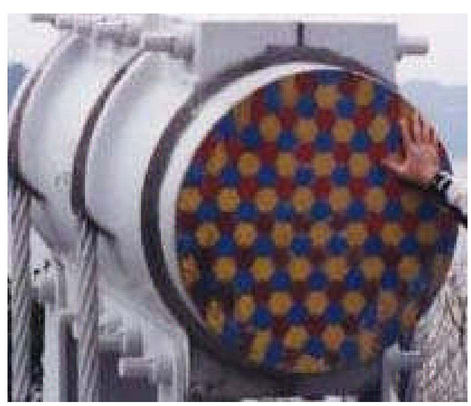

Figure 16.1.8 Parallel Strand Cable

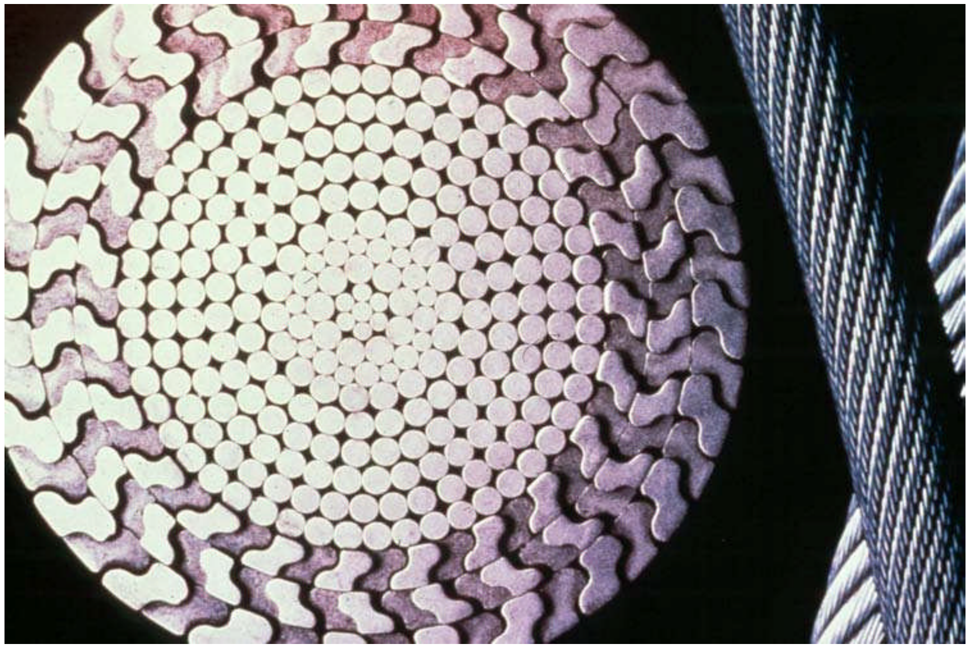

Figure 16.1.9 Locked Coil Strand Cross-Section

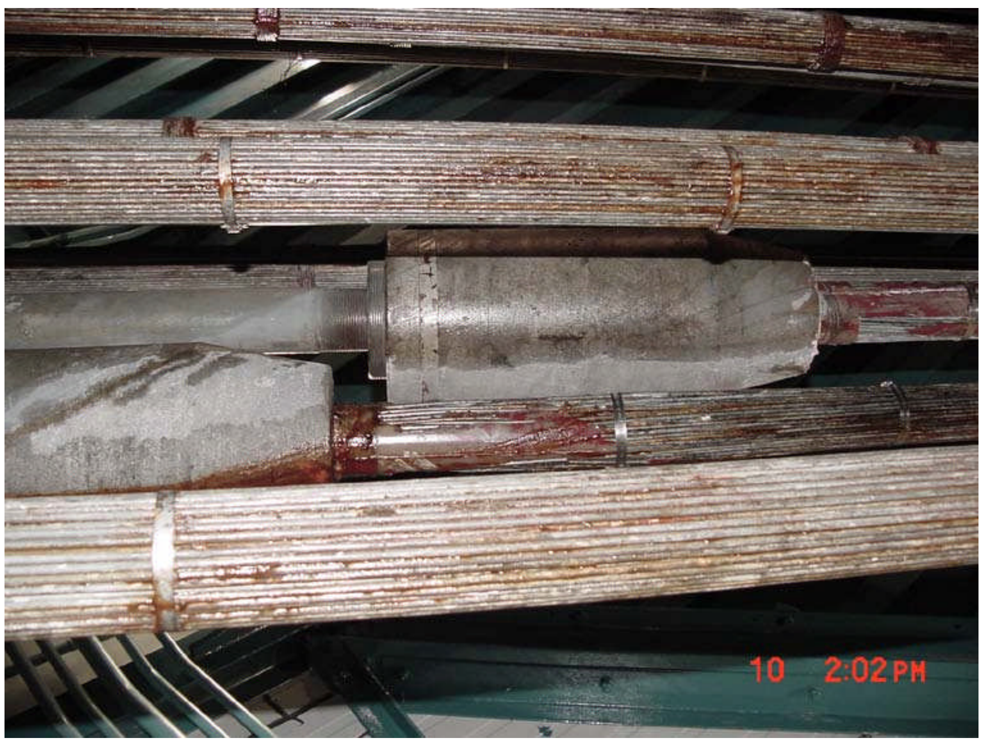

Figure 16.1.10 Parallel Wire

Figure 16.1.11 Parallel Strand

Corrosion Protection of Cables

Methods used for corrosion protection include:

- Galvanizing the individual wires
- Painting the finished cable
- Wrapping the finished cable with spirally wound soft galvanized wire, neoprene, or plastic wrap type tape
- Polyethylene sheathing filled with cement grout or grease
- Polyethylene sheathing filled with no grouting
- Any combination of the above systems (see Figure 16.1.12).

Figure 16.1.12 Cable Wrapping on the Wheeling Suspension Bridge

Types of Towers

- Portal tower – typical of suspension bridges (see Figure 16.1.13 (a))
- Towers fixed to pier (see Figure 16.1.13 (b))
- Towers fixed to superstructure (see Figure 16.1.13 (c))
- Single column tower (see Figure 16.1.13 (d))
- A-frame tower (see Figure 16.1.13 (e))
- Laterally offset tower fixed to pier (see Figure 16.1.13 (f))
- Diamond shaped tower (see Figure 16.1.13 (g))

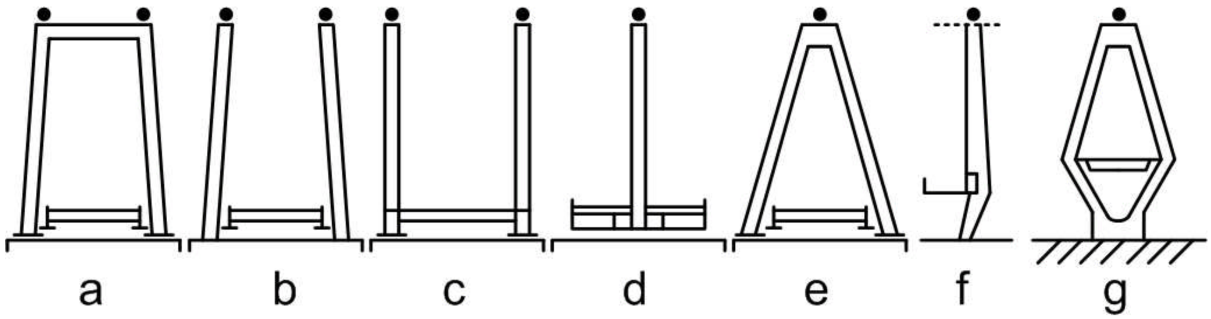

Figure 16.1.13 Shapes of Towers Used for Cable-Stay Bridges

Towers are constructed of reinforced concrete or steel or a combination of the two materials (see Figures 16.1.14 and 16.1.15).

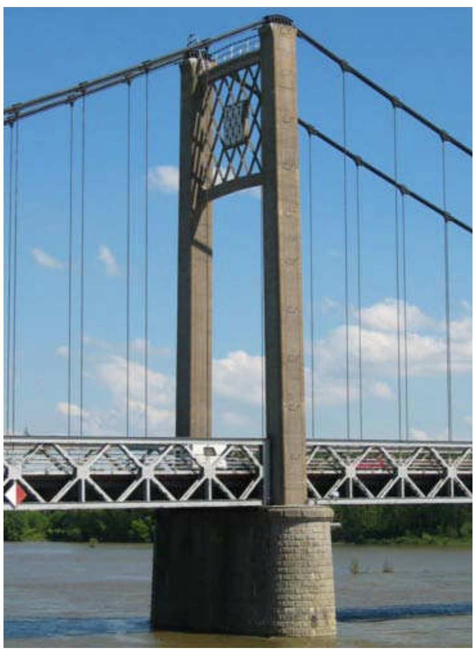

Figure 16.1.14 Tower Types: Concrete "Portal Tower" and "A-Frame Tower"

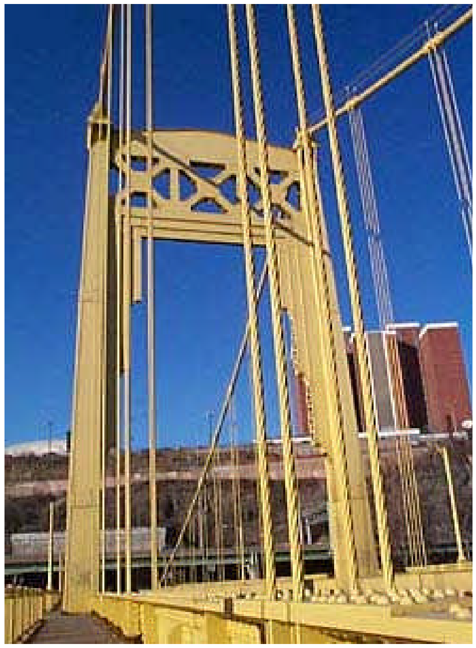
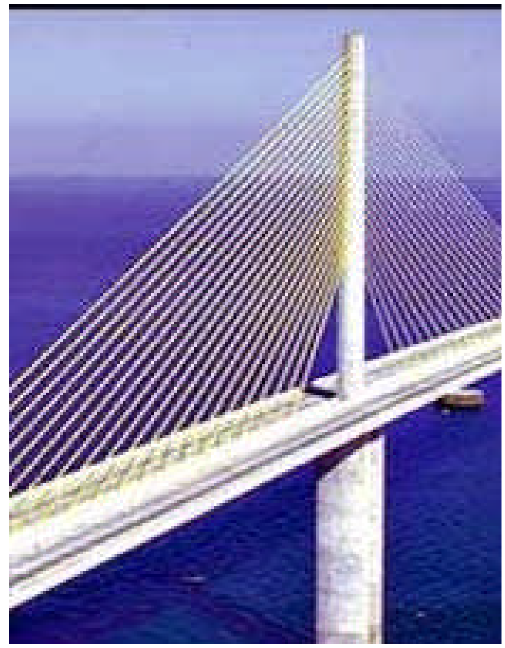

Figure 16.1.15 Tower Types: Steel "Portal Tower" and Concrete "Single Column Tower"

The deck structures are also constructed of concrete or steel.

16.1.3 Suspension Bridges

In this subtopic, only those bridge elements that are unique to suspension bridges are presented. Refer to the appropriate topic for other bridge elements that are common to similar bridge types (i.e. floor systems, open web girders, box sections, etc.).

Main Suspension Cables and Suspender Cables

Main suspension cables are generally supported on saddles at the towers and are anchored at each end. Sometimes, main suspension cables are referred to as catenary cables. Suspender cables are vertical cables that connect the deck and floor system to the main suspension cables (see Figure 16.1.16). .

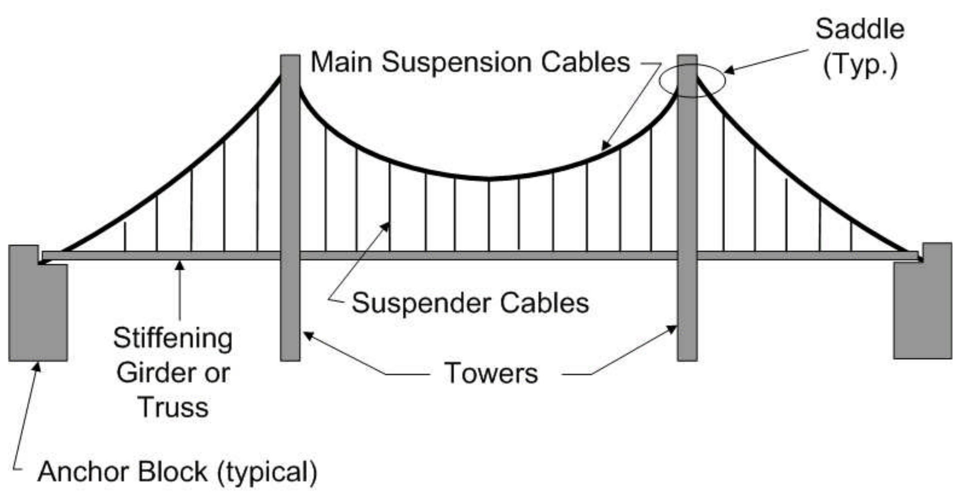

Figure 16.1.16 Three-Span Suspension Bridge Schematic

If a suspension bridge has only two main suspension cables, the cables are considered to be fracture critical members since there is no load path redundancy. Refer to Topic 6.4 for a detailed description of fracture criticality and redundancy.

Another type of suspension bridge uses a self-anchoring system where the main suspension cables are anchored into the edge girders that span continuously from end to end in the suspension spans. The force from the main suspension cables puts the edge girders into compression. The edge girders support the floor system and the suspender cables support the edge girders in this arrangement.

This type suspension bridge may be used to create long clear spans for navigation and not have to continue the suspension spans to the shorelines for anchorage. The alignment for the approach spans can be different than the suspension spans. These benefits are seen in the new Oakland Bay View Bridge in California, where the approach alignment is on a curve, the suspension span creates the wide navigation channel and the anchoring is self contained within the superstructure of the suspension spans.

Anchorage and Connections

Anchorages

In bridges with common earth anchored cable systems, either above or below ground, the total force of the main suspension cable has to be transferred into the anchor block (see Figure 16.1.17). The void area inside the anchor block is referred to as the Chain Gallery. The force from the main cable is distributed through the splay saddle, bridge wires, strand shoes and anchor bars. The anchor bars are embedded and secured in the concrete of the anchor block. The anchor bars may consist of steel bars, rods, pipes, or prestressed bars / strands.

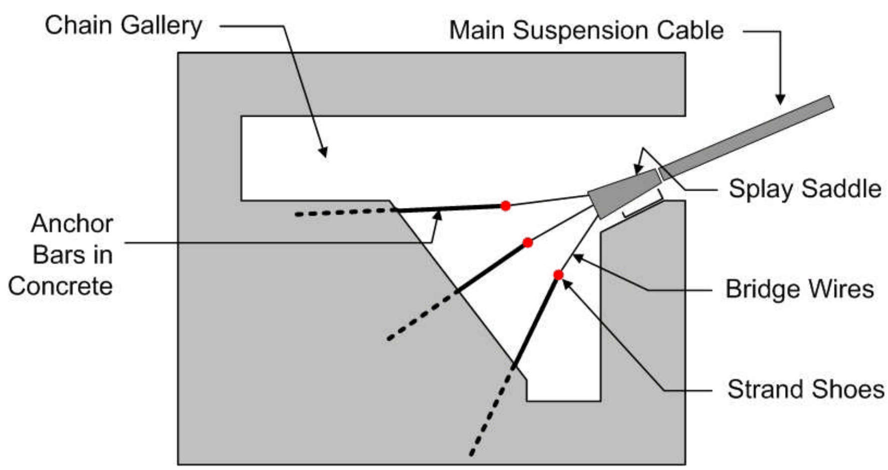

Figure 16.1.17 Anchor Block Schematic

Saddles

The connection between main cable and tower is usually made through saddles. The saddle supports the main cable as it crosses over the tower (see Figure 16.1.18). Saddles are commonly made from fabricated steel or castings.

Figure 16.1.18 Cable Saddles for Manhattan Bridge, NYC (Main Span 1,480 ft)

Suspender Cable Connections

The connection between the main suspension cable and suspender cable is made by means of a cable band. The cable band consists of two semi-cylindrical halves connected by high-tensile steel bolts to develop the necessary friction.

Grooved cable bands have been used in the majority of suspension bridges (see Figure 16.1.19). The top surfaces of the bands are grooved to receive the suspender cables, which are looped over the band.

Instead of looping the hanger cables around the main suspension cable, the hanger might be socketed at the upper end and pin connected to the cable band. This connection is called an open socket (see Figure 16.1.20). Connection to the deck and floor system can also be a similar open socket arrangement or it can be connected directly to a floorbeam - similar to the tied arch bridge.

Figure 16.1.19 Grooved Cable Bands

Figure 16.1.20 Open Socket Suspender Cable Connection

Vibrations

The flexibility of cable-supported structures, associated with high stress levels in the main load carrying members, makes these structures especially sensitive to dynamic forces caused by earthquake, wind, or vehicular loads. The term local vibration is used when dealing with the vibration in an individual member (see Figure 16.1.21). When the vibration of the entire structure as a whole is analyzed, it is known as global vibration (see Figure 16.1.22). Due to the amount of vibration in cable-supported structures, it may be common to see various types of damping systems attached to cables. Damping systems may be a tie between two cables, neoprene cushions, shock absorbers mounted directly to the cables, or other systems that act to dampen the cable vibrations (see figures 16.1.23 and 16.1.24).

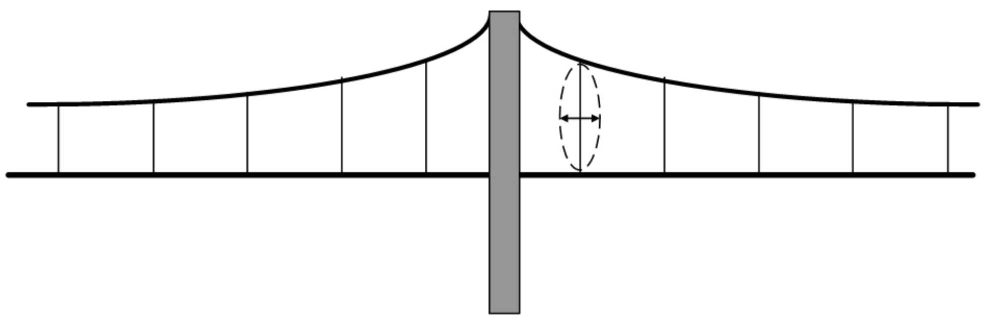

Figure 16.1.21 Cable Vibrations Local System Schematic

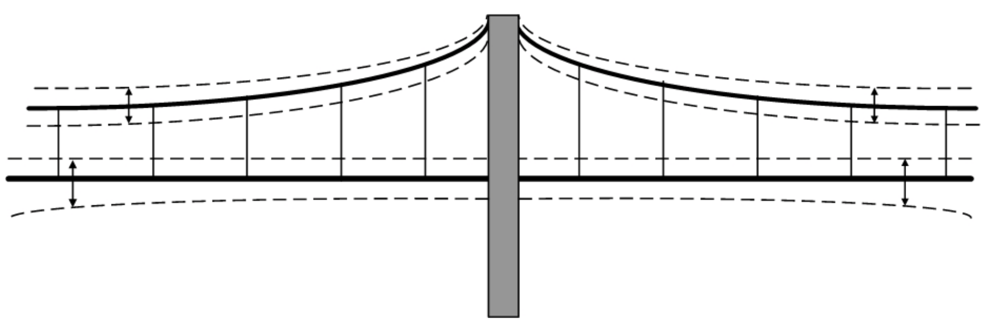

Figure 16.1.22 Cable Vibrations Global System Schematic

Vibrations can affect suspension cables in several ways. Vibration opens cable wires allowing entry of corrosive chemicals and accelerates corrosion. Vibrations create fretting, cracks in the protective coating and cement grout, and accelerate corrosion and possibly fatigue.

Figure 16.1.23 Cable Damping System - Wheeling Suspension Bridge (Photo Courtesy of Geoffrey H. Goldberg, 1999)

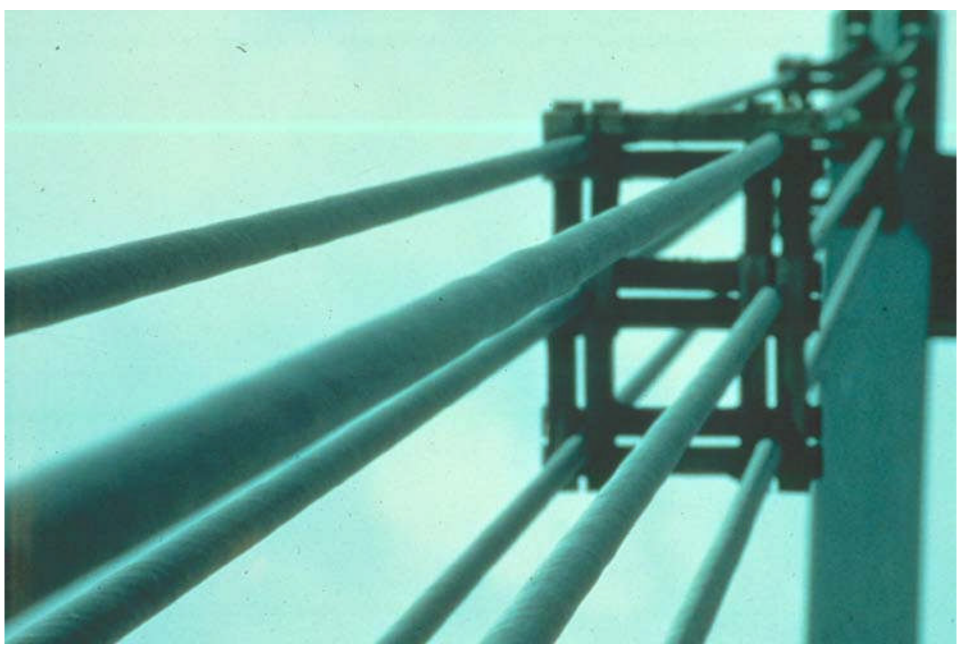

Figure 16.1.24 Cable Tie Damper System

16.1.4 Cable-Stayed Bridges

Only the cable and its elements are described in this subtopic. Refer to the appropriate topic for other bridge elements that are common to similar bridge types (i.e. floor systems, open web girders, box sections, etc.).

Due to the complexity of the various cable arrangements and systems, fracture criticality for individual cable-stayed structures can only be determined through a detailed structural analysis.

Cable Arrangements and Systems

Cable-stayed bridges may be categorized according to the various longitudinal cable arrangements. These cable arrangements are categorized into the following four basic systems:

- Radial or Converging Cable System
- Harp Cable System
- Fan Cable System
- Star Cable System

Radial or Converging Cable System

In this system, all cables are leading to the top of the tower at a common point. Structurally, this arrangement is the most effective. By anchoring all the cables to the tower top, the maximum inclination to the horizontal is achieved (see Figure 16.1.25).

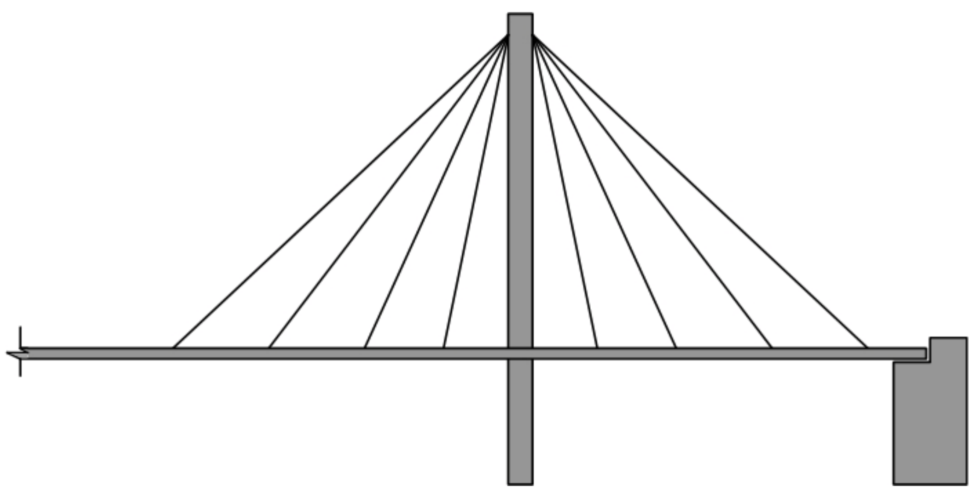

Figure 16.1.25 Radial or Converging Cable System Schematic

Harp Cable System

The harp system, as the name implies, resembles harp strings. In this system, the cables are parallel and equidistant from each other. The cables are also spaced uniformly along the tower height and connect to the deck floor system or superstructure at the same spacing (see Figure 16.1.26).

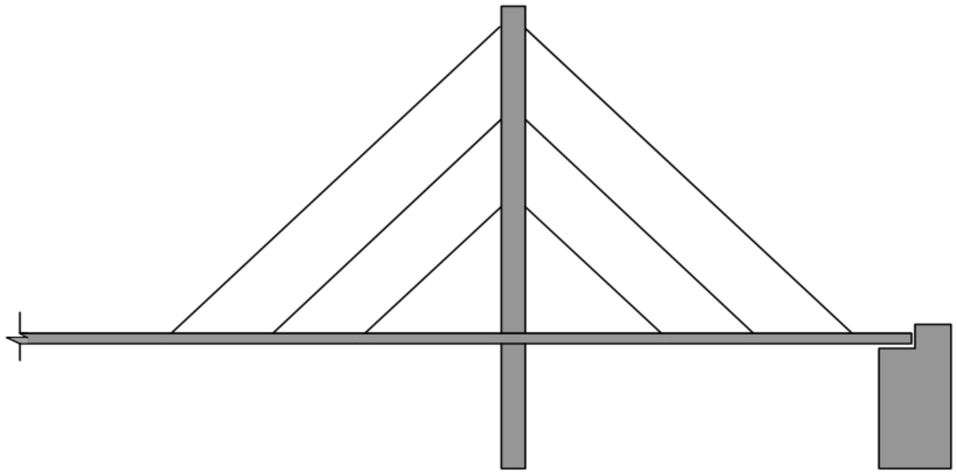

Figure 16.1.26 Harp or Parallel Cable System Schematic

Fan Cable System

The fan system is a combination of the radial and the harp systems. The cables emanate from the top of the tower at equal spaces and connect to the superstructure at larger equal spaces (see Figure 16.1.27).

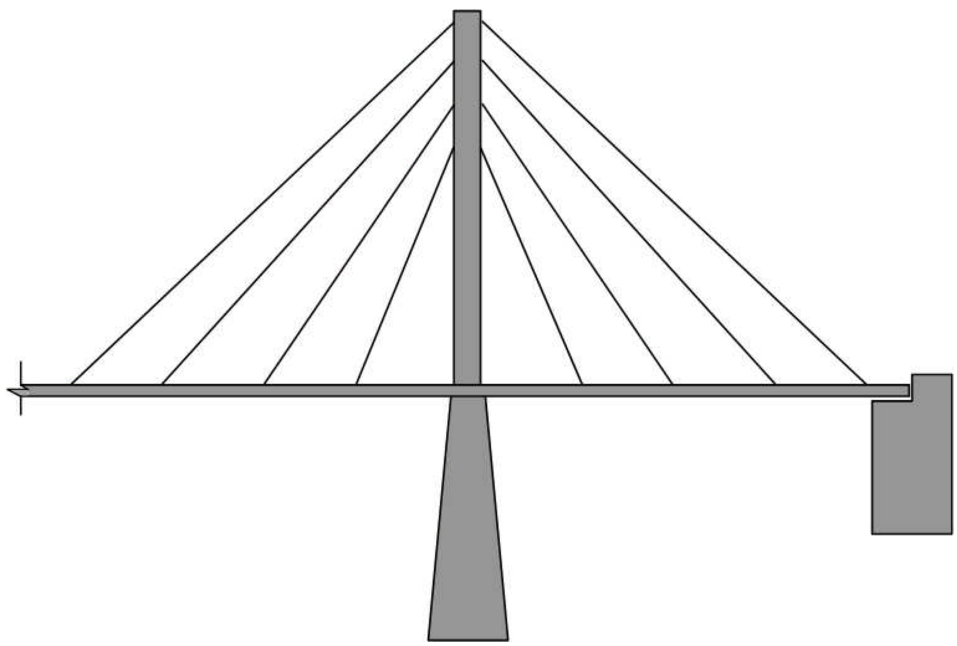

Figure 16.1.27 Fan or Intermediate Cable System Schematic

Star Cable System

In the star system, the cables intersect the tower at different heights and then converge on each side of the tower to intersect the deck structure at a common point. The common intersection in the anchor span is usually located over the abutment or end pier. The star system is uncommon compared to the three systems previously presented. The star system requires a much stiffer superstructure since the cables are not distributed longitudinally along the deck and superstructure (see Figure 16.1.28).

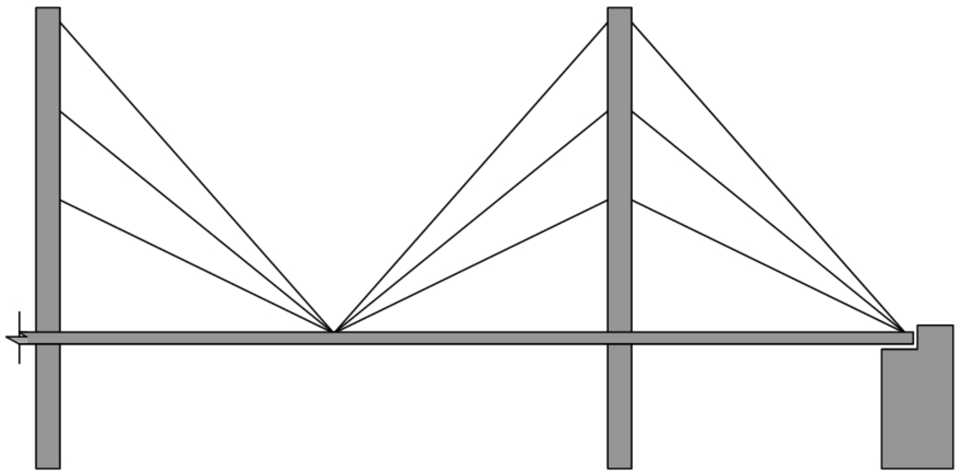

Figure 16.1.28 Star Cable System Schematic

Cable Planes

The cables may lie in either a single or a double plane, may be symmetrical or asymmetrical, and may lie in oblique or vertical planes.

Single Plane

The single-plane cable arrangement is used with a divided deck structure with the cables passing through the median area and anchored below the deck. A single-plane cable system generally utilizes single column or A-frame towers (see Figure 16.1.29).

Figure 16.1.29 Single Vertical Plane Cable System

Double Vertical Plane

The double vertical plane system incorporates two vertical cable planes connecting the tower to the edge girders along the deck structure. The structure may utilize twin towers or a portal frame tower (see Figure 16.1.30). The portal frame tower is a twin tower with a connecting strut at the top. Wider bridges may utilize a triple plane system that is basically a combination of the single and double plane systems.

Figure 16.1.30 Double Vertical Plane Cable System

Double Inclined Plane

In this two plane system the cable planes are oblique, sloping toward each other from the edges of the deck and intersecting at the tower along the longitudinal centerline of the deck (see Figure 16.1.31). Generally the tower is an A-frame type, receiving the sloping cables that intersect close to the centerline on the tower.

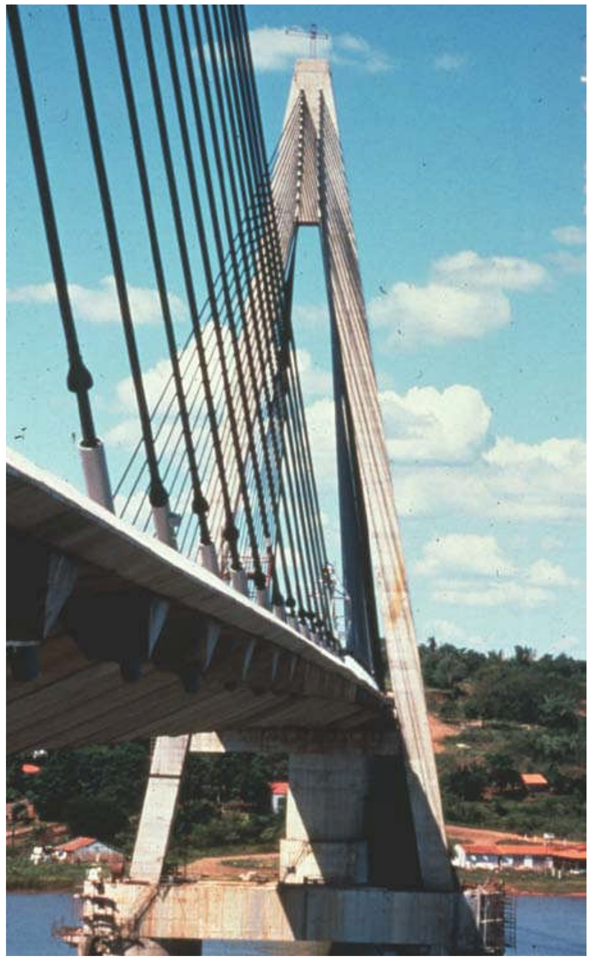

Figure 16.1.31 Double Inclined Plane Cable System

Anchorages and Connections

The cables may be continuous and pass through or over the tower or be terminated at the tower. If continuous across the tower, a saddle is incorporated.

Saddles

The cable saddles are constructed from fabricated plates or steel castings with grooves through which the cables pass (see Figure 16.1.32). Between the end and center spans differential forces will occur at the cable saddles unless they are supported by rollers or rocker bearings. When the saddles are fixed, the rigidity of the system is at the maximum.

Figure 16.1.32 Cable Saddle

End Fittings

If terminated at the tower, an end fitting or anchorage is incorporated. A similar end fitting is utilized at the edge girder (see Figure 16.1.33).

Figure 16.1.33 Cable Deck Anchorage

Socket

A socket widely used for the anchoring of parallel-wire strands is a poured zinc socket. The wires are led through holes in a locking plate at the end of the socket and have the bottom heads providing the resistance against slippage of wires. The cavity inside the socket is filled with hot zinc alloys. To improve the fatigue resistance of the anchor, a cold casing material is used. The zinc cools and locks the wire strands into the socket.

Figure 16.1.34 Anchor Inspection on Veterans Bridge

The problems encountered with low fatigue strength of zinc-poured sockets lead to the development of HiAm sockets in 1968 for use with parallel wire stays.

This anchorage incorporates a flat plate with countersunk radial holes to accommodate the geometry of flared wires that transition from the compact wire bundle into the anchorage. The anchorage socket is filled with zinc dust and with an epoxy binder. This method of anchoring the stays increases the magnitude of fatigue resistance to almost twice that for the zinc-poured sockets.

A common anchorage type for strands is the Freyssinet type anchor.

In the Freyssinet socket the seven wire strand is anchored to an anchor plate using wedges similar to prestressing wedges. This wedge anchor is used during erection. After application of the permanent dead load, the anchor tube is filled with an epoxy resin, zinc dust, and steel ball composition. Under transient live load, the additional cable force will be transformed by shear from the cable strand to the tube.

Vibrations

Several of the primary causes of vibration in stay cables consist of rain-wind induced vibrations, sympathetic vibration of cables with other bridges elements excited by wind, inclined cable galloping, and vortex excitation of single cable or groups of cables. Due to the amount of vibration in cable-supported structures, it may be common to see various types of damping systems attached to cables. Damping systems may be a tie between two cables, neoprene cushions, shock absorbers mounted directly to the cables, or other systems that act to dampen the cable vibrations (see Figure 16.1.35).

Vibrations can affect stay cables in several ways. Vibration opens cable wires allowing entry of corrosive chemicals and accelerates corrosion. Vibrations create fretting, cracks in the protective coating and cement grout, and accelerate corrosion and possibly fatigue.

Figure 16.1.35 Damper on Cable-Stayed Bridge

16.1.5 Overview of Common Deficiencies

Common deficiencies that can occur on steel cable members:

- Corrosion
- Fatigue Cracking
- Overloads
- Collision Damage
- Heat Damage
- Paint Failure

Refer to Topic 6.3.5 for a more detailed presentation of the properties of steel, types and causes of steel deficiencies, and the examination of steel.

16.1.6 Inspection Locations and Methods for Suspension Bridge Cable System Elements

The inspection and maintenance methods presented in this Topic are not exhaustive, but are unique to the particular bridge type. Therefore, include both the procedures presented in this Topic as well as the general procedures previously presented in this manual during the inspection of special bridges.

These bridges are considered to be complex according to the NBIS regulations. The NBIS requires identification of specialized inspection procedures, and additional inspector training and experience required to inspect these complex bridges. The bridges are then to be inspected according to these procedures.

Due to the specialized nature of these bridges and because no two cable-supported bridges are identical, the inspection should be led by someone very familiar with the particular bridge. Many major bridges, such as cable-supported bridges, will have individual inspection and maintenance manuals developed specifically for that bridge, like an "owner's" manual. If available, use this valuable tool throughout the inspection process and verify that specified routine maintenance has been performed. Use customized, preprinted inspection forms wherever possible to enable the inspector to report the findings in a rigorous and systematic manner.

Main Cable Anchorage Elements

The anchorage system, at the ends of the main cables, consists of a number of elements that require inspection (see Figure 16.1.36).

- Splay saddle
- Bridge Wires
- Strand shoes or sockets
- Anchor bars
- Chain Gallery

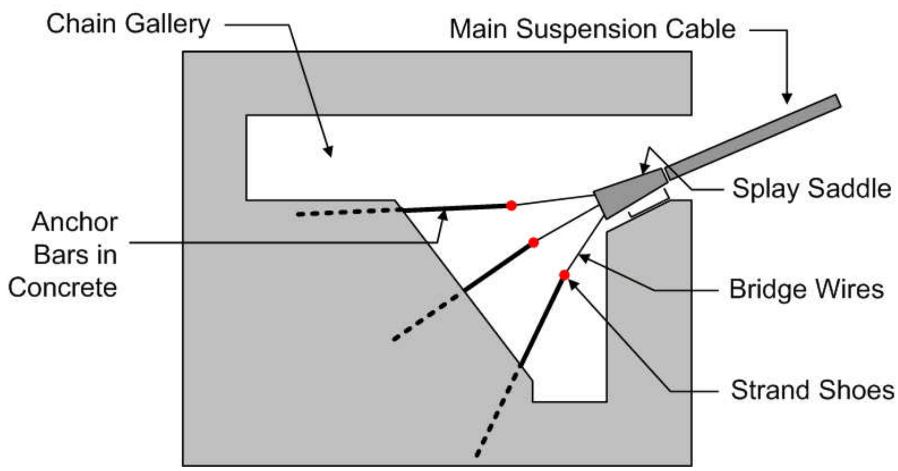

Figure 16.1.36 Anchor Block Schematic

Splay Saddle

Inspect the splay saddles for missing or loose bolts and the presence of cracks in the casting itself. There is a possibility of movement up the cable away from the splay. Signs of this movement may be the appearance of unpainted strands on the lower side or “bunched up” wrapping on the upper side

Bridge Wires

In parallel wire type suspension bridges, inspect the unwrapped wires between the strand shoes and the splay saddle. Carefully insert a large screwdriver between the wires and apply leverage. This will help reveal broken wires. Inspect the wires for abrasion damage, corrosion, and movement.

Strand Shoes or Sockets

At the anchorages of parallel wire type suspension bridges, inspect the strand shoes for signs of displaced shims, along with movement, corrosion, misalignment, and cracks in the shoes.

At the anchorages of prefabricated strand type suspension bridges, inspect the strand sockets for signs of movement, slack or sag, corrosion, and broken sockets. Unpainted or rusty threads at the face of the sockets may indicate possible “backing off” of the nuts.

Anchor Bars

Inspect the anchor bars or rods for corrosion (section loss), deficiencies, or movement at the face of their concrete embedment. Check for corrosion or other signs of distress over the entire visible (unencased) portion.

Chain Gallery

Inspect the interior of the anchorage for corrosion and deficiencies of any steel hardware, and cracks and spalls in the concrete anchor. Note if there is protection against water entering or collecting where it may cause corrosion, and also if there is proper ventilation (see Figure 16.1.37).

Figure 16.1.37 Anchorage Interior of Ben Franklin Bridge, Philadelphia, PA

Main Suspension Cables

Inspect the main suspension cables as follows:

Cables

Inspect the main suspension cables for indications of corroded wires. Inspect the condition of the protective covering or coating, especially at low points of cables, areas adjacent to the cable bands, saddles over towers, and at anchorages.

Cable Wrapping

Inspect the wrapping wire for cracks, staining, and dark spots. Check for loose wrapping wires. If there are cracks in the caulking where water can enter, this can cause corrosion of the main suspension cable. Check for evidence of water seepage at the cable bands, saddles, and splay castings (see Figure 16.1.38).

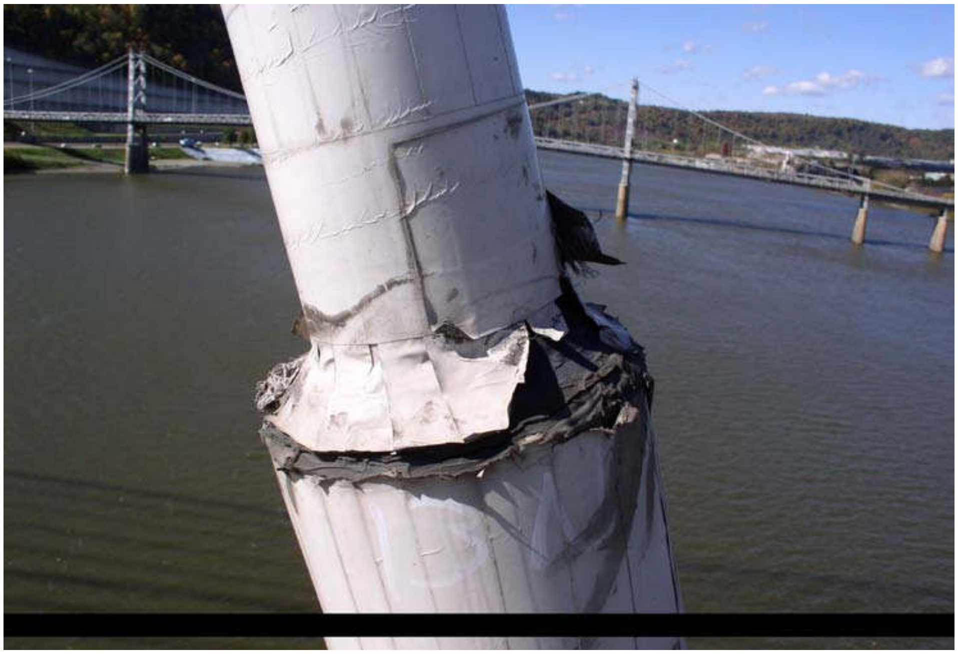

Figure 16.1.38 Tape and Rubber Seal Torn Around Cable Allowing Water Penetration into Top of Sheath

Hand Ropes

Inspect the hand ropes and connections along the main cables for loose connections of stanchion (hand rope supports) to cable bands or loose connections at anchorages or towers. Check also for corroded or deteriorated ropes or stanchions, bent or twisted stanchions, and too much slack in rope.

Vibration

Note and record all excessive vibrations.

Saddles

Inspect the saddles for missing or loose bolts, and corrosion or cracks in the casting. Check for proper connection to top of tower or supporting member and possible slippage of the main cable.

Suspender Cables and Connections

Inspect the suspender cables for corrosion or deficiencies, broken wires, and kinks or slack. Check for abrasion or wear at sockets, saddles, clamps, and spreaders. Be sure to note excessive vibrations.

Sockets

Inspect the suspender rope sockets for:

- Corrosion, cracks, or deficiencies
- Abrasion at connection to bridge superstructure
- Possible unanticipated movement

Cable Bands

Inspect the cable bands for missing or loose bolts, or broken suspender saddles. Signs of possible slippage are caulking that has pulled away from the casting or "bunching up" of the soft wire wrapping adjacent to the band. Check for the presence of cracks in the band itself, corrosion or deficiencies of the band, and loose wrapping wires at the band.

Recordkeeping and Documentation

Prepare a set of customized, preprinted forms for documenting all deficiencies encountered in the cable system of a suspension bridge. A suggested sample form is presented in Figure 16.1.39. Separate forms are to be used for each main suspension cable. Designations used to identify the suspender ropes and the panels provide a methodology for locating the problems in the structure. Note and describe vibrations whether local or global, while performing inspections of cable-supported structures.

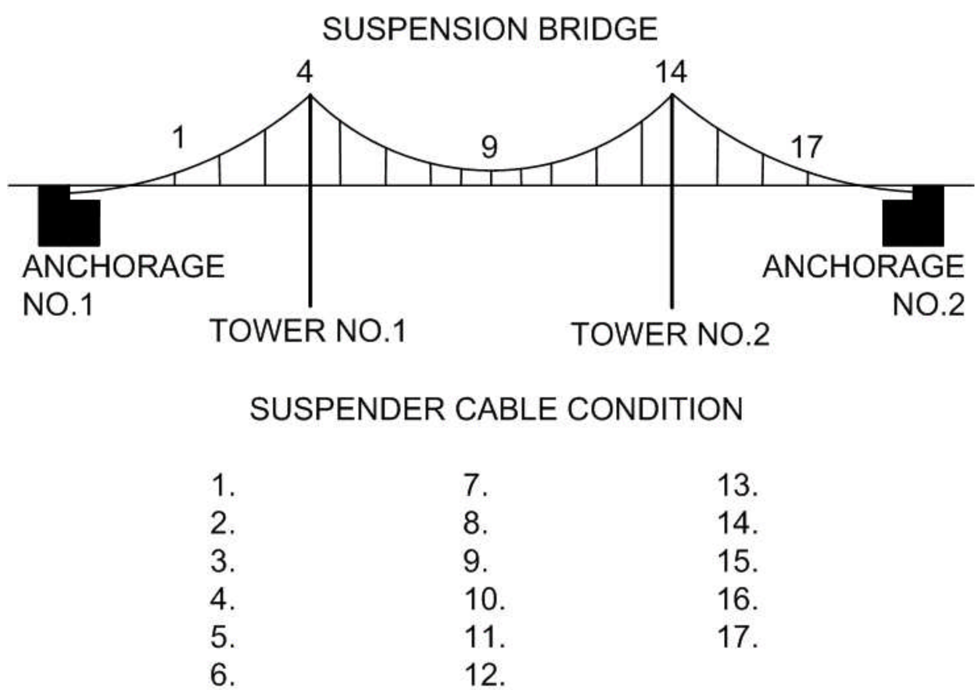

Figure 16.1.39 Form for Recording Deficiencies in the Cable System of a Suspension Bridge

16.1.7 Inspection Locations and Methods for Cable-Stayed Bridge Cable System Elements

A cable-stayed bridge is a bridge in which the superstructure is supported by cables, or stays, passing over or attached directly to towers located at the main piers (see Figure 16.1.40 and 16.1.41). There are several special elements that are unique to cable-stayed bridges.

See the National Cooperative Highway Research Program (NCHRP) Synthesis 353 “Inspection and Maintenance of Bridge Cable Systems”, 2005 for a detailed description of inspection locations and procedures for cable-stayed bridge cable element systems.

These bridges are considered to be complex according to the NBIS regulations. The NBIS requires identification of specialized inspection procedures, and additional inspector training and experience required to inspect these complex bridges. The bridges are then to be inspected according to these procedures.

Figure 16.1.40 Cable-Stayed Bridge

Figure 16.1.41 Cable-Stayed Bridge Cables

Inspection Elements

Cable element inspection includes:

- Cable wrappings and wrap ends near the tower and deck
- Cable sheathing assembly
- Dampers
- Anchorages

Cable Wrapping

Common wrapping methods for corrosion protection of finished cables include spirally wound soft galvanized wire, neoprene, or plastic wrap type tape (see Figure 16.1.42). Inspect the wrappings for corrosion and cracking of soft galvanized wire, staining and dark spots indicating possible corrosion of the cables, and loose wrapping wires or tape. Bulging or deforming of wrapping material may indicate possible corrosion or broken wires (see Figure 16.1.43). Check for evidence of water seepage at the cable bands, saddles, and castings.

Figure 16.1.42 Cable Wrapping Placement

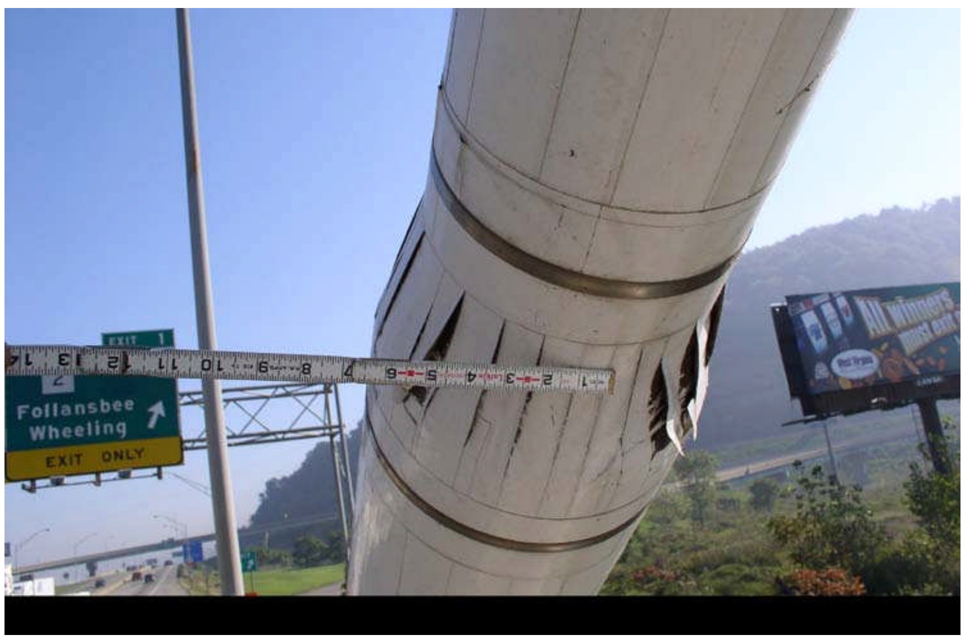

Figure 16.1.43 Deformed Cable Wrapping

Cable Sheathing Assembly

The most common types of cable sheathing assemblies are steel sheathing and polyethylene sheathing.

Steel Sheathing

If steel sheathing is used, inspect the system for corrosion (see Figure 16.1.44), condition of protective coatings, and weld fusion. Bulging may indicate corrosion or broken wires (see Figure 16.1.45). Splitting may be caused by water infiltration and corrosive action. Cracking is sometimes caused by fatigue (see Figure 16.1.46).

Polyethylene Sheathing

If polyethylene sheathing is used, inspect the system for nicks, cuts, and abrasions. Check for cracks and separations in caulking and in fusion welds. Bulging may indicate broken wires (see Figure 16.1.45). Splitting is sometimes caused by temperature fluctuations (see Figure 16.1.47). Coefficient of the thermal expansion for polyethylene is three times higher than the value for steel or concrete. Cracking is sometimes caused by fatigue.

Figure 16.1.44 Corrosion of Steel Sheathing

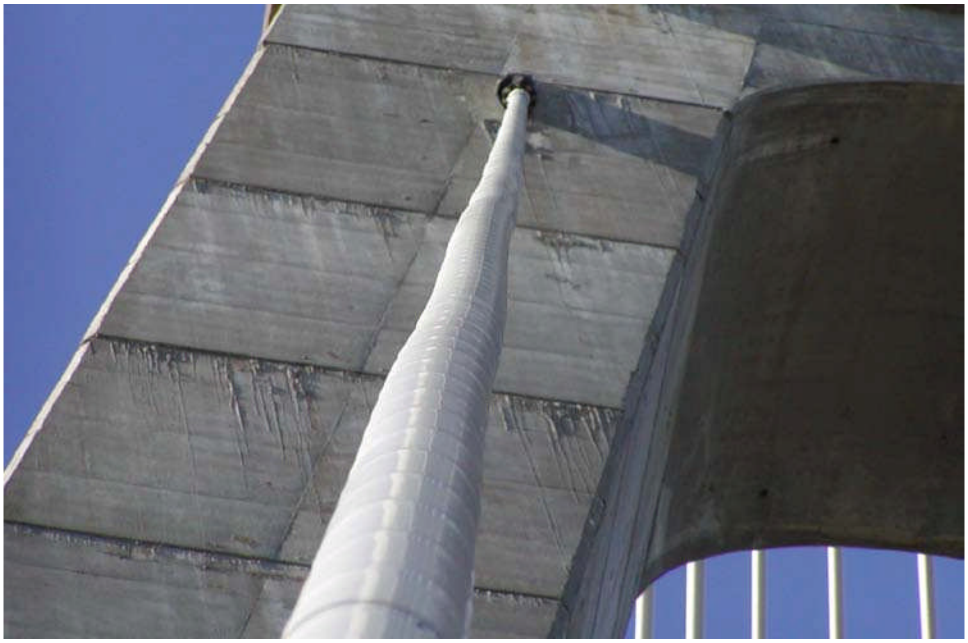

Figure 16.1.45 Bulging of Cable Sheathing

Figure 16.1.46 Cracking of Cable Sheathing

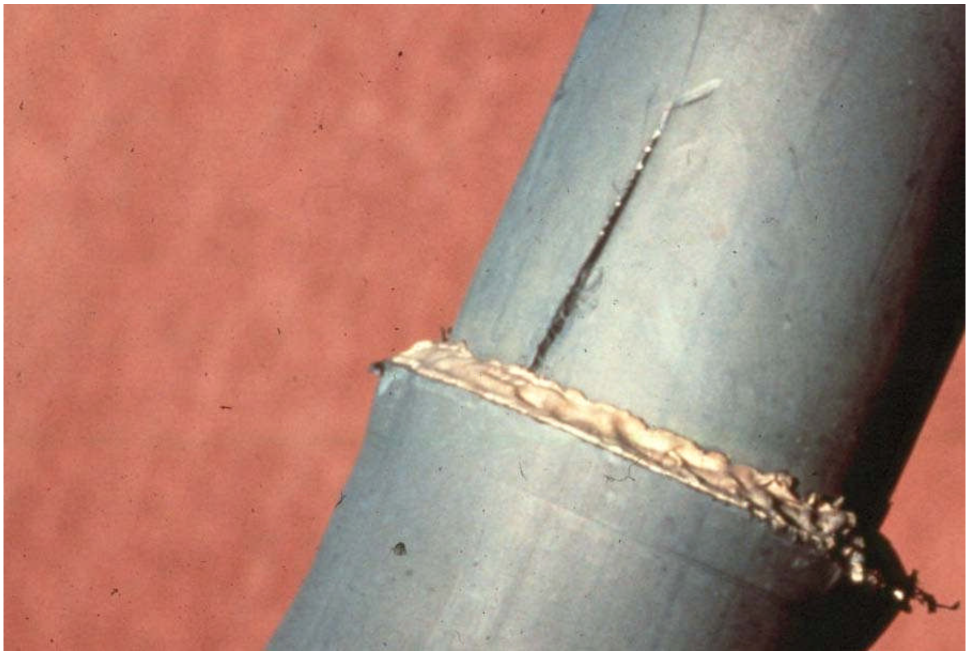

Figure 16.1.47 Splitting of Cable Sheathing

Dampers

Shock Absorber Type

A variety of damper types may have been installed (see Figure 16.1.48 and 16.1.49). If shock absorber type dampers are used, inspect the system for corrosion, oil leakage in the shock absorbers, and deformations in the bushings. Check for tightness in the connection to the cable pipe, and torque in the bolts.

Figure 16.1.48 Shock Absorber Damper System

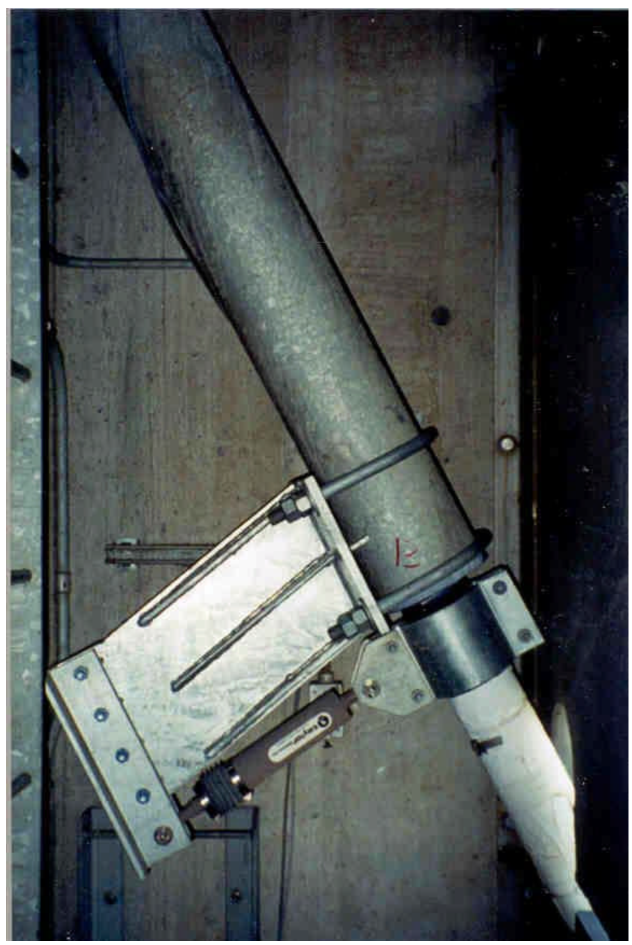

Figure 16.1.49 Shock Absorber Damper System

Tie Type

Inspect the tie type dampers (see Figure 16.1.50) for corrosion, and deformations in the bushings. Check for tightness in the connection to the cable pipe, and torque in the bolts.

Figure 16.1.50 Cable Tie Type Damper System

Tuned Mass Type

Inspect the tuned mass dampers (see Figure 16.1.51) for corrosion, and deformations in the bushings. Check for tightness in the connection to the cable pipe, and torque in the bolts.

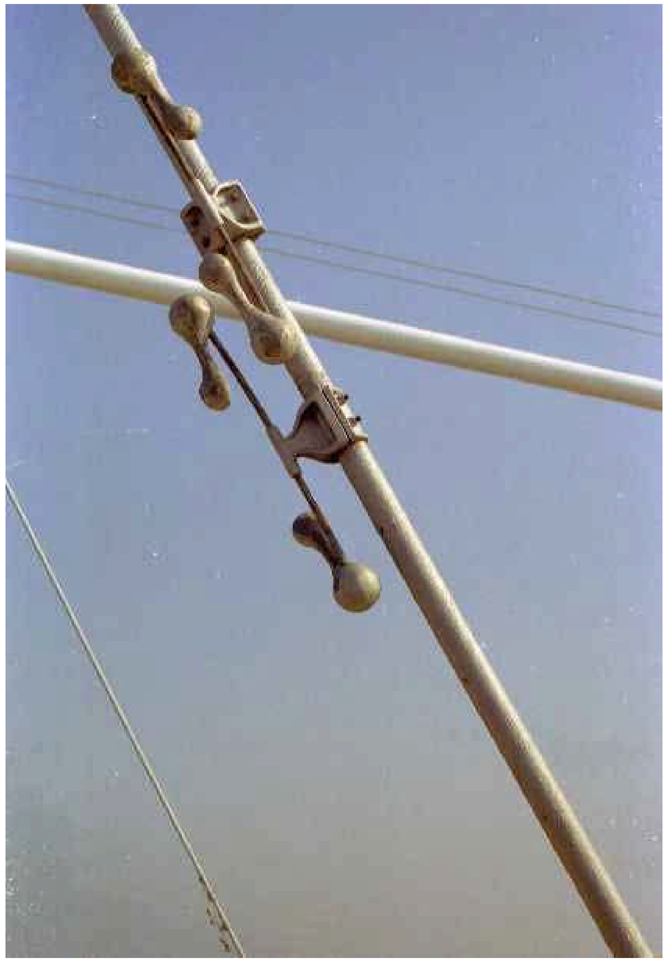

Figure 16.1.51 Tuned Mass Damper System

Anchorages

End Anchorage

Inspect the transition area between the steel anchor pipe and cable for water tightness of neoprene boots at the upper ends of the steel guide pipes (see Figure 16.1.52). Check for drainage between the guide pipe and transition pipe, and deteriorations, such as splits and tears, in the neoprene boots (see Figure 16.1.53). Check for sufficient clearance between the anchor pipe and cable, noting rub marks and kinks.

Figure 16.1.52 Neoprene Boot at Steel Anchor Pipe Near Anchor

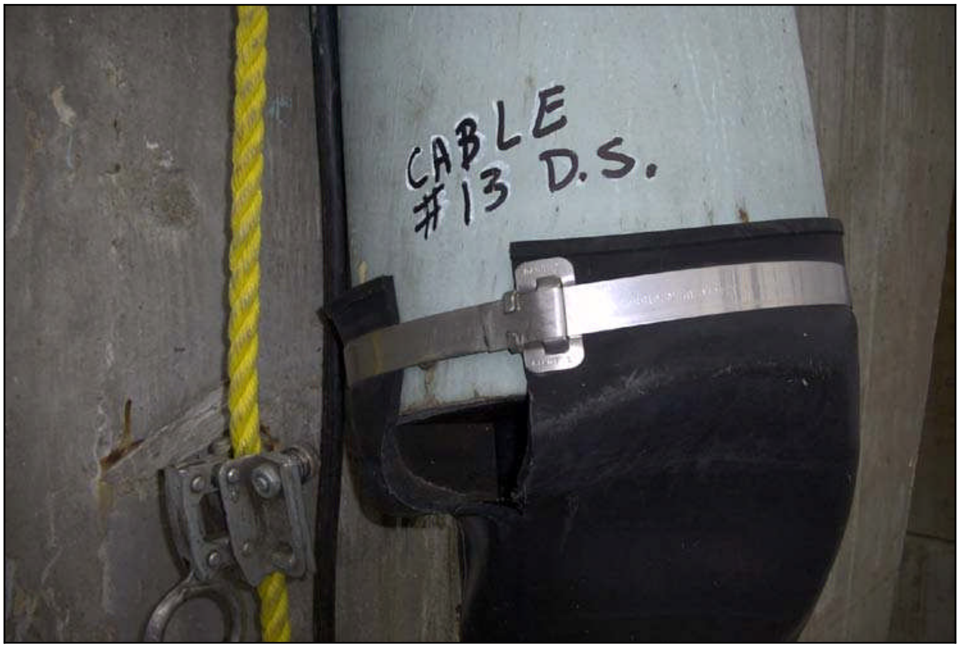

Figure 16.1.53 Split Neoprene Boot

Tower Anchorage

Inspect the cable anchorages for corrosion of the anchor system (see Figure 16.1.54). Check for cracks and nut rotation at the socket and bearing plate, and seepage of grease from the protective hood.

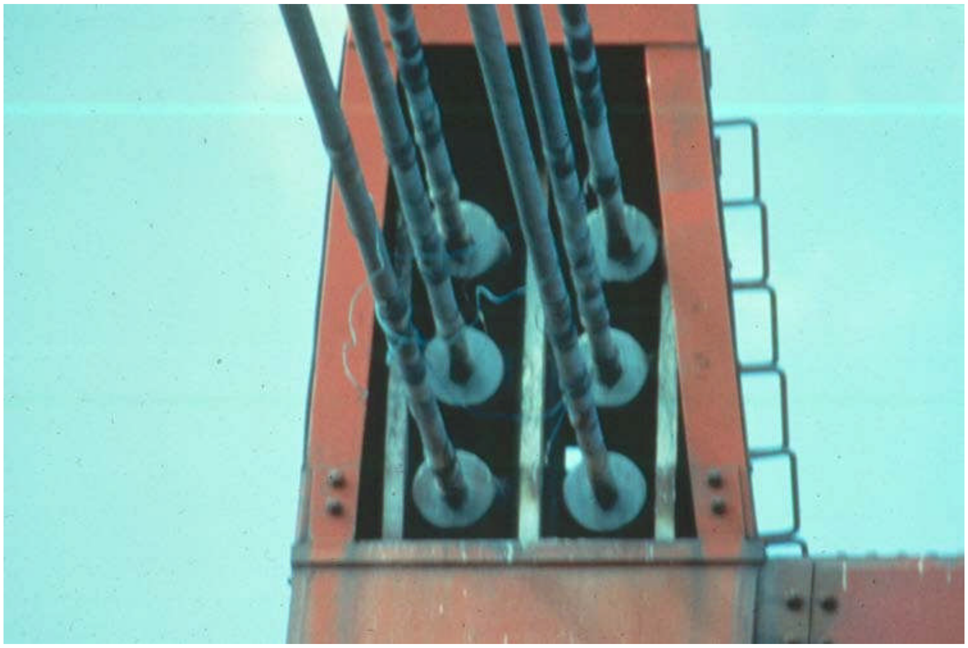

Figure 16.1.54 Corrosion of the Anchor System

Other Inspection Items

Include anchor pipe clearances, flange joints, and polyethylene expansion joints within the inspection of the cable system. Read the load cells and record the forces in the cables. Note and record all excessive vibrations including amplitude and type of vibration along with wind speed and direction, or other forces including vibrations such as traffic. Also evaluate cable and tower lighting systems.

Recordkeeping and Documentation

Prepare a set of customized, preprinted forms for documenting all deficiencies encountered in the cable system of a cable-stayed bridge. A suggested sample form is presented in Figure 16.1.55. Use a separate form for each plane or set of cables. Designations used to identify the cables and the panels provide a methodology for locating the deficiencies in the structure. Note and describe vibrations whether local or global, while performing inspections of cable-supported structures.

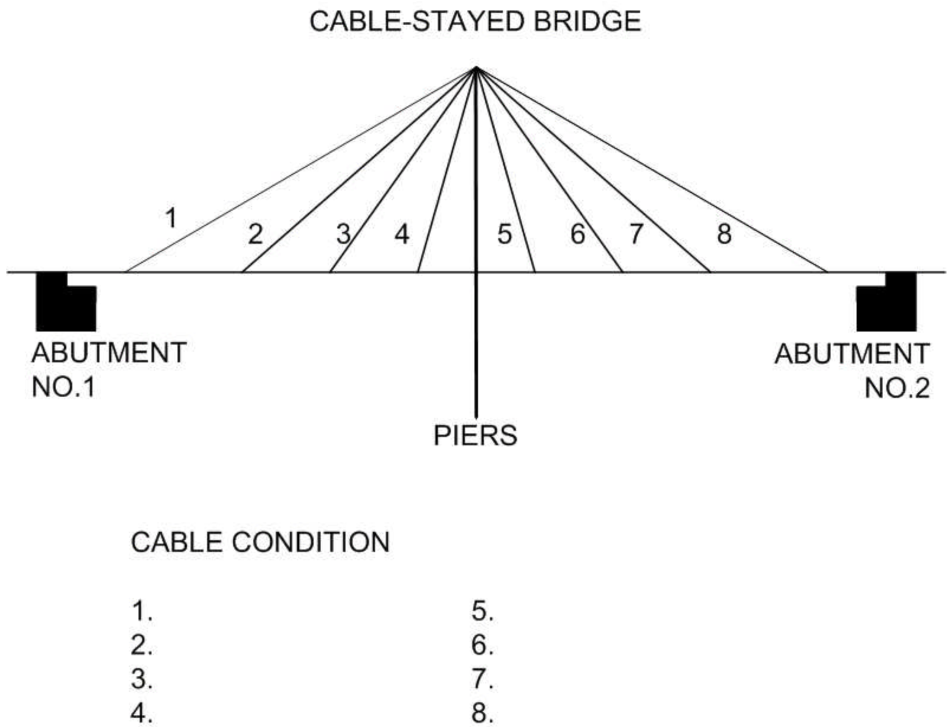

Figure 16.1.55 Form for Recording Deficiencies in Cable System of a Cable-Stayed Bridge

16.1.8

Advanced Inspection Methods

In bridge cables, whether a suspension bridge or cable-stayed bridge, the greatest problems generally occur due to corrosion and fracture of individual wires. Visual inspection of unwrapped cables is limited to the outer wires, while visual inspection of wrapped cables is limited to the protective sheathing. Therefore, advanced inspection methods are used to achieve a more rigorous and thorough inspection of steel bridges, including:

- Acoustic Emissions Testing
- Corrosion Sensors
- Smart Coatings
- Dye Penetrant
- Magnetic Particle
- Radiography Testing
- Computed Tomography
- Robotic Inspection

- Ultrasonic Testing
- Eddy Current
- Electrical fatigue sensor (EFS)
- Magnetic flux leakage
- Laser vibrometer

See Topic 15.3 for Advanced Inspection Procedures for steel.

Other methods specific to cables include:

- Cable force measurements using the precursor transformation matrix - this method uses a linearly elastic finite-element analysis (FEA) model of the cable-supported bridge. Through the model, the temperature each of cable is raised to simulate loss of stiffness one cable, noting the resultant changes in force of the other cables. Field measurements are then taken and compared with the matrix to identify cables that have suffered a loss of stiffness. Alternatively, a matrix may be formed using resultant deck elevations instead of resultant cable stiffnesses from the single cable temperature change.
- Accelerometer - this method operates on the vibrating string theory and is an alternative to the laser vibrometer for vibration-based cable force measurements. The accelerometer measures the natural frequency of the cable, which is then used to calculate the tension in the cable from the known length and mass per unit length. This method is generally taken as an estimate, since the vibrating string theory does not take into consideration cable bending stiffness, cable sag, neoprene rings, viscous dampers, and variable stiffness.
- Vibration decay - this method measures the cable damping by inducing high-vibration amplitudes. The cable is then allowed to slow down, decaying the signal of the accelerometer and providing the damping ratio.

16.1.9 Evaluation

State and Federal rating guideline systems have been developed to aid in the inspection of steel superstructures. The two major rating guideline systems currently in use are the FHWA's *Recording and Coding Guide for the Structural Inventory and Appraisal of the Nation's Bridges* used for the National Bridge Inventory (NBI) component condition rating method and the AASHTO *Guide Manual for Bridge Element Inspection* for element level condition state assessment.

NBI Component Condition Rating Guidelines

Using the NBIS component condition rating guidelines, a one-digit code on the Federal Structure Inventory and Appraisal (SI&A) sheet indicates the condition of the superstructure. Component condition rating codes range from 9 to 0 where 9 is the best rating possible. See Topic 4.2 (Item 59) for additional details about NBIS component condition rating guidelines.

Consider previous inspection data along with current inspection findings to determine the correct component condition rating.

Element Level Condition State Assessment

In an element level condition state assessment of a cable-supported bridge, possible AASHTO National Bridge Elements (NBEs) and Bridge Management Elements (BMEs) are:

NBE No.	**Description**
Superstructure	
147	Steel Main Cables (not embedded in concrete)
148	Secondary Steel Cables (not embedded in concrete)

BME No.	**Description**
Wearing Surfaces and Protection Systems	
515	Steel Protective Coating

The unit quantity for cables is feet. The total length cable is distributed among the four available condition states depending on the extent and severity of the deficiency. The unit quantity for protective coating is square feet, and the total area is distributed among the four available condition states depending on the extent and severity of the deficiency. The sum of all condition states equals the total quantity of the National Bridge Element or Bridge Management Element. Condition State 1 is the best possible rating. See the *AASHTO Guide Manual for Bridge Element Inspection* for condition state descriptions.

The following Defect Flags are applicable in the evaluation of cable-supported bridges:

Defect Flag No.	**Description**
356	Steel Cracking/Fatigue
357	Pack Rust
362	Superstructure Traffic Impact (load capacity)

See Chapters 9 and 10 for the inspection and evaluation of concrete and steel girders, floorbeams and stringers.

See Chapter 7 for the inspection and evaluation of decks.

See Chapter 12 for the inspection and evaluation of abutments, piers and bents.

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Chapter 16
Complex Bridges

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Topic 16.2 Movable Bridges

16.2.1 Introduction

This topic serves as an introduction to the highly specialized area of movable bridge inspection. It focuses on the types of movable bridges and special elements associated with the various bridge types.

Each of these specialized bridge types has their unique features and unique mechanisms for movement. The following sections cover common types of movable bridges, including information on the operation, maintenance and inspection of the structure and the movement mechanisms. The inspection of these specialized bridges requires a diverse team collectively capable of inspecting the structure as well as the mechanical, electrical, pneumatic or other movement mechanisms. The duties of the bridge inspector are defined by the bridge owner for the inspection of these type structures and should be complemented, as necessary, by duties of other inspectors for the inspection of the movement mechanisms and by the duties for maintenance and operation personnel. The bridge inspector should confirm with the owner their role in the inspection of these specialized structures (see Figure 16.2.1).

Figure 16.2.1 Movable Bridge

Movable bridges are normally constructed only when fixed bridges are either too expensive or impractical. Movable bridges are constructed across designated "Navigable Waters of the United States", in accordance with "Permit Drawings" approved by the U.S. Coast Guard. When a movable bridge is fully open, it must provide the channel width and the underclearance shown on the Permit Drawings (see Figure 16.2.2). If the bridge cannot be opened to provide these clearances, notify the U.S. Coast Guard immediately and take action to restore the clearances. If that is impossible, an application must be submitted to revise the Permit Drawings.

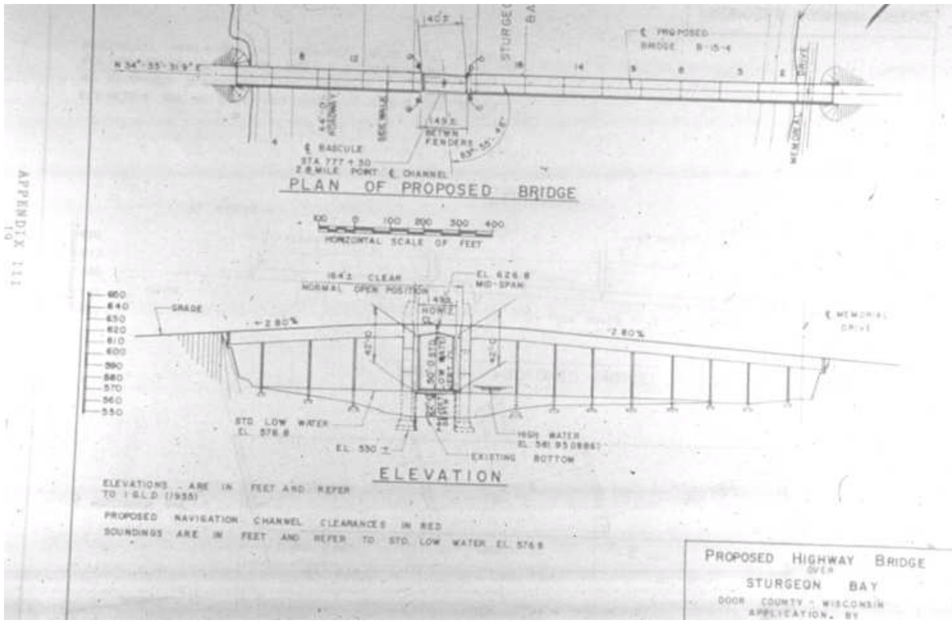

Figure 16.2.2 Typical “Permit Drawing” Showing Channel Width and Underclearance in Closed and Open Position

If any work is to be done in the channel or on the movable span to reduce the clearances from those shown on the Permit Drawing, obtain an additional permit, from the U.S. Coast Guard District covering the scheduled time for the work.

The U.S. Coast Guard publishes Local Notices to Mariners to keep waterway users informed of work in progress that may affect navigation. The permittee keeps the U.S. Coast Guard informed of all stages of construction.

Verify that the bridge conforms to the Permit Drawing and that the operator is instructed to open the bridge to the fully open position every time the bridge is operated. Failure to do this would establish a precedent that a vessel is expected to proceed before the green navigation lights have turned “on”. Any accident caused as a result of this practice could be ruled the fault of the bridge owner.

Early America's engineering literature did not establish where the first iron drawbridge was built. The first all-iron movable bridge in the Midwest was completed in 1859 carrying Rush Street over the Chicago River (see Figure 16.2.3). The bridge was a rim bearing swing span and was probably operated by steam. It was destroyed on November 3, 1863 when it was opened while a drove of cattle was on one end. It was rebuilt but destroyed by the great Chicago fire of 1871.

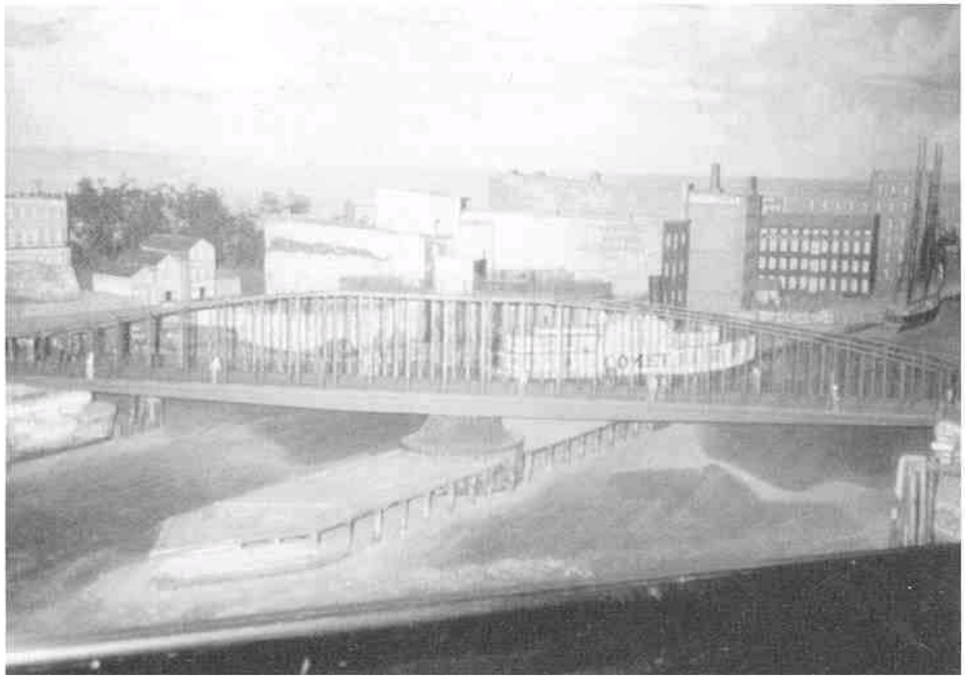

Figure 16.2.3 The First All-Iron Movable Bridge in the Midwest was Completed in 1859 (Photo on File at the Chicago Historical Society)

All categories of movable bridges are powered by electric-mechanical or hydraulic-mechanical drives with power driven pinions operating against racks, or by hydraulic cylinders. A small number are hand powered for normal operation. A few bridges use hand power for standby operation. Three categories of movable bridges comprise over 95 percent of the total number of movable bridges within the United States. These categories include:

- Swing bridges
- Bascule bridges
- Vertical lift bridges

16.2.2 Swing Bridges Design Characteristics

Swing bridges consist of two-span trusses or continuous girders, which rotate horizontally about the center (pivot) pier (see Figure 16.2.4). The spans are usually, but not necessarily, equal. When open, the swing spans are cantilevered from the pivot (center) pier and must be balanced longitudinally and transversely about the center. When closed, the spans are supported at the pivot pier and at two rest (outer) piers or abutments. In the closed condition, wedges are usually driven under the outer ends of the bridge to lift them, thereby providing a positive reaction sufficient to offset any possible negative reaction from live load and impact in the other span. This design feature prevents uplift and hammering of the bridge ends under transient live load conditions.

Figure 16.2.4 Center-Bearing Swing Bridge

Swing spans are subdivided into two types:

- Center-bearing
- Rim-bearing

Center-Bearing

Center-bearing swing spans carry the entire load of the bridge on a central pivot (usually metal discs). Balance wheels are placed on a circular track around the outer edges of the pivot pier to prevent tipping (see Figures 16.2.5 and 16.2.6). When the span is closed, wedges similar to those at the rest piers are driven under each truss or girder at the center pier. This relieves the center bearing from carrying any live load. However, these wedges do not raise the span at the pivot pier, but are merely driven tight.

The latest swing spans built are nearly all of the center-bearing design. Center-bearing swing spans are less complex and less expensive to build than rim-bearing swing spans.

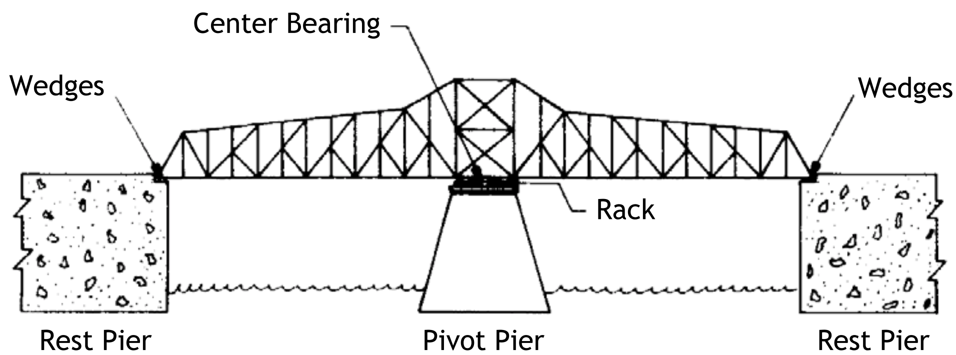

Figure 16.2.5 Center-Bearing Swing Span in Closed Position

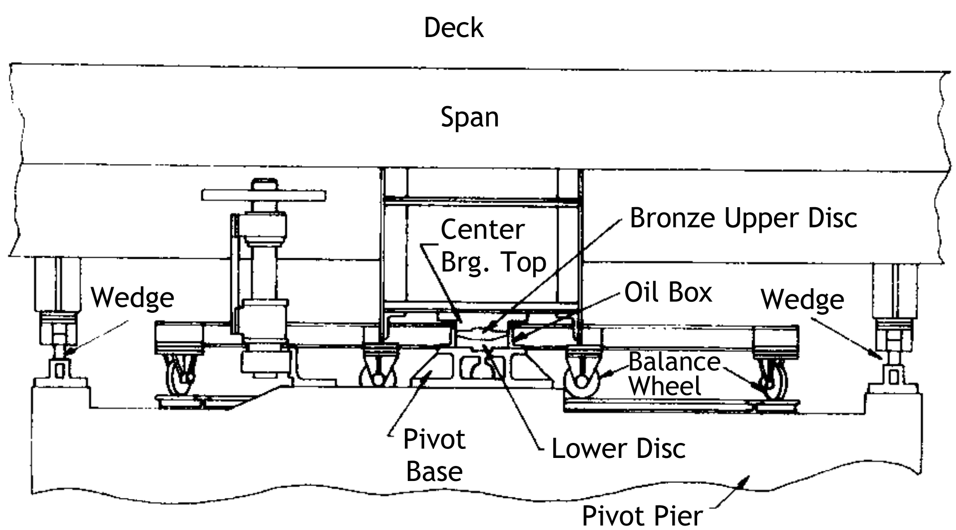

Figure 16.2.6 Layout of Center-Bearing Type Swing Span with Machinery on the Span

Rim-Bearing

Rim-bearing swing spans transmit all loads, both dead and live, to the pivot pier through a circular girder or drum to beveled rollers. The rollers move on a circular track situated inside the periphery of the pier. The rollers are aligned and spaced on the track by concentric spacer rings. This type of swing span bridge also has a central pivot bearing which carries part of the load. This pivot bearing is connected to the rollers by radial roller shafts and keeps the span centered on the circular track.

On both types of swing bridges, the motive power is usually supplied by electric motor(s), hydraulic motor(s), or hydraulic cylinder(s), although gasoline engines or manual power may also be used. The bridge is rotated horizontally by a circular rack and pinion arrangement, or cylinders.

16.2.3 Bascule Bridges Design Characteristics

Bascule bridges open by rotating a leaf or leaves (movable portion of the span) from the normal horizontal position to a point that is nearly vertical, providing an open channel of unlimited height for marine traffic (see Figure 16.2.7).

Figure 16.2.7 Bascule Bridge in the Open Position

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

A counterweight is necessary to hold the raised leaf in position. In older bridges, the counterweight is usually overhead, while in more modern bascule bridges, the counterweight is placed below the deck and lowers into a pit as the bridge is opened.

The leaf lifts up by rotating vertically about a horizontal axis. The weight of the counterweight is adjusted by removing or adding balance blocks in pockets to position the center of gravity of the moving leaf at the center of rotation. When the bridge is closed, a forward bearing support located in front of the axis is engaged and takes the live load reaction. On double-leaf bascule bridges, a tail-lock behind the axis and a shear lock at the junction of the two leaves are also engaged to stiffen the deck.

There are many types of bascule bridges, but the most common are the following three types:

- Rolling lift (Scherzer) bridge
- Simple trunnion (Chicago) bridge
- Multi-trunnion (Strauss) bridge

Rolling Lift (Scherzer) Bridge

The first rolling lift bridge was completed in 1895 in Chicago, and was designed by William Scherzer. The entire moving leaf, including the front arm with the roadway over the channel and the rear arm with the counterweight, rolls away from the channel while the moving leaf rotates open (see Figures 16.2.8 and 16.2.9). On this type of bridge, curved tracks are attached to each side of the tail end of the leaf. The curved tracks roll on flat, horizontal tracks mounted on the pier. Square or oblong holes are machined into the curved tracks. The horizontal tracks have lugs (or teeth) to mesh with the holes preventing slippage as the leaf rolls back on circular castings whose centerline of roll is also the center of gravity of the moving leaf.

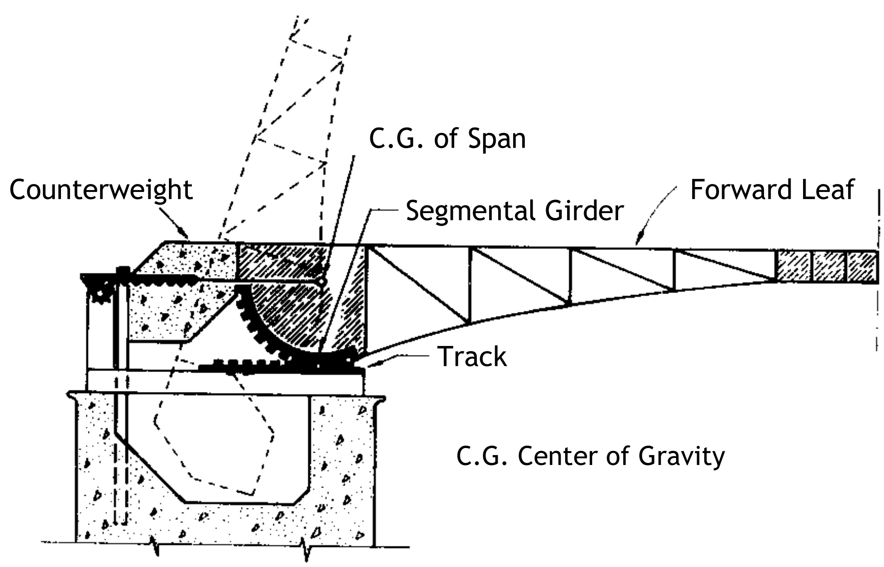

Figure 16.2.8 Rolling Lift Bascule Bridge Schematic

Figure 16.2.9 Double-Leaf Rolling Lift Bascule

The simple principal of this type of bridge can be seen easiest with a railroad bridge. The dead load of the bridge is balanced about the centerline of the drive pinion (center of roll). The pinion teeth are engaged with the teeth on the rack casting. When the pinion turns it moves along on the fixed rack and causes the span to rotate on the circular tread casting as it rolls back on the track casting.

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

On one variation of this type, the trusses on the two leaves acted as three-hinged arches when closed. Locks are engaged in the closed position, allowing the bridge to function as a simple span. In the open position, the leaves operate as a cantilever span. There is a 310 feet span between the centerline of bearings. This bridge was built across the Tennessee River at Chattanooga in 1915, and it is believed to be the third longest double-leaf bascule in the world. It provides an 295 foot channel, which is the widest channel spanned by a bascule bridge.

Simple Trunnion (Chicago) Bridge

The Chicago Bridge Department staff of Engineers built the first Chicago type simple trunnion bascule bridge in 1902. This type of bascule bridge consists of a forward cantilever arm out over the channel and a rear counterweight arm (see Figure 16.2.10). The leaf rotates about the trunnions. Each trunnion is supported on two bearings, which in turn, are supported on the fixed portion of the bridge such as trunnion cross-girder, steel columns, or on the pier itself (see Figures 16.2.11, 16.2.12 and 16.2.13). Forward bearing supports located in front of the trunnions are engaged when the leaf reaches the fully closed position. They are intended to support only live load reaction. Uplift supports are located behind the trunnions to take uplift until the forward supports are in contact (if misadjusted) and to take the live load uplift that exceeds the dead load reaction at the trunnions. If no forward live load supports are provided or if they are grossly misadjusted, the live load and the reaction at the uplift supports are added to the load on the trunnions. A double-leaf bascule bridge of this type in Lorain, Ohio has 333 feet between trunnions. Of the three types of movable bridges, the simple trunnion is by far the most popular.

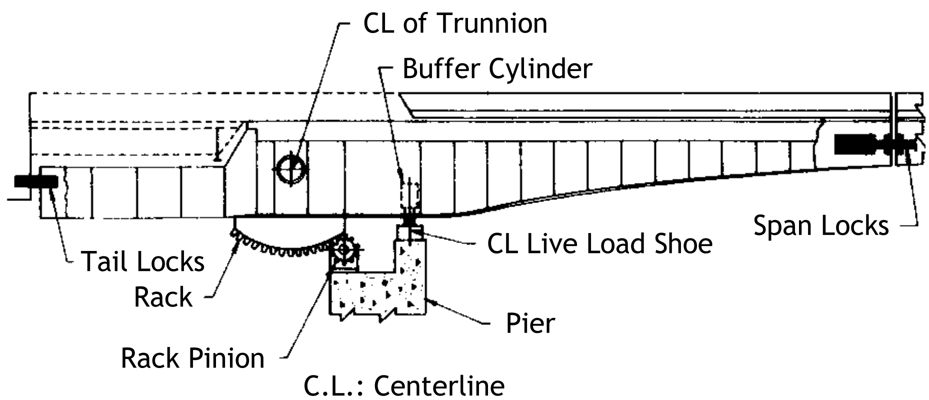

Figure 16.2.10 Trunnion Bascule Bridge Schematic

Figure 16.2.11 Double-Leaf Trunnion Bascule Bridge

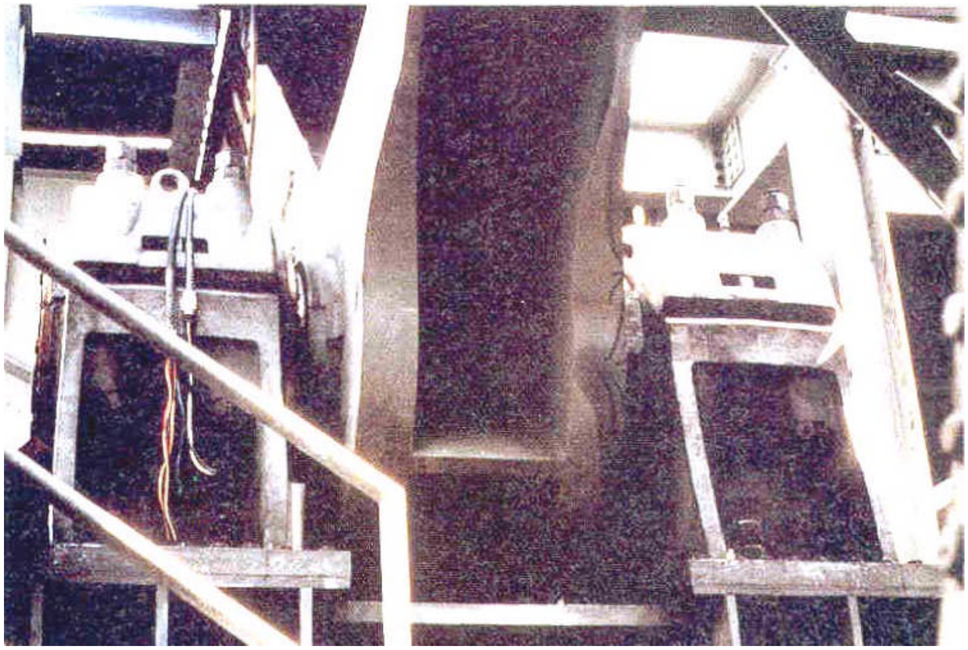

Figure 16.2.12 Each Trunnion is Supported on Two Bearings

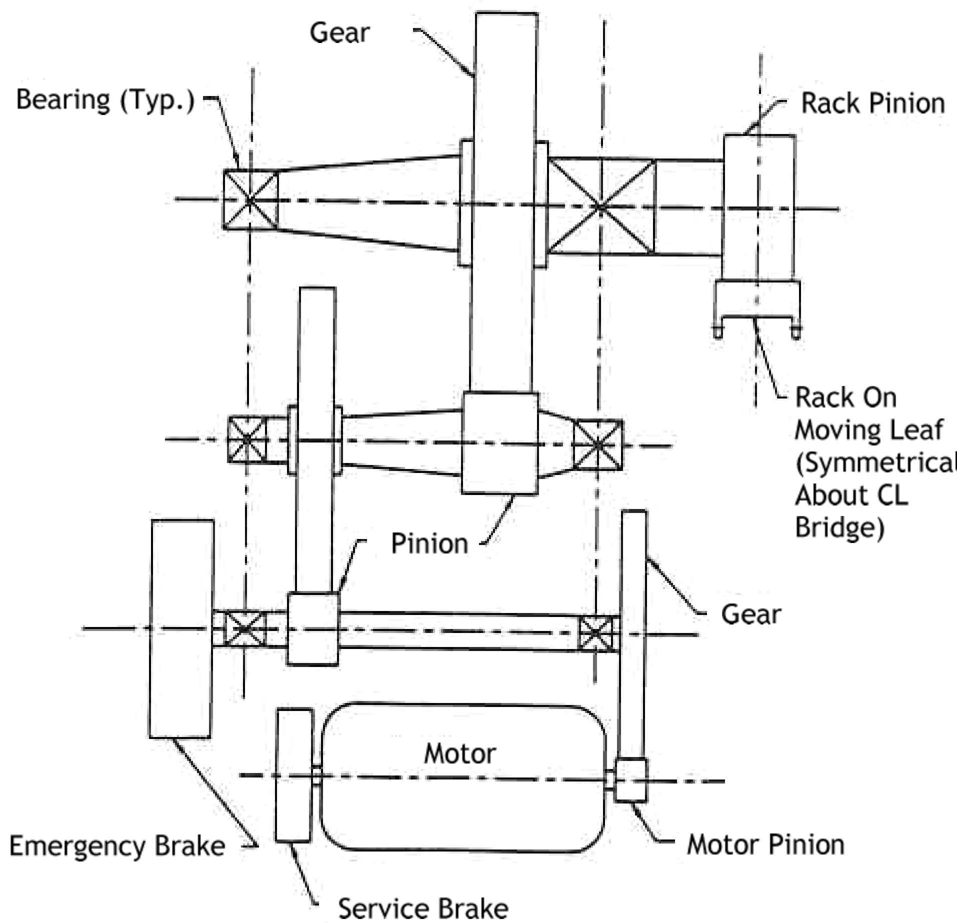

Figure 16.2.13 Trunnion Bascule Bridge Machinery (One Quarter Shown) is Located Outside of the Bascule Trusses on the Pier

Multi-Trunnion (Strauss Bridge)

The first multi-trunnion (Strauss) bascule bridge was designed by J.B. Strauss and completed during 1905 in Cleveland, Ohio. There are many variations of multi-trunnion bascule bridges, but basically one trunnion supports the moving span, one trunnion supports the counterweight, and two link pins are used to form the four corners of a parallelogram-shaped frame that changes angles as the bridge is operated. The counterweight link keeps the counterweight hanging vertically from the counterweight trunnions while the moving leaf rotates about the main trunnions (see Figure 16.2.14). One variation of this parallelogram layout is the heel trunnion. A double-leaf bascule bridge of this type in Sault St. Marie, Michigan has 336 feet between the span trunnions. It was built across the approach to a lock in 1914, and it is believed to be the longest double-leaf bascule in the world.

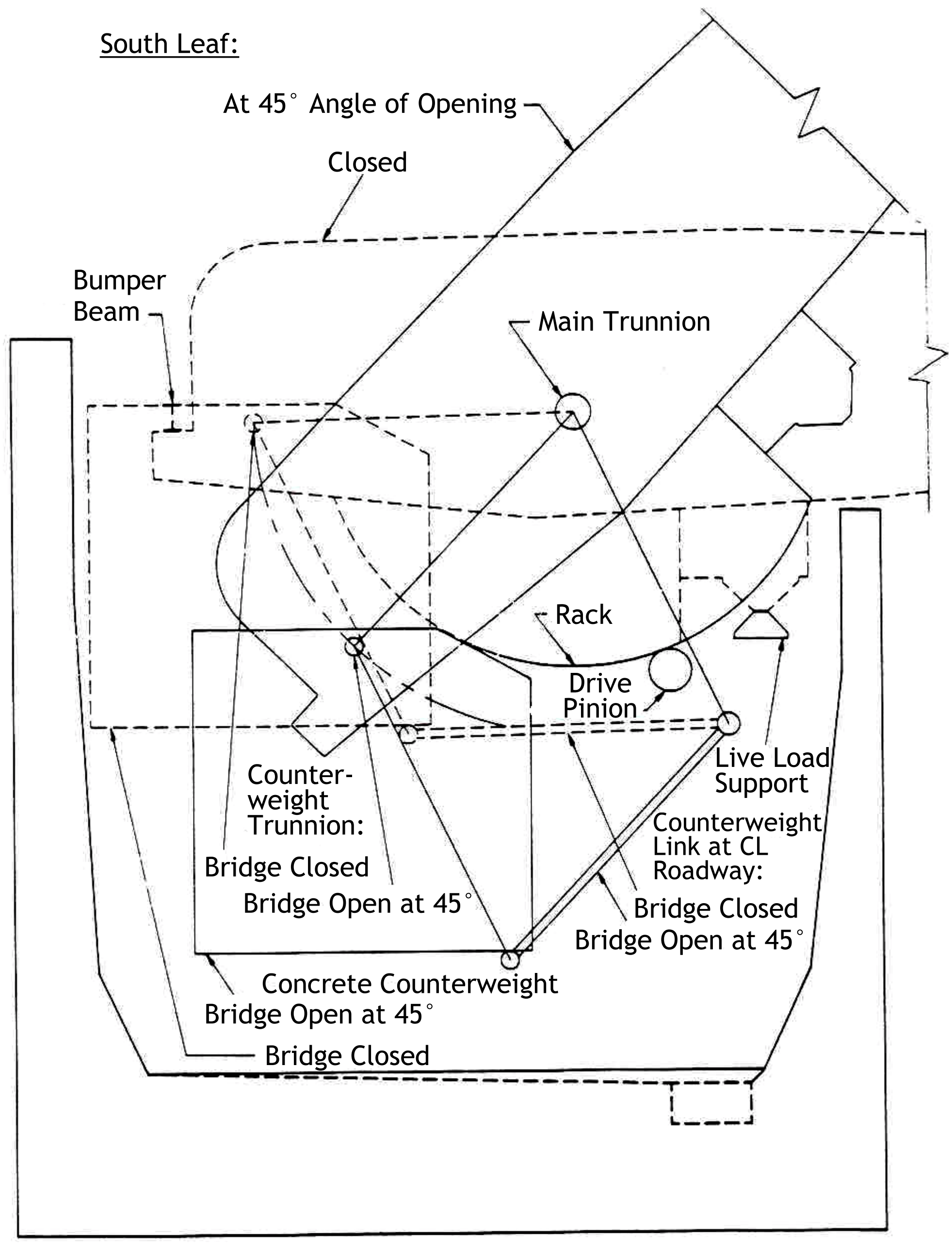

Figure 16.2.14 Multi-Trunnion, Strauss Type Bascule Bridge

16.2.4 Vertical Lift Bridges Design Characteristics

Vertical lift movable bridges have a movable span with a fixed tower at each end. The span is supported by steel wire ropes at its four corners. The ropes pass over sheaves (pulleys) atop the towers and connect to counterweights on the other side. The counterweights descend as the span ascends (see Figure 16.2.15).

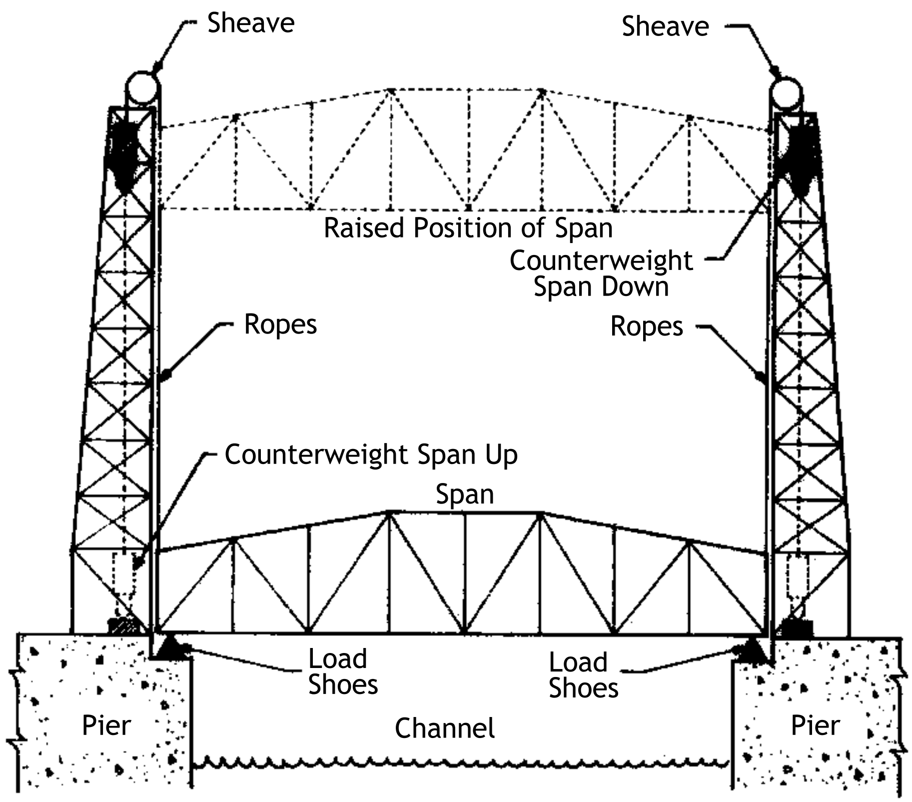

Figure 16.2.15 Vertical Lift Bridge Schematic

There are two basic types of vertical lift bridges:

- Power and drive system on lift span
- Power and drive system on towers

Power and Drive System on Lift Span

The first vertical lift bridge completed during 1894 in Chicago was designed by J.A.L. Waddell. This bridge type locates the power on top of the lift truss span. The actual lifting is accomplished using “up-haul and down-haul ropes” where turning drums wind the up-haul (lifting) ropes as they simultaneously unwind the down-haul ropes. Vertical lift bridge machinery is located on top of the lift truss span, and the operating drums rotate to wind the up-haul (lifting) ropes as they simultaneously unwind the down-haul ropes (see Figure 16.2.16). A variation of this type provides drive pinions at both ends of the lift span which engage racks on the towers.

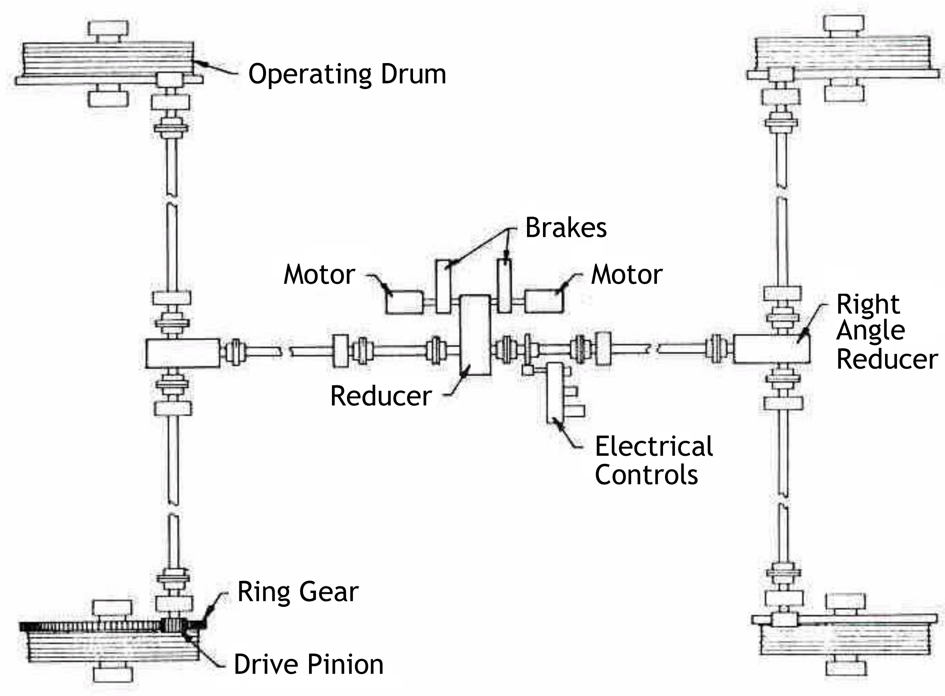

Figure 16.2.16 Vertical Lift Bridge Machinery is Located on Top of the Lift Truss Span, and the Operating Drums Rotate to Wind the Up-Haul (Lifting) Ropes as They Simultaneously Unwind the Down-Haul Ropes

Power and Drive System on Towers

The other basic type of vertical lift bridge locates the power on top of both towers, where drive pinions operate against circular racks on the sheaves. The lifting speed at both towers must be synchronized to keep the span horizontal as it is lifted (see Figures 16.2.17 and 16.2.18).

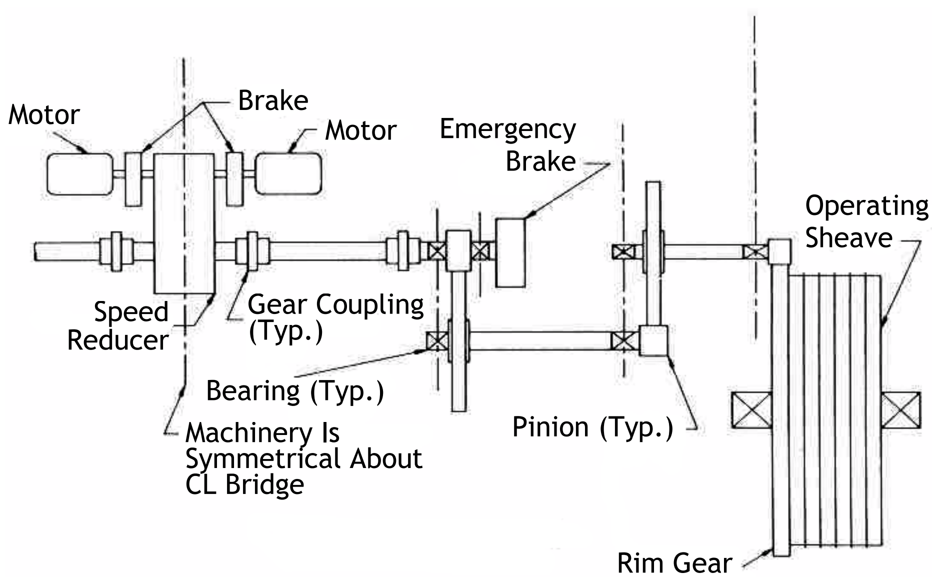

Figure 16.2.17 Vertical Lift Bridge Machinery is Located on the Towers, and the Rim Gears (and Operating Sheaves) are Rotated to Raise and Lower the Bridge

Figure 16.2.18 Vertical Lift Bridge with Power and Drive System on Towers

16.2.5 Special Elements Common to All Movable Bridges

Give particular attention to the special elements found in swing bridges, bascule bridges, and vertical lift bridges during inspection. These elements are commonly found on all types of movable bridges:

- Open Gearing
- Speed Reducers Including Differentials
- Shafts and Couplings
- Bearings
- Brakes
- Drives
- Air Buffers and Shock Absorbers
- Span Locks
- Counterweights
- Live Load shoes and Strike Plates
- Traffic Barriers

Open Gearing

Open gearing is used to transmit power from one shaft to another and to alter the speed and torque output of the machinery. Beveled gears are also used to change direction (see Figure 16.2.19).

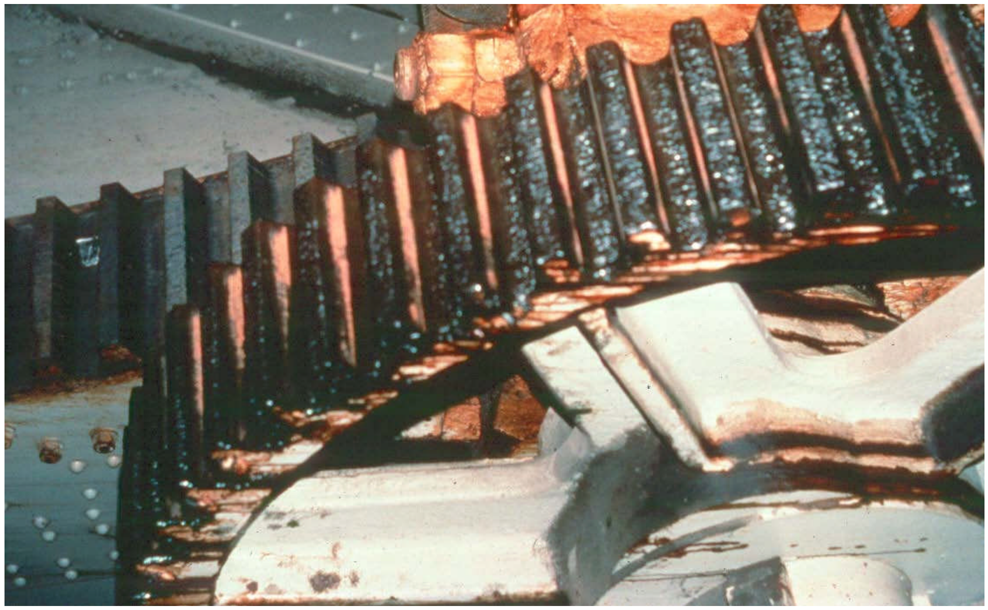

Figure 16.2.19 Open Gearing

Speed Reducers Including Differentials

Speed reducers including differentials serve the same function as open gearing (see Figure 16.2.20). However, they may contain several gear sets, bearings, and shafts to provide a compact packaged unit, which protects its own mechanical elements and lubrication system with an enclosed housing. Differential speed reducers also function to equalize torque and speed from one side of the mechanical operating system to the other.

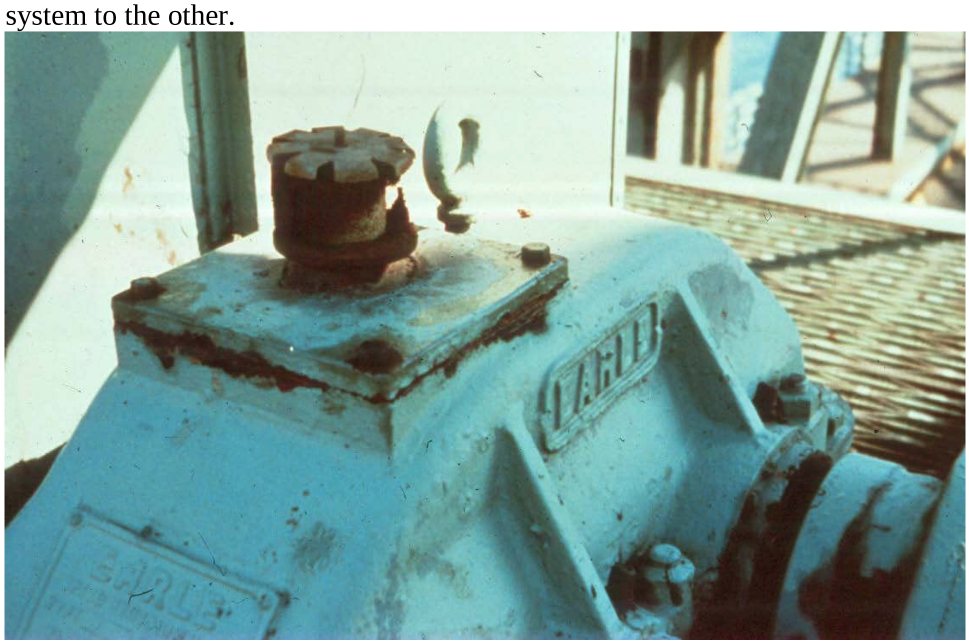

Figure 16.2.20 Speed Reducer

Shafts and Couplings

Shafts transmit mechanical power from one part of the machinery system to another. Couplings transmit power between the ends of shafts in line with one another, and several types can be used to compensate for slight imperfections in alignment between the shafts (see Figure 16.2.21).

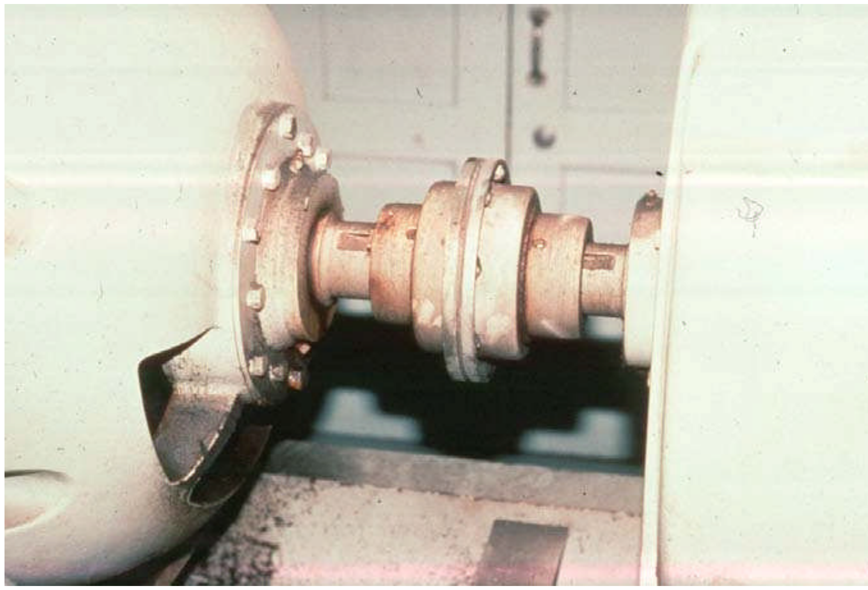

Figure 16.2.21 Coupling

Bearings

Bearings provide support and prevent misalignment of rotating shafts, trunnions, and pins (see Figure 16.2.22).

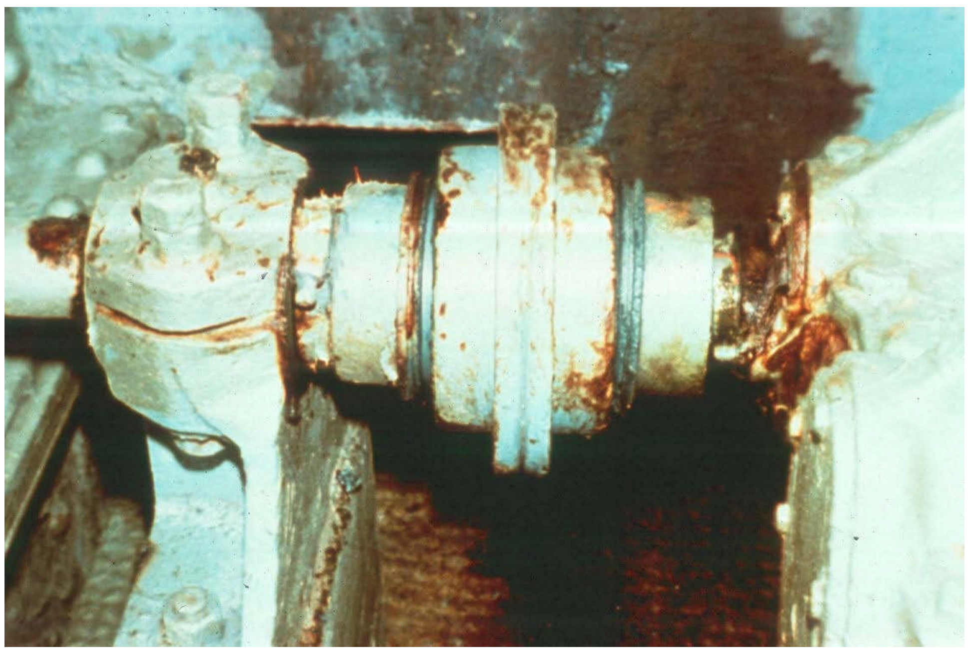

Figure 16.2.22 Bearing

Brakes

Brakes can be of either the shoe type or disc type, and can be released manually, electrically, or hydraulically (see Figures 16.2.23 and 16.2.24). They are generally spring applied for fail safe operation. Motor brakes are located close to the drive to provide dynamic braking capacity, except that some types of drives can provide their own braking capability, thereby eliminating the need for separate motor brakes. Machinery brakes are located closer to the operating interface between movable and fixed parts of the bridge and are used to hold the span statically, in addition to serving as emergency brakes in many cases. Supplemental emergency brakes are sometimes also provided.

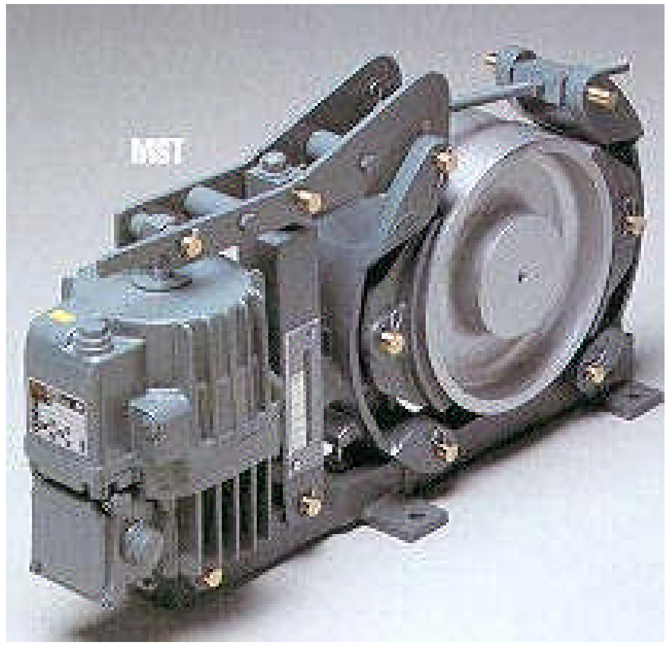

Figure 16.2.23 Shoe Type Break

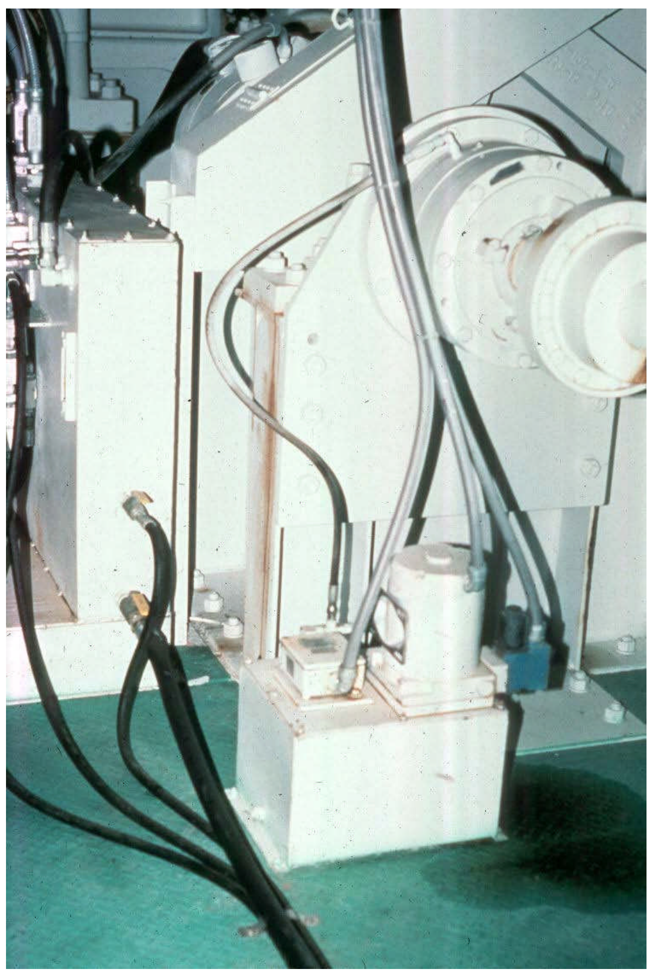

Figure 16.2.24 Spring Set Hydraulically Released Disc Break

Drives

Drives can consist of electric motors, hydraulic equipment, or auxiliary drives.

For electric motors, either AC or DC power may be used. AC power is often used to power wound rotor motors with torque controllers on older bridges, while new bridges may utilize squirrel cage induction motors with adjustable frequency speed control. DC motors can also provide speed control.

For hydraulic equipment, prime movers may include either large actuating cylinders or hydraulic motors (see Figure 16.2.25). Either type of drive must be supplied with pressure to provide force and fluid flow to provide speed to the operating system. Electrically operated hydraulic power units consisting of a reservoir and pump, with controls, provide power to the operating systems.

For auxiliary drives, emergency generators are provided to serve in the event of power failure. Auxiliary motors and hand operators, with their clutches and other mechanical power transmission components, are provided to serve in the event the main drive fails (see Figure 16.2.26). In some cases, to prevent the need for larger auxiliary generators, the auxiliary motors are required for use any time the auxiliary generators are used, requiring increased time of operation.

Figure 16.2.25 Low Speed High Torque Hydraulic Motor

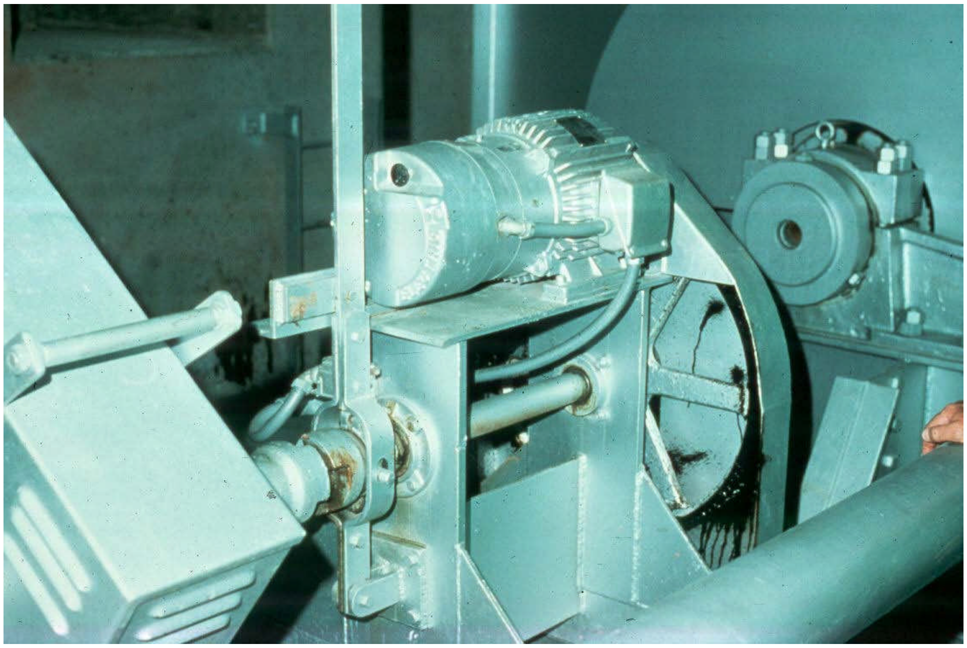

Figure 16.2.26 AC Emergency Motor

Air Buffers and Shock Absorbers

Air buffers and shock absorbers are located between the span and the pier at points where impact may occur between the two (see Figures 16.2.27 and 16.2.28). A cross section of the buffer shows the air chamber and seals on the piston. As the span lowers, the rod is pushed in, causing the air inside to be compressed (see Figure 16.2.29). A pressure relief valve allows the air to escape beyond the pressure setting. Forces are required to build-up and keep the pressure of the air at the movement of the span for a “soft” touchdown on the bearings. Shock absorbers provide the same purpose as the air buffers. However, they are completely self-contained and, therefore, require very little maintenance.

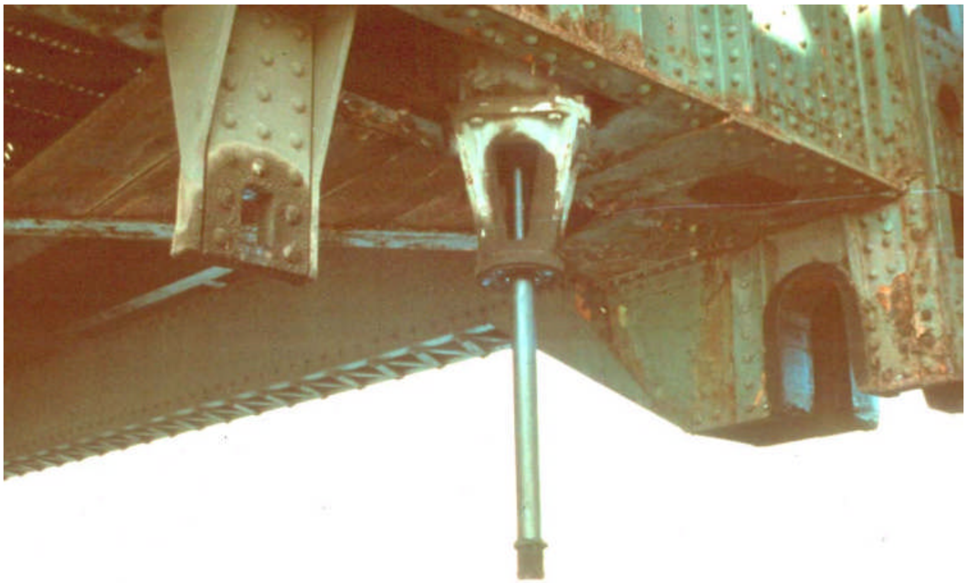

Figure 16.2.27 Air Buffer

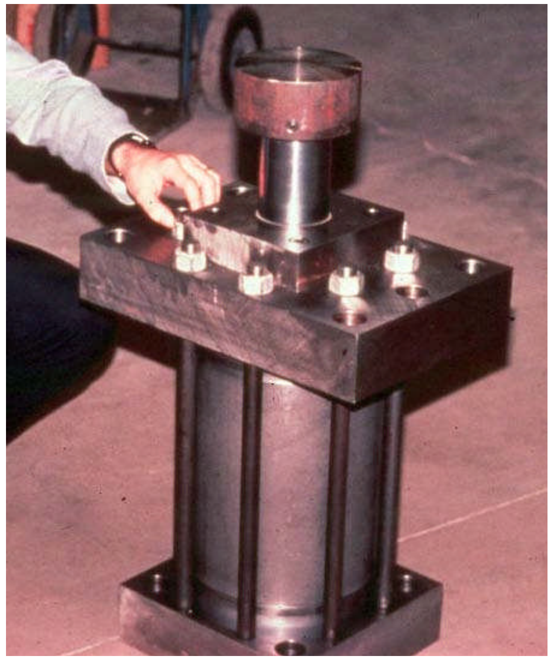

Figure 16.2.28 Shock Absorber

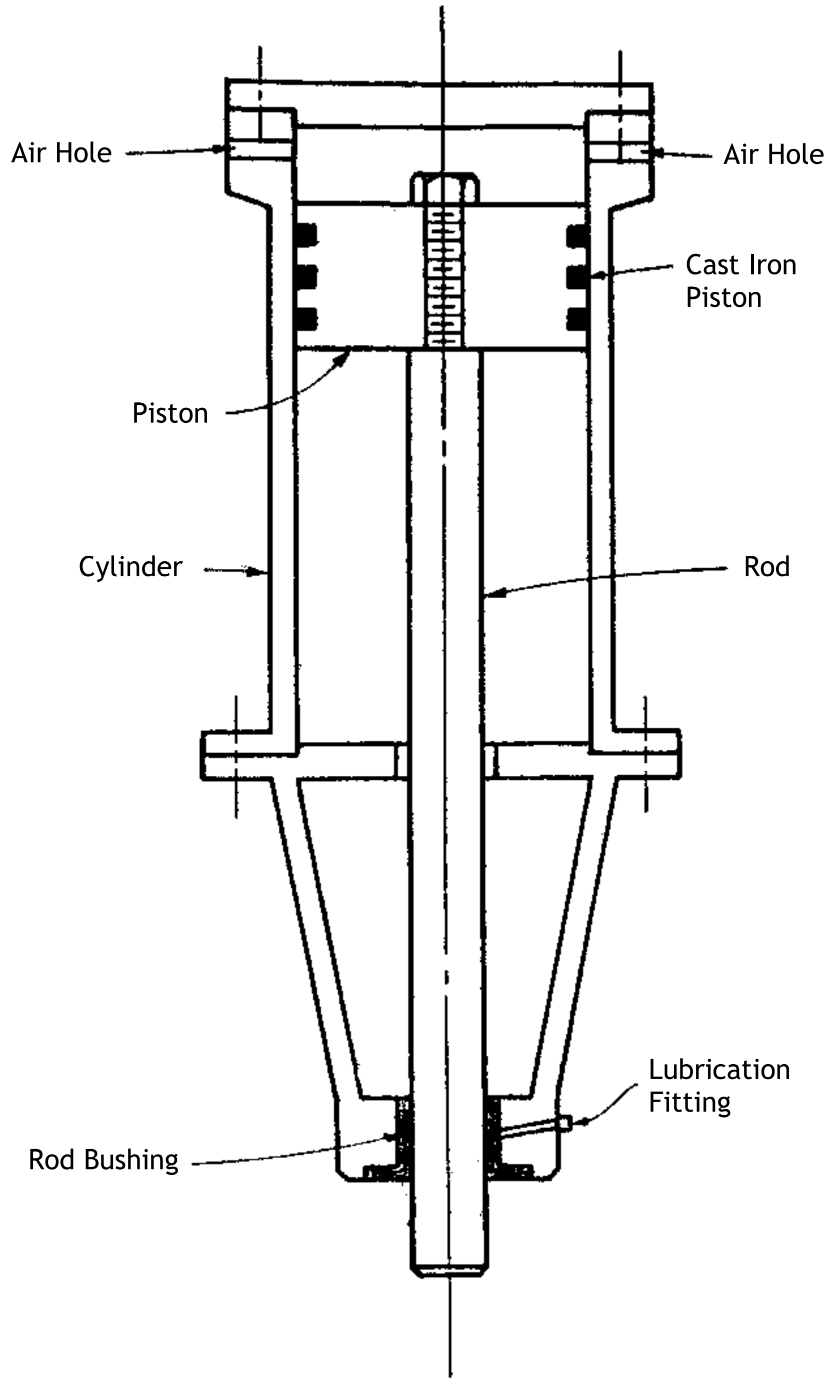

Figure 16.2.29 Typical Air Buffer Schematic

Span Locks

Span lock bars at the end of the span are driven when the span is fully closed to prevent movement under live load. Span locks may also be provided at other locations on the span to hold the span in an open position against strong winds or to prevent movement from an intermediate position. They can be driven either mechanically or hydraulically (see Figures 16.2.30 and 16.2.31).

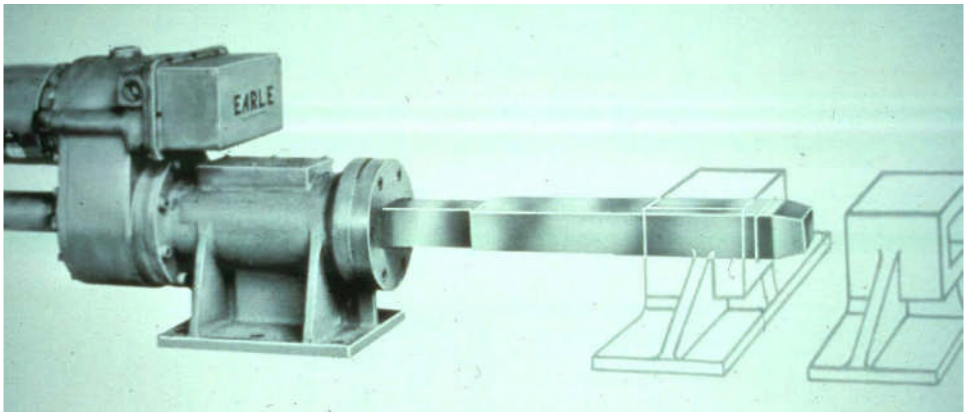

Figure 16.2.30 Typical Mechanically Operated Span Lock

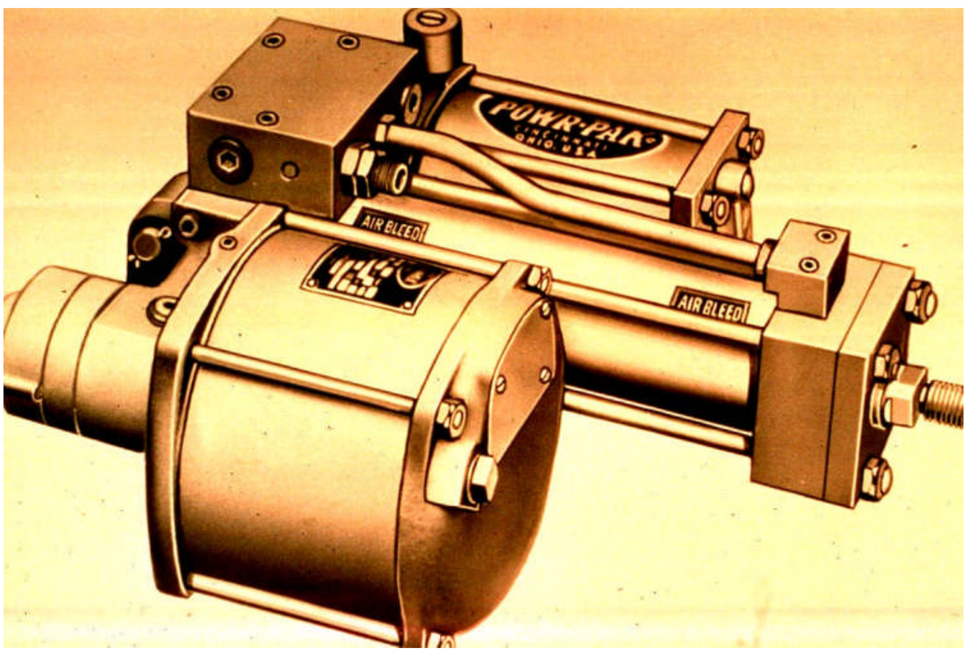

Figure 16.2.31 Hydraulic Cylinder that Drives Lock Bars

Counterweights

Adjustable quantities of counterweight blocks are provided in addition to the permanent counterweight, which is part of the structure so that adjustments may be made from time to time due to changes in conditions (see Figures 16.2.32 and 16.2.33). A movable span is designed to function in a balanced condition, and serious unbalanced conditions will cause overstress or even failure of the mechanical or structural elements.

Figure 16.2.32 Concrete Counterweight on a Single-Leaf Bascule Bridge

Figure 16.2.33 Concrete Counterweight on a Vertical Lift Bridge

Live Load Shoes and Strike Plates

Live load shoes and strike plates between the movable and fixed portions of the bridge are designed to bear most or all of the live load when the bridge is carrying traffic (see Figure 16.2.34).

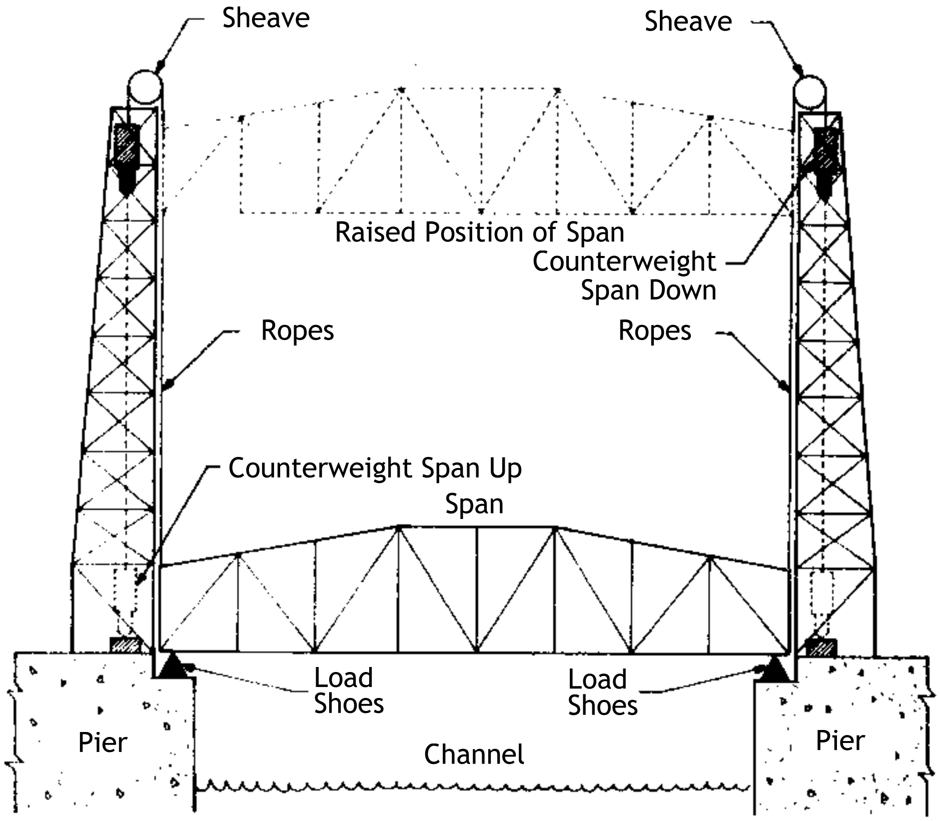

Figure 16.2.34 Closed Span Resting on Live Load Shoes

Traffic Barriers

Traffic barriers are heavy-duty movable gates or posts that are designed to prevent a vehicle from plunging from the roadway into the draw or into the pit below the bridge (see Figure 16.2.35. Their operation is important for public safety. They are used mainly in situations where a large opening exists between the approach span and the movable span when it is open.

Figure 16.2.35 Traffic Barrier

16.2.6 Swing Bridge Special Elements

Swing bridges are designed utilizing the following special elements:

- Pivot Bearings
- Balance Wheels
- Rim-Bearing Rollers
- Wedges
- End Latches

Pivot Bearings

In center-bearing types (with balance wheels), the axially loaded thrust bearing is usually composed of spherical discs, attached to top and bottom bases, enclosed in an oil box to provide lubrication and prevent contamination (see Figure 16.2.36). In rim-bearing types, the pivot bearing is also enclosed but will be radial loaded, maintaining the position of the pivot shaft or king pin.

Figure 16.2.36 Center Pivot Bearing

Balance Wheels

On center-bearing types only, non-tapered balance wheels bear on the circular rail concentric to the pivot bearing only when the span is subjected to unbalanced loading conditions (see Figure 16.2.37). At other times, when the span is not subjected to unbalanced loads, a gap will be present between each wheel and the rail.

Figure 16.2.37 Balance Wheel in-place over Circular Rack

Rim-Bearing Rollers

Usually tapered to allow for the differential rolling distance between the inside and outside circumferences of the rail circle, rim-bearing rollers usually bear at all times.

Wedges

End wedges are used to raise the ends of the span and support live load under traffic (see Figure 16.2.38). The end wedge bearings are under all four corners of the span. Center wedges are used to stabilize the center of the span and to prevent the center bearing from supporting live load. Wedges may be actuated by machinery and linkage, which connects wedges to actuate together or each wedge may have its own actuator (see Figure 16.2.39).

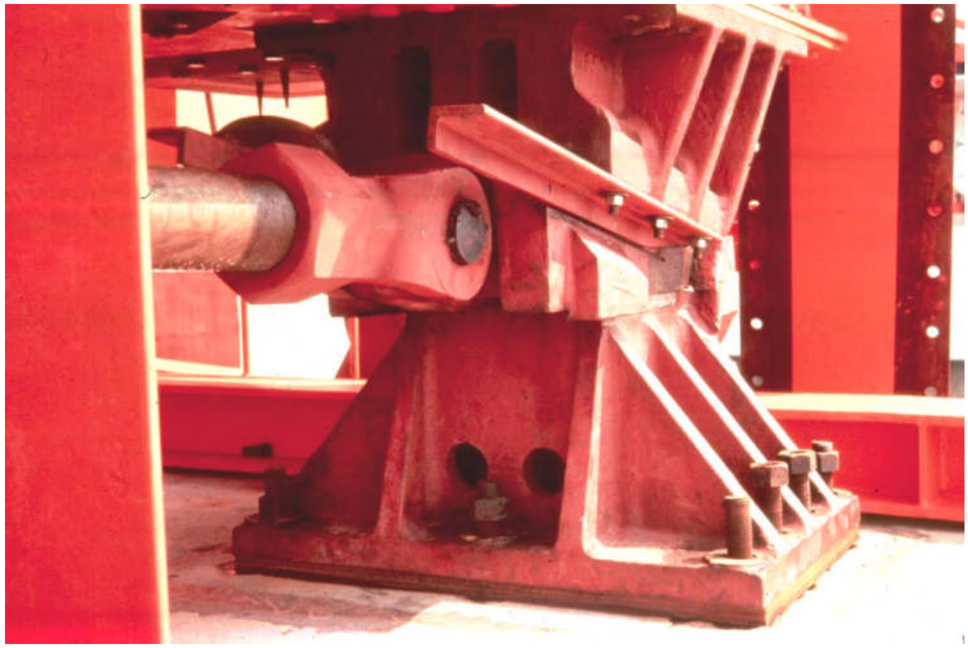

Figure 16.2.38 End Wedge

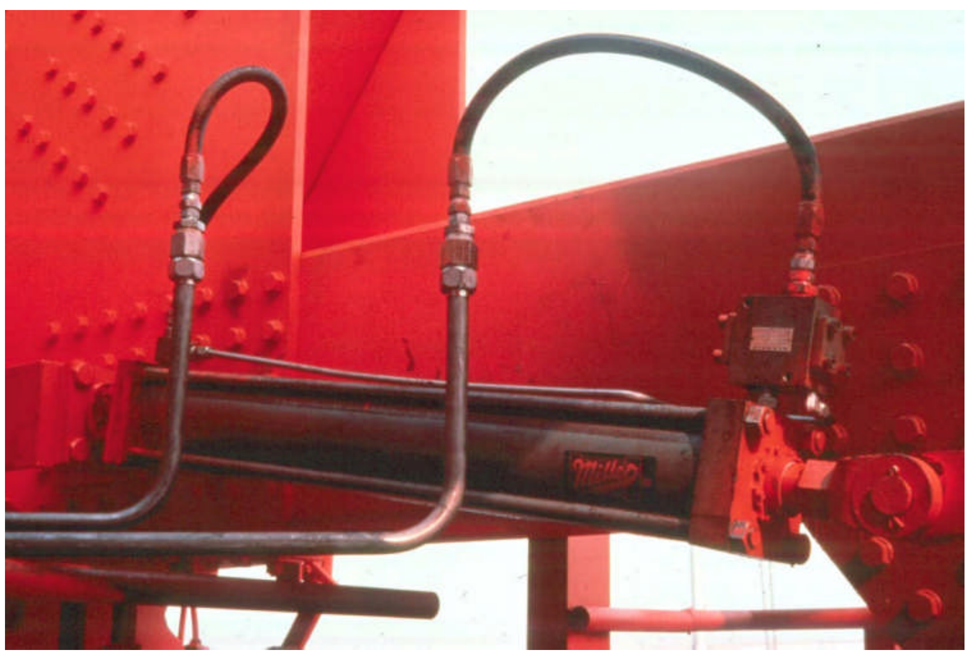

Figure 16.2.39 Hydraulic Cylinder Actuator

End Latches

Located at the center of one or both rest piers, end latches generally consist of a guided tongue with roller mounted on the movable span that occupies a pocket mounted on the rest pier when the span is in the closed position. To open the span, the tongue is lifted until it clears the pocket at the time the wedges are withdrawn (see Figure 16.2.40). As the span is swung open, the latch tongue is allowed to lower or fall into a position in which the roller may follow along a rail or track mounted on the pier. When closing, the tongue rolls along the rail or track and up a ramp which leads to the end latch pocket where the tongue is allowed to drop to center the span.

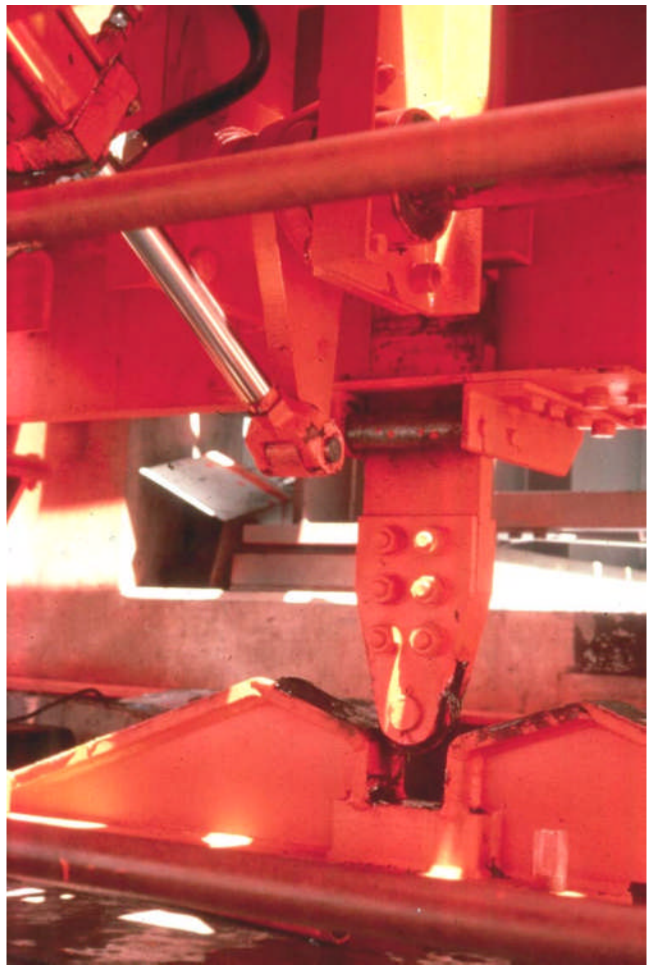

Figure 16.2.40 End Wedges Withdrawn and End Latch Lifted

16.2.7 Bascule Bridge Special Elements

Bascule bridges utilize the following elements specific to their design:

- Rolling Lift Tread and Track Castings
- Racks and Pinions
- Trunnions and Trunnion Bearings
- Hopkins Frame
- Tail (Rear) Locks
- Center Locks
- Transverse Locks

Rolling Lift Tread and Track Castings

Rolling lift tread and track castings are rolling surfaces which support the bascule leaves as they roll open or closed (see Figure 16.2.41). Tread sockets and track teeth prevent transverse and lateral movement of the span due to unbalanced conditions, such as wind, during operation and especially when held in the open position.

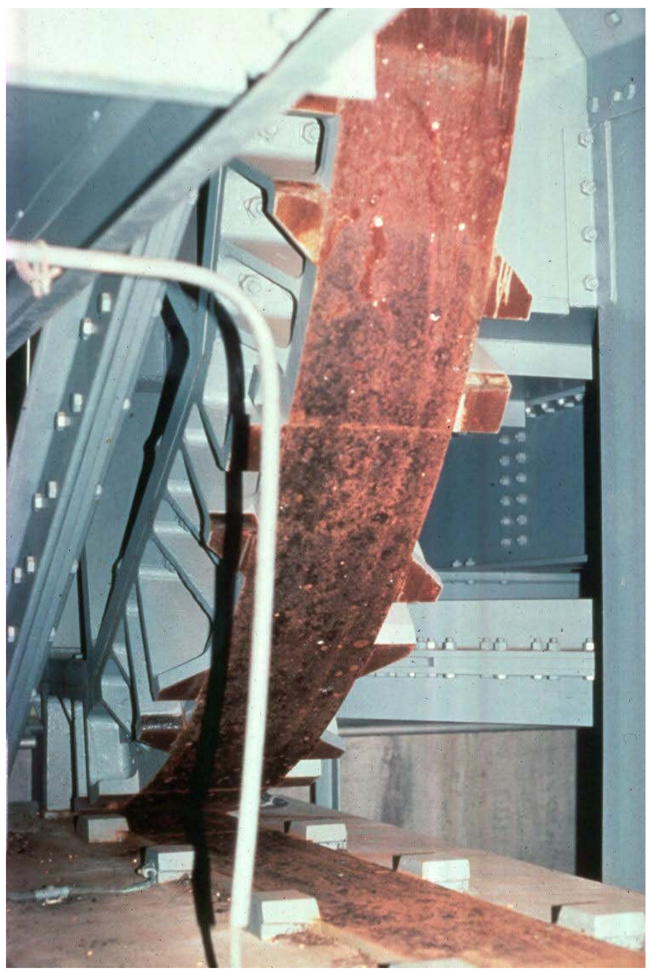

Figure 16.2.41 Circular Lift Tread and Track Castings

Racks and Pinions

In the rolling lift rack and pinion, the driving pinion engages the rack teeth at the centerline of the roll (see Figure 16.2.42).

In the trunnion rack and pinion, the circular rack castings are attached in the plane of the truss (or girder) in front of the counterweight (see Figures 16.2.43 and 16.2.44).

The drive pinions are overhung in order to engage the rack teeth. A cover is placed over the pinions for safety and to keep debris from falling on it.

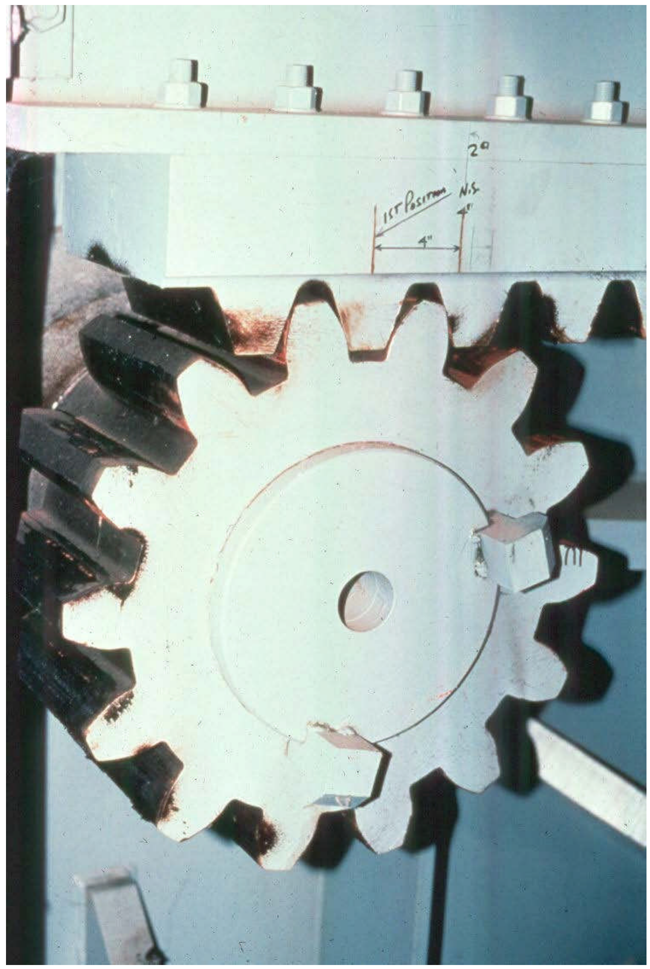

Figure 16.2.42 Rack Casting and Pinion

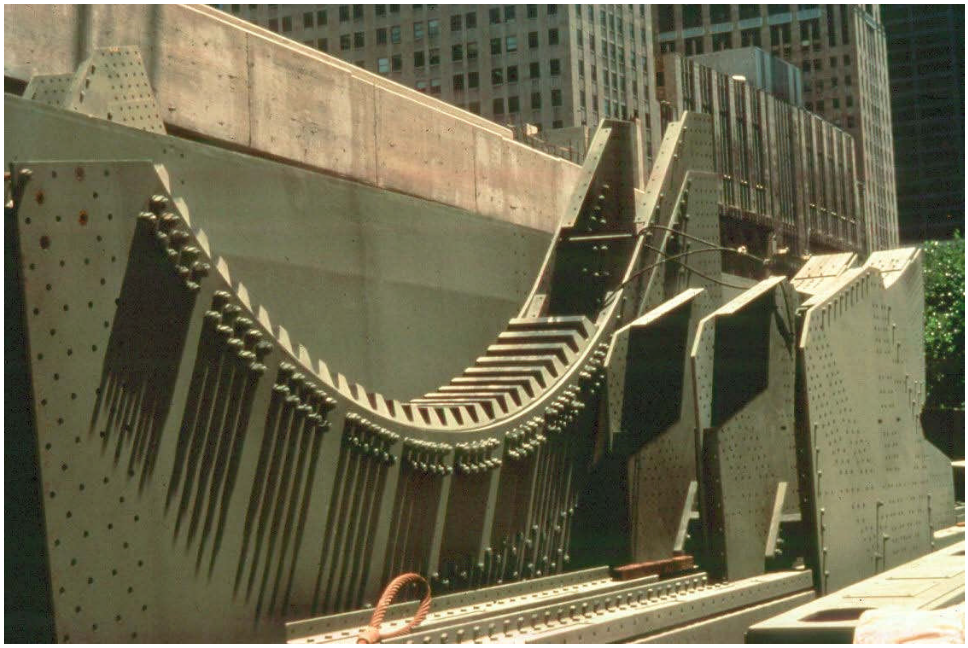

Figure 16.2.43 Rack Casting Ready for Fabrication

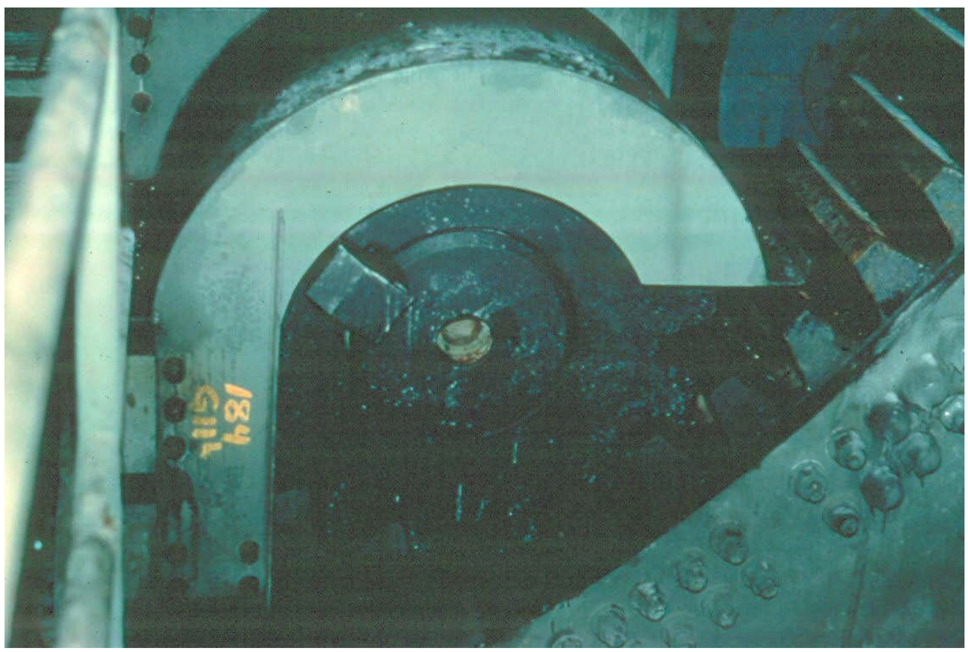

Figure 16.2.44 Drive Pinion

Trunnions and Trunnion Bearings

Trunnions and trunnion bearings (see Figure 16.2.45) are large pivot pins or shafts. Their bearings support the leaf as it rotates during operation as well as supporting dead load when the bridge is closed. Some designs require the trunnions to carry live load in addition to dead load (see Figure 16.2.46).

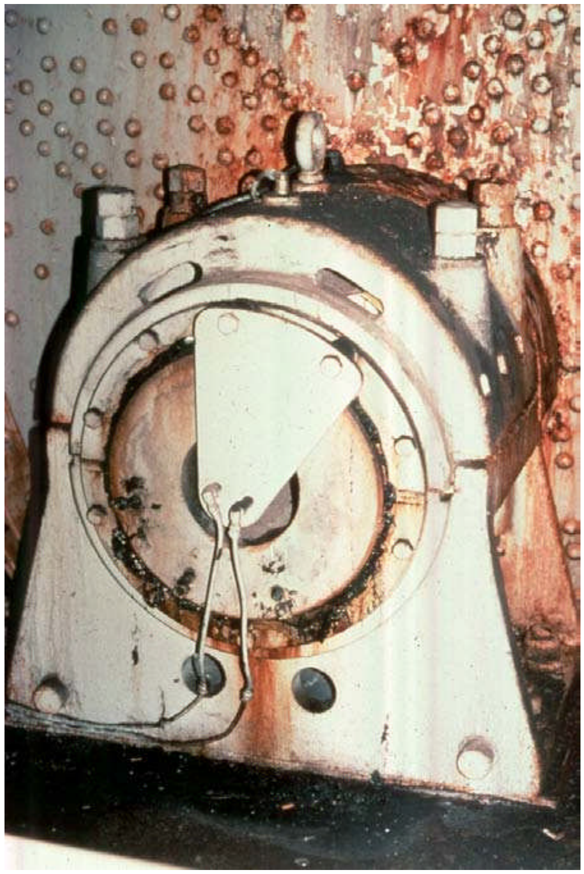

Figure 16.2.45 Trunnion Bearing

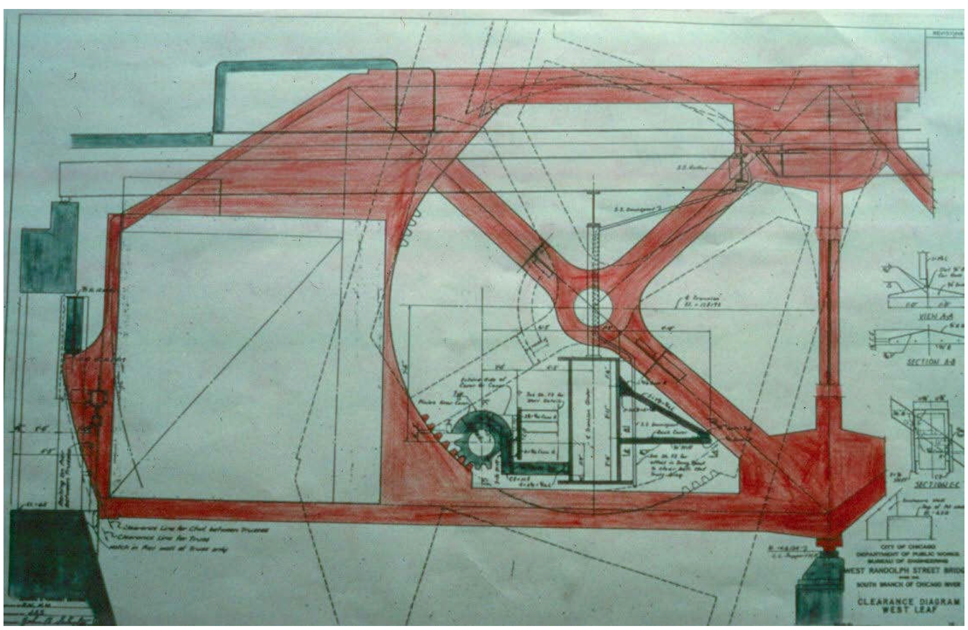

Figure 16.2.46 Trunnion Design Drawing

Hopkins Frame

A Hopkins frame machinery arrangement is provided on some trunnion bascule bridges. The main drive pinion locations are established in relationship to their circular racks by a pivot point on the pier and pinned links attached to the trunnions.

Tail (Rear) Locks

Located at the rear of the bascule girder on the pier, tail locks prevent inadvertent opening of the span under traffic or under a counterweight-heavy condition if the brakes fail or are released (see Figure 16.2.47).

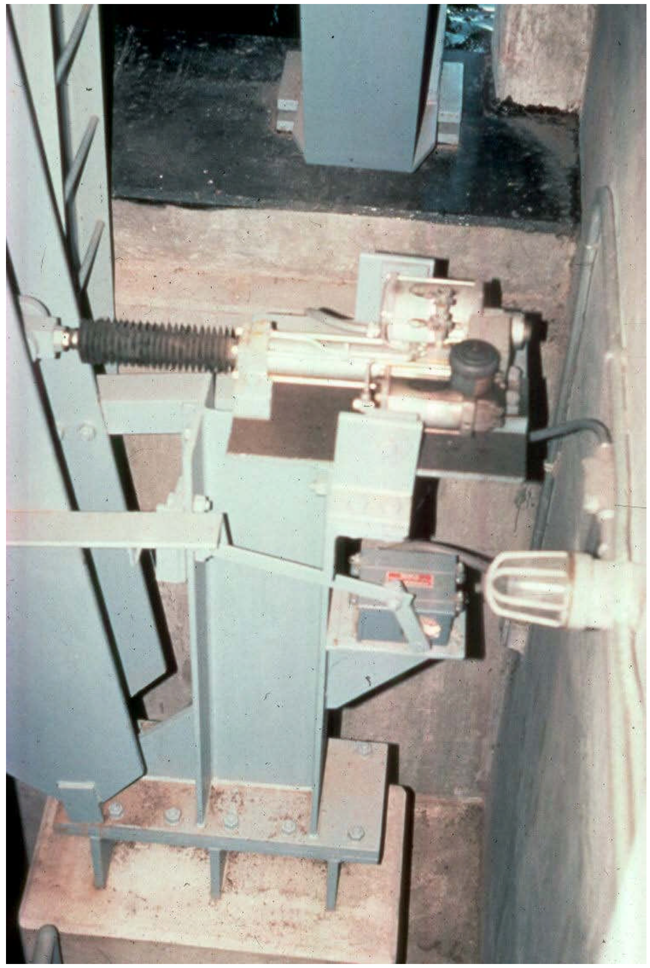

Figure 16.2.47 Rear Lock Assembly

Center Locks

Center locks are provided to transfer shear load from one leaf to the other when the bridge is under traffic. Center locks may consist of a driven bar or jaw from one leaf engaging a socket on the other leaf, or may be a meshing fixed jaw and diaphragm arrangement with no moving parts (see Figure 16.2.48).

The superstructure acts as a cantilever when opening and closing the bridge with the maximum negative moment near the supporting piers and zero moment at the ends of the cantilever. Once the bridge is lowered into position, center locks are engaged. These locking mechanisms are designed to transmit shear necessary to produce equal deflections at mid point under unbalanced transient loads. These center locks are not normally designed to carry superstructure moment.

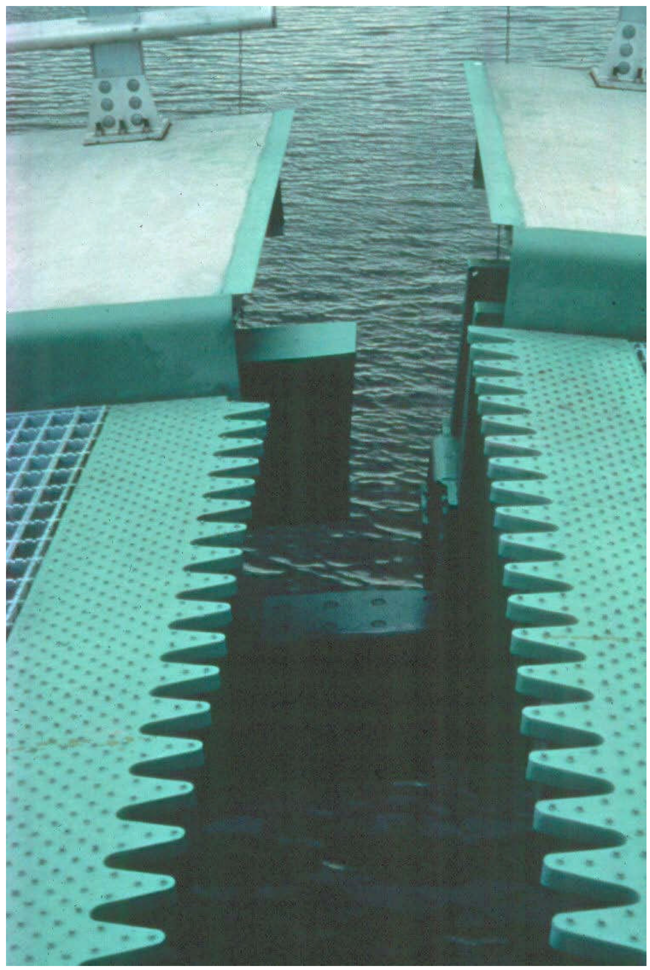

Figure 16.2.48 Center Lock Jaws

Transverse Locks

In twin bascule bridges that are split longitudinally to allow flexibility during construction, repair, or rehabilitation; transverse locks between the inside girders are used to keep the pairs together during operation (see Figure 16.2.49). These are usually operated manually, as they are not normally released for long periods of time.

Figure 16.2.49 Transverse Locks on Underside can be Disengaged

16.2.8 Vertical Lift Bridge Special Elements

Vertical lift bridges may utilize the following elements peculiar to their design:

- Wire Ropes and Sockets
- Drums, Pulleys, and Sheaves
- Span and Counterweight Guides
- Balance Chains
- Span Leveling Devices

Wire Ropes and Sockets

Wire ropes and sockets include up-haul and down-haul operating ropes and counterweight ropes (see Figures 16.2.50 and 16.2.51). Ropes consist of individual wires twisted into several strands that are wound about a steel core. Fittings secure the ends of the rope and allow adjustments to be made.

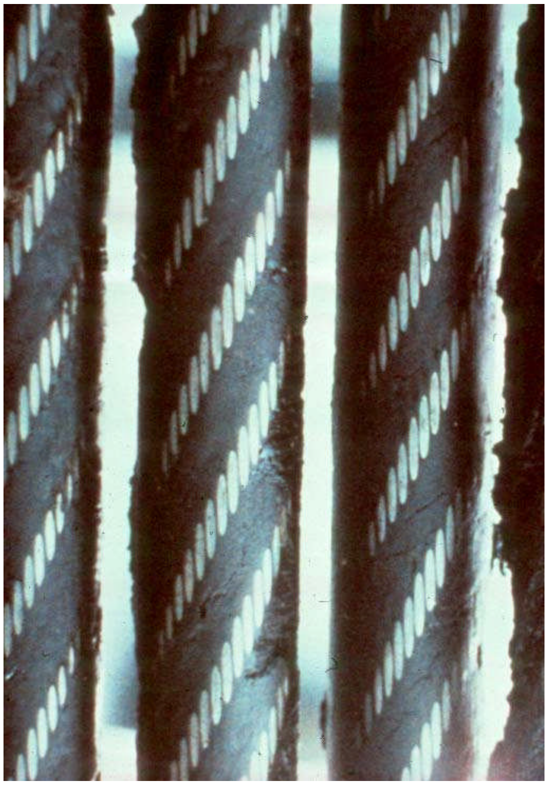

Figure 16.2.50 Wire Rope

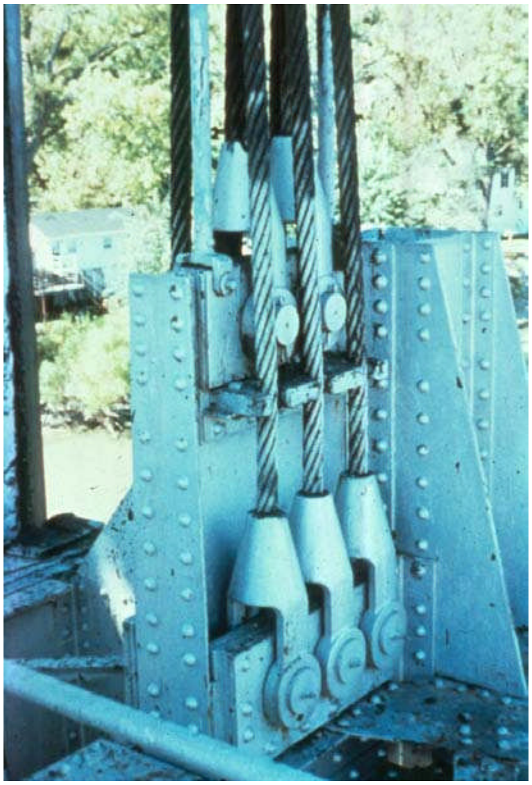

Figure 16.2.51 Wire Rope Sockets and Fittings

Drums, Pulleys, and Sheaves

Drums are used to wind a rope several times around to extend or retract portions of the bridge (see Figure 16.2.52). Pulleys and sheaves change the direction of the rope or guide it at intermediate points between ends of the rope.

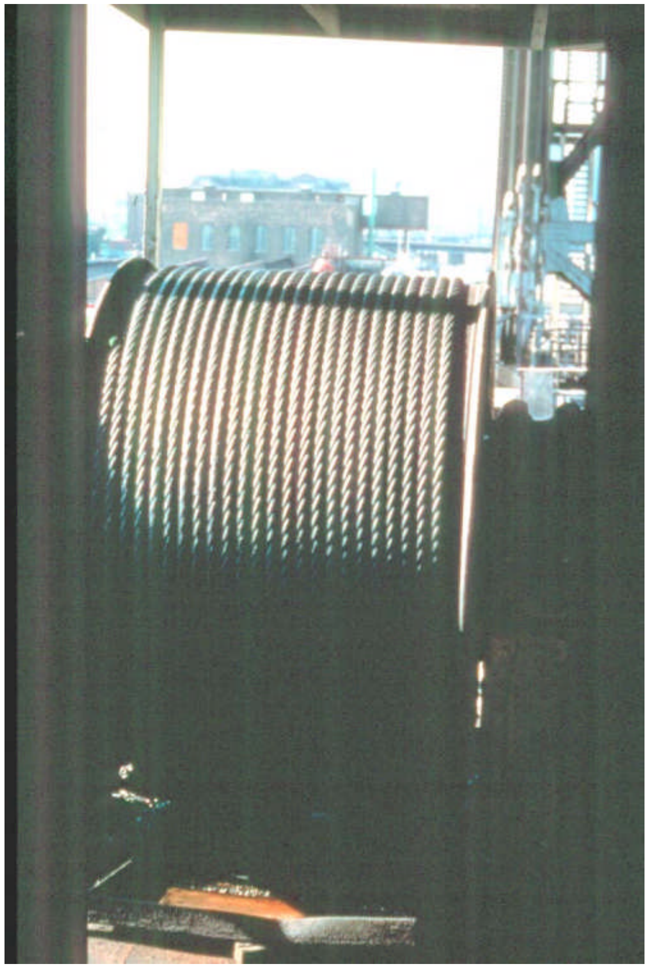

Figure 16.2.52 Drums Wind Up the Up-Haul (Lifting) Ropes as they Simultaneously Unwind the Down-Haul Ropes

Span and Counterweight Guides

Span and counterweight guides are located between tower and span or counterweight to prevent misalignment.

Balance Chains

Balance chains are provided to compensate for the weight of counterweight rope that travels from the span side to the counterweight side of the sheaves at the top of the tower as the span is raised. Weight of chain is removed from the counterweight and is supported by the tower as rope weight is increased on the counterweight side of the sheaves on the tower.

Span Leveling Devices

Mechanical or electrical, span leveling devices compensate and adjust the movement of the two ends of the span during operation to prevent unsynchronized movement.

16.2.9 Overview of Common Deficiencies

Steel

Common deficiencies that can occur to steel members of movable bridges include:

- Corrosion
- Fatigue cracking
- Overloads
- Collision damage
- Heat damage
- Paint failures

See to Topics 6.3.4 – 6.3.7 for a detailed presentation of the properties of steel, types and causes of steel deficiencies, and the examination of steel. Refer to Topic 6.4 for Fatigue and Fracture in Steel Bridges.

Concrete

Common deficiencies that occur to concrete members of movable bridges include:

- Cracking (structural, flexure, shear, crack size, nonstructural, crack orientation)
- Scaling
- Delamination
- Spalling
- Chloride contamination
- Freeze-thaw
- Efflorescence
- Alkali silica reactivity (ASR)
- Ettringite formation
- Honeycombs
- Pop-outs
- Wear
- Collision damage
- Abrasion
- Overload damage
- Internal steel corrosion
- Loss of prestress
- Carbonation

Refer to Topics 6.2.3 – 6.3.8 for a detailed explanation of the properties of concrete, types and causes of concrete deficiencies, and the examination of concrete.

16.2.10 Inspection Locations and Methods - Safety

Movable Bridge Inspector Safety

It is imperative that a movable bridge inspectors coordinate their work with the Bridge Operator and emphasize the need for advance warning of a bridge opening. The Bridge Operator cannot operate the bridge until being notified by all inspectors that they are ready for an opening. There are many ways that this can be accomplished, such as placing a warning note on the control console or opening the circuit breakers and locking the compartment to the equipment that they will be inspecting.

Inspection Considerations

Important considerations for a movable bridge inspector include observing and making comments in the inspection report on the following safety considerations.

Public Safety

Public safety considerations include good visibility of roadway and sidewalk for the Bridge Operator (see Figure 16.2.53), adequate time delay on traffic signals for driver reaction and before lowering gates, all "gates down" before raising bridge (bypass available if traffic signals are on), the bridge is closed before gates can be raised (bypass available if locks are driven), and traffic signals do not turn off until all gates are fully raised (bypass available).

Observe the location of the bridge opening in relation to the gates, traffic lights and bells, and determine whether approaching motorists can easily see them. Check their operation and physical condition to determine if they are functioning and well maintained. Recommend replacement when conditions warrant.

Unprotected approaches, such as both ends of a swing bridge and vertical lift bridge and the open end of a single-leaf bascule bridge, preferably have positive resistance barriers across the roadway, with flashing red lights as provided on the gate arms (see Figure 16.2.54). High-speed roadways and curved approaches to a movable bridge preferably have advanced warning lights (flashing yellow).

Figure 16.2.53 Operator's House with Clear View of Traffic Signals and Lane Gates

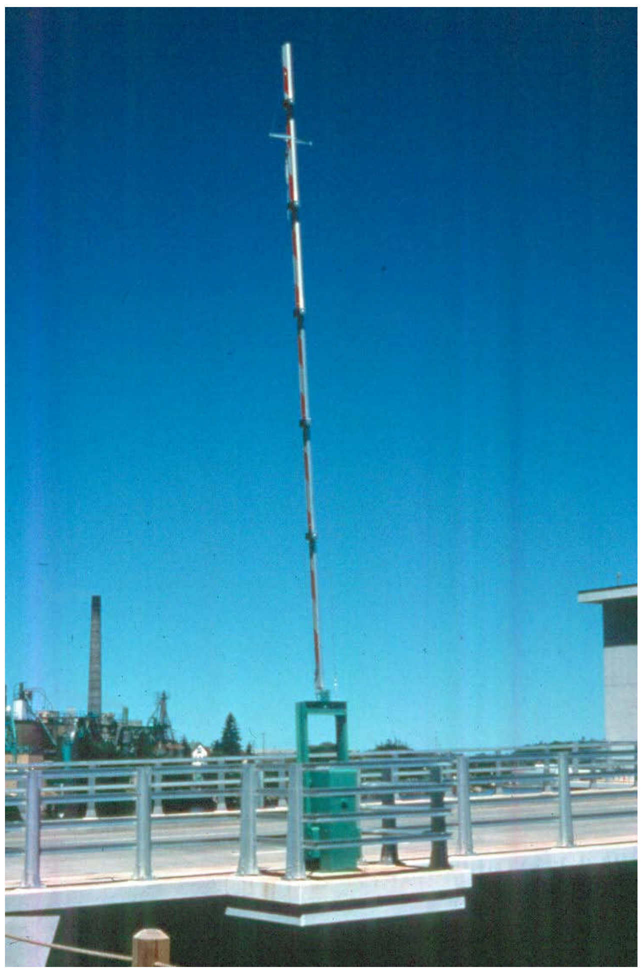

Figure 16.2.54 Traffic Control Gate

Navigational Safety

Navigational safety considerations include compliance with minimum channel width with any restriction on vertical clearance when span is open for navigation. Minimum underclearance designated on the permit drawing are to be provided. Inspect underclearance gauges for closed bridges for accuracy, visibility, and legibility.

See that all navigation lights have a relay for backup light, and red span lights do not change to green until both leaves are fully open (see Figure 16.2.55). Check navigation lights for broken lenses, deteriorated insulation of wiring and cable, and dry and clean interior, as these lights are very important to navigational safety.

Check that the marine radio communication equipment is functional (see Figure 16.2.56). Verify that the Operator can automatically sound the emergency signal to navigation vessels if bridge cannot be opened.

Figure 16.2.55 Navigational Light

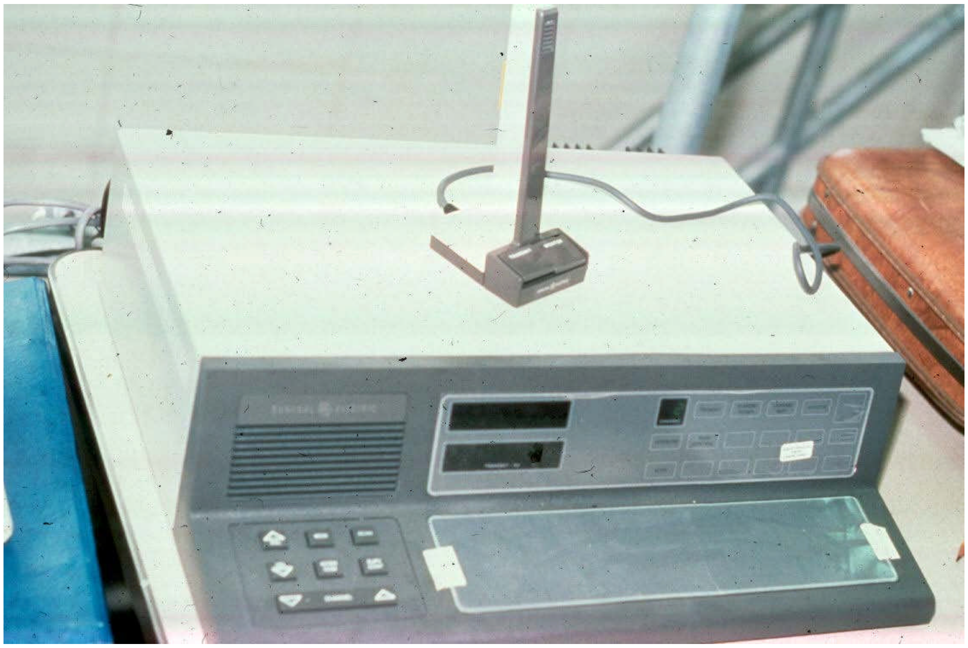

Figure 16.2.56 Marine Two-Way Radio Console

Structure Safety

Structure safety considerations include the structural ability to carry the anticipated loads. Pressure relief valves on hydraulic power units are used to limit hydraulic forces applied to machinery and structure. Horsepower applied to machinery and structure are to be kept within design limits by limiting speed.

Dependable Operation

Operate the movable bridge in both normal and emergency modes to check all interrelated interlocks and to verify every component is operating correctly.

16.2.11 Inspection Locations and Methods of Movable Bridge Opening and Closing Sequences

Movable bridges are considered to be complex according to the NBIS regulations. The NBIS requires identification of specialized inspection methods, and additional inspector training and experience required to inspect these complex bridges. The bridges are then to be inspected according to these methods.

Interlocking for Normal Operation

During normal operation, verify that each interlock functions properly and can be bypassed (when provided). Verify the controls for the traffic signals, traffic gates, center or rear locks, emergency brakes, and the bridge operation are interlocked so that they can only be operated in the following sequences.

Opening Sequence

The bridge opening sequence:

1. Activate traffic signals.
2. Lower oncoming gates and, when traffic has cleared, lower off-going gates. “All gates down” interlocked for withdrawing locks (bypass provided).
3. Press "raise" button if automatic operation is provided or, if manual operation is provided, proceed as follows:

a. Withdraw locks – "Locks Withdrawn." Interlocked for bridge operation (no bypass).

b. Release emergency brakes - no interlock provided. Warning buzzer sounds if brakes are not released when power is applied to motors to move bridge.

c. Accelerate leaves to full speed.

d. When advanced to nearly open position, decelerate leaves to slow speed and stop at nearly open position.

e. At nearly open position, with reduced power, lower leaves to stop at fully open position.

f. Set emergency brakes.

Closing Sequence

The bridge closing sequence:

1. Press "lower" button if automatic operation is provided or, if manual operation is provided, proceed as follows:

   a. Release emergency brakes.

   b. Accelerate leaves to full speed.

   c. For all types of bridges with lock bars:

      (1) At advanced nearly closed position, decelerate leaves to slow speed. Leaves stop at nearly closed position by action of the bridge limit switch.

      (2) At nearly closed position with reduced power, lower leaves to stop at fully closed position.

      (3) With machinery wound up (bascule bridges and counterweight heavy vertical lift bridges) or when span is fully closed (swing bridges and span heavy vertical lift bridges), set the brakes and drive lock bars.

   d. For rolling lift bridges having jaw and diagram shear locks with no moving parts:

      (1) At advanced nearly closed position, decelerate to slow speed. The jaw leaf stops at the "locking position" (within the "window" to receive the diaphragms) by action of the bridge limit switch.

      (2) At advance nearly closed position, decelerate to slow speed. The diaphragm leaf stops in the "clear position" (where the lower jaw will clear the diaphragm) by action of the bridge limit switch.

      (3) Depress foot switch to provide reduced power from this point until both leaves are closed.

      (4) Lower the diaphragm leaf to make "soft" contact with lower jaw.

      (5) Close both leaves together with diaphragm castings against lower jaws.

      (6) When leaves are fully closed, drive the rear locks. "Fully closed" interlock provided for rear lock operation (no

bypass).

(7) Set emergency brakes with reduced power applied to motors to hold machinery wound up.

2. Deactivate automatic traffic control, or manually raise gates:

a. All gates raise, off-going gates start up before oncoming gates raise.

b. Warning signals and red lights do not turn off until all gates are raised, even if the power switch is turned “off” (bypass is provided), after which the green traffic lights are turned “on”.

Bypass Note: All bypass switches have handles that are spring returned to “off”. When the switch is turned to bypass momentarily, a holding relay holds the bypass activated until power is removed from the controls or the switch is turned to cancel bypass. Verify these circuits are provided in order to prevent inadvertent use of any bypass. Until a malfunction is corrected, the operator is required to initiate the use of any bypass switch that is needed every time the bridge is operated.

16.2.12 Inspection Locations and Methods for the Control House

Inspection of the control house is necessary to assure the safety of a movable bridge. The operator is responsible for public and navigational safety during operation and, together with maintenance personnel, is usually the most familiar with any known structural or operational issues. Operational and maintenance log books are to be kept in the control house for reference. The resources within the control house can therefore provide a great deal of general information, through the knowledge of its personnel and the records stored there. The position of the control house provides the best general view of the bridge itself.

Consult with the bridge operators to ascertain whether there are any changes from the normal operation of the bridge. Note whether all Coast Guard, Corps of Engineers, and local instructional bulletins are posted. Check for obvious hazardous operating conditions involving the safety of the operator and maintenance personnel.

Note where the control panel is located in relation to roadway and waterway, and also whether the bridge operator has a good view of approaching boats, vehicles, and pedestrians (see Figure 16.2.57). Check operation of all closed circuit TV equipment, and evaluate its position for safe operation. If controls are in more than one location, note description of the other locations and include their condition as well as the information about the control house. Note whether alternate warning devices such as bullhorns, lanterns, flasher lights, or flags are available.

Note whether the structure shows cracks, and determine whether it is windproof and insulated. Check for any accumulations of debris, which may be readily combustible. Check controllers while bridge is opening and closing. Look for excess play and for sparking during operation. Note whether the submarine cables are kinked, hooked, or deteriorated, especially at the exposed area above or below the water. In tidal areas, check for marine and plant growth. Note if the ends of the cable have been protected from moisture.

Figure 16.2.57 Control Panel

16.2.13 Inspection Locations and Methods for Structural Members

Deficiencies

During the inspection of any type of movable structures, be sure to note any deficiencies that are detrimental to all steel and concrete structures. Most of the bridge structure deficiencies are listed in Chapter 6: Materials, as potential problems apply to movable spans also.

Fatigue

Fatigue can be a problem with movable bridges due to the reversal or the fluctuation of stresses as the spans open and close (see Figure 16.2.58). Carefully inspect any member or connection subject to such stress variations for signs of fatigue.

Figure 16.2.58 Stress Reversals in Members

Counterweights and Attachments

Inspect the counterweights to determine if they are sound and are properly affixed to the structure. Also check temporary supports for the counterweights that are to be used during bridge repair and determine their availability in the event such an occasion arises. Determine whether the counterweight pockets are properly drained. On vertical lift bridges, be sure that the sheaves and their supports are well drained. Examine every portion of the bridge where water can collect. All pockets that are exposed to rain and snow are to have a removable cover. Check for debris, birds, animals, and insect nests in the counterweight pockets.

Where steel members pass through or are embedded in the concrete, check for any corrosion of the steel member and for rust stains on the concrete. Look for cracks and spalls in the concrete.

Where lift span counterweight ropes are balanced by chains (or other means), make sure the links hang freely, and check these devices along with slides, housings, and storage devices for deficiencies and for adequacy of lubrication, where applicable.

Determine whether the bridge is balanced and whether extra balance blocks are available. A variation in the power demands on the motor, according to the span's position, is an indication of an unbalanced leaf or span. If the controls provide a “drift” position, use this to test the balance. Several coats of paint can increase the structure dead load. Otherwise, the counterweights will eventually be inadequate due to excess paint dead load.

Piers

Take notice of any rocking of the piers when the leaf is lifted. This is an indicator of a serious deficiency or critical finding and is to be reported at once. Survey the spans including towers to check both horizontal and vertical displacements. This will help to identify any foundation movements that have occurred.

Check the braces, bearings, and all housings for cracks, especially where stress risers would tend to occur. Inspect the concrete for cracks in areas where machinery bearing plates or braces are attached (see Figure 16.2.59). Note the tightness of bolts and the tightness of other fastening devices used.

Check the pier protection system (see Figure 16.2.60).

Figure 16.2.59 Concrete Bearing Areas

Figure 16.2.60 Pier Protection Systems – Dolphins and Fenders

Steel Grid Decks

Verify that structural welds are sound and the grid decks have adequate skid resistance. Check the roadway surface for evenness of grade and for adequate clearance at the joints where the movable span meets the fixed span. For more information on steel grid decks, see Topic 7.4.

Concrete Decks

A solid concrete deck is used over the pier areas (pivot or bascule pier) to keep water and debris from falling through onto the piers and mechanical devices. Since the machinery room is usually under the concrete deck, check the ceiling for leaks or areas that allow debris and rust to fall on the machinery. For more information of concrete decks, see Topic 7.2.

Other Structural Considerations

Other structural considerations include:

- Examine the live load bearings and wedges located under the trusses or girders at the pivot pier for proper fit alignment and amount of lift.
- Inspect the fully open bumper blocks and the attaching bolts for cracks in the concrete bases.
- Examine the counterweight pit for water. Check the condition of the sump pump, the concrete for cracks, and the entire area for debris.
- See if the shear locks are worn. Measure the exterior dimensions of the lock bars or diaphragm casting and the interior dimensions of sockets or space between jaws to determine the amount of clearance (wear). Report excessive movement and investigate further.
- On swing bridges, check the wedges and the outer bearings at the rest piers for alignment and amount of lift. This can be recognized by excessive vibration of span or uplift when load comes upon the other span.
- On double-leafed bascule bridges, measure the differential vertical movement at the joint between the two leaves under heavy loads. On other types, check for this type of movement at deck joints (breaks in floor) between movable and fixed portions of the structure. This can indicate excessive wear on lock bars or shear lock members.
- Inspect the joint between the two leaves on double-leaf bascule bridges, or the joints between fixed and movable portions of the structure for adequate longitudinal clearance for change in temperature (thermal expansion).
- On bascule bridges, see if the front live load bearings fit snugly. Also observe the fit of tail locks at rear arm and of supports at outer end of single-leaf bridges.
- On rolling lift bascule bridges, check the segmental and track castings and their respective supporting track girders (if used) for wear on sides of track teeth due to movement of sockets on segmental castings. Compare all wear patterns for indications of movement of the leaves. Check for cracking at the fillet of the angles forming the flanges of the segmental and track girders, cracking in the flanges opposite joints in the castings, and cracking of the concrete under the track. Inspect rack support for lateral movement when bridge is in motion.
- 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 opened.

16.2.14 Inspection Locations and Methods for Machinery Members

Mechanical, electrical, and hydraulic equipment includes specialized areas, which are beyond the scope of this reference manual. Since operating equipment is the heart of the movable bridge, it is recommended that expert assistance be obtained when conducting an inspection of movable spans. In many cases, the owners of these movable bridges follow excellent programs of inspection, maintenance, and repair. However, there is always the possibility that some important feature may have been overlooked. Any problems noted during the inspection are reported to the owner.

Trial Openings

Conduct trial openings as necessary to insure proper operational functioning and that the movable span is properly balanced. Trial openings are specifically for inspection. During the trial openings, the safety of the inspection personnel, traveling public and boat operators is a primary concern.

Machinery Inspection Considerations

On all movable structures, the machinery is so important that considerable time is to be devoted to its inspection. The items covered and termed as machinery include all motors, brakes, gears, tracks, shafts, couplings, bearings, locks, linkages, over-speed controls, and any other integral part that transmits the necessary mechanical power to operate the movable portion of the bridge. Inspect machinery not only for its current condition, but also for operational and maintenance methods and analysis of the characteristics of operation. The items listed below and items similar to them are to be inspected and analyzed by a machinery or movable bridge specialist. Refer to FHWA-IP-77-10, *Bridge Inspector's Manual for Movable Bridges* and the *AASHTO Movable Bridge Inspection, Evaluation and Maintenance Manual, Manual for Bridge Evaluation* for further information on inspecting these items. The FHWA-IP-77-10 manual is published by the Federal Highway Administration (FHWA), but is currently out of print.

Operation and General System Condition

Observe the general condition of the machinery as a whole, and its performance during operation. Check for smoothness of operation, and note any abnormal performance of components. Note any noise or vibration and the source determined. Document any unsafe or detrimental methods followed by the operator to prevent injury to the public or to personnel, or deficiencies to the equipment. Also note the condition of the paint system.

Maintenance Methods

Perform an evaluation of maintenance methods in light of design details for the equipment. Check application methods and frequency of lubrication in the maintenance logbook, if available. Note general appearance of existing applied lubricant.

Open Gearing

Check open gearing for tooth condition and alignment including over- and under-engagement. Verify that the pitch lines match. Note excessive or abnormal wear. Inspect the teeth, spokes, and hub for cracks. Observe and note the general appearance of the applied lubricants on open gearing. If the lubricant has been contaminated, especially with sand or other gritty material, remove the old lubricant and have new lubricant applied. If there is a way to prevent future contamination, recommend this appropriate procedure as part of the inspector's comments in the report. Check the teeth of all gears for wear, cleanliness, corrosion, and for proper alignment.

Speed Reducers Including Differentials

Examine the exterior of the housing and mountings for cracks and deficiencies (see Figure 16.2.61 and 16.2.62). Check bolts for tightness and note any corrosion. Inspect the interior of the housing for condensation and corrosion. Check the condition of gears. Watch for abnormal shaft movement during operation, indicating bearing and seal wear. Periodically check oil levels and condition of lubricant. Check that circulating pumps and lubricating lines are properly operating. Any abnormal noise is to be documented. Leaking oil may indicate the presence of a crack.

Figure 16.2.61 Cracked Speed Reducer Housing

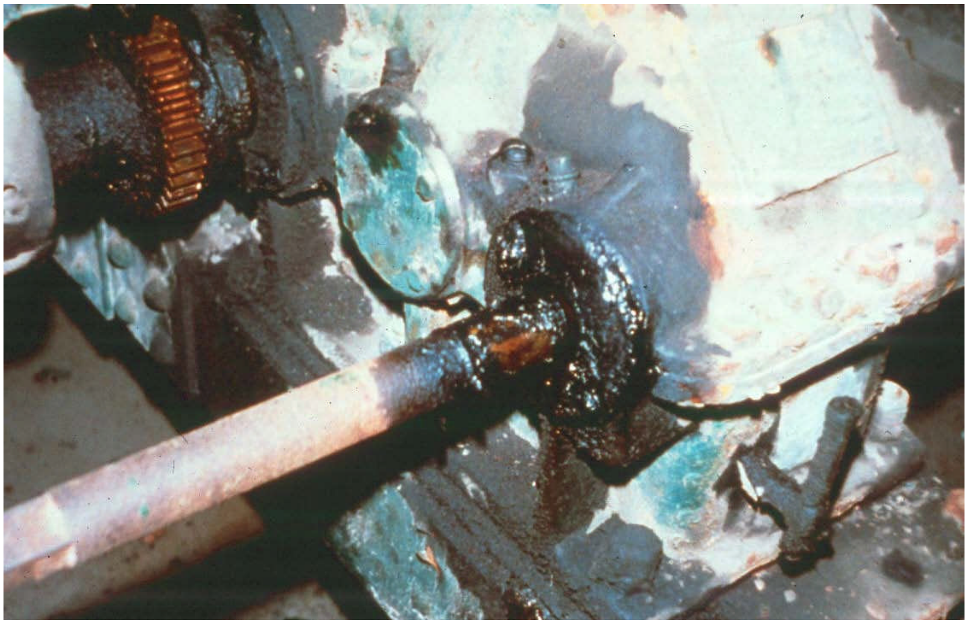

Figure 16.2.62 Leaking Speed Reducer

Shafts and Couplings

Examine shafts damage, twisting, and strain. Cracks, if suspected, may be detected using non-destructive evaluations (NDE) such as magnetic particle or dye penetrant (see Figure 16.2.63). Various advanced inspection methods for steel members are presented in Topic 15.3. Cracks in mechanical components may be determined to be a critical finding. Note misalignment with other parts of the machinery system. Document cracks in shafts and record the exact location. Examine other shafts in the same locations as they were probably made from the same material and fabricated to the same details. They have also been exposed to the same magnitude and frequency of loading. Check coupling hubs, housings, and bolts for condition. Inspect seals and gaskets for leaks. Internal inspection of couplings is warranted if problems are suspected and can be used to determine tooth wear in gear couplings.

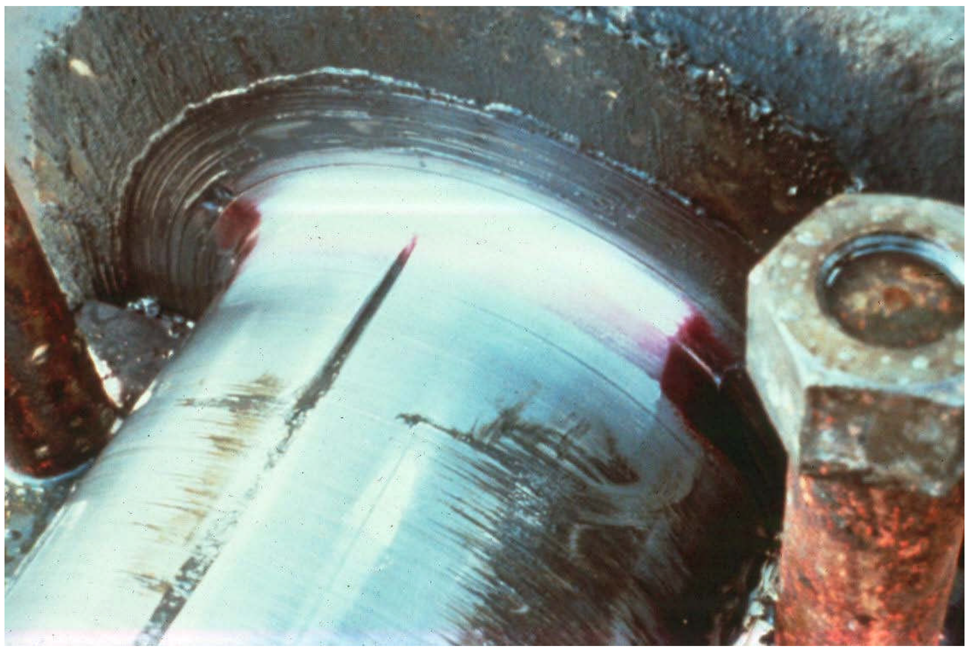

Figure 16.2.63 Hairline Crack Revealed on Shaft from Dye Penetrant Test

Bearings

Examine bearing housings, pedestals, and supports for external condition, noting any cracks. Check bolts in housings and those used for anchors for tightness, damage, and corrosion, noting apparent lubrication characteristics. Grinding noises can be caused the lack of lubricant (see Figure 16.2.64). In sleeve bearings, inspect the bushings for damage and excessive wear. Note evidence of seal damage in anti-friction bearings. Investigate any unusual noise. Check the trunnion bearings for excessive wear, lateral slip, and loose bolts.

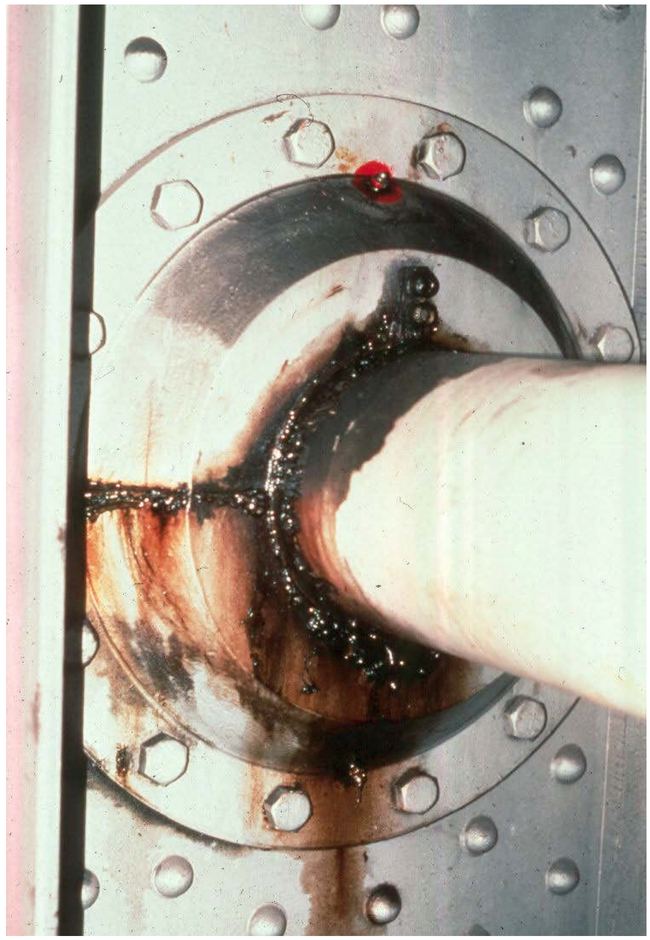

Figure 16.2.64 Leaking Bearing

Brakes

Inspect all braking devices for proper setting of braking torque and for complete release of the brakes when actuated. On shoe brakes, check drums and shoes for wear, damage, and corrosion, for misalignment of shoes with drums, and for clearance when released. Determine if worn linings need replaced. Check for proper actuation without leakage by actuators. Verify that linkages and hand releases are free but not sloppy. On enclosed hydraulic disc brakes, make certain there is proper actuation without leakage at connections or seals. Check the brakes, limit switches, and stops (cylinders and others) for excessive wear and slip movement. Note whether the cushion cylinder ram sticks or inserts too easily. Inspect the brake limit switches for proper setting. Observe the surface of the brake drum for indications of contact with the brake shoes. Check the pressure developed by each disc brake power unit to be sure the brakes are releasing. Also check the manual release on all of the brakes.

Drives - Electric Motors

Check the housing and mountings for damage, corrosion, and fastener condition. Inspect bearings for lubrication and note indications of wear (movement) and seal leakage at shaft extensions.

Drives - Hydraulic Equipment

Look for any leakage at connections and seals. Note any corrosion on the cylinder rods. Listen to motors and pumps, and note any unusual noise. Check power units to make sure all components are functioning and that pressures are properly adjusted. Sample fluid periodically and examine for contamination and wear metal. Check all main hydraulic power units for charge pressure setting and maximum pressure that can be developed by the unit. Check all filters routinely and replace as needed. Also check the level of fluid in the vertical reservoir.

Auxiliary Drives

Check emergency generators for operation and readiness, verifying that there are no oil leaks or abnormal noises. Mechanical service specialists and electrical inspectors are required for more thorough inspections. Auxiliary motors and hand operators, with their clutches and other transmission components, are to be checked for adjustment and readiness to perform when called upon.

Drives - Internal Combustion Engines

Detailed inspections of internal combustion engines are made by mechanical engine specialists. The inspection may include but is not limited to checking of the following conditions:

- If a belt drive is used, look for any wear or slippage. Note the condition of all belts and the need for replacement, if any.
- If a friction drive is used, check that all bracing and bearings are tight.
- If a liquid coupling is used, make sure that the proper quantity of fluid is used. Look for leaks.

Locks

Examine the center locks and tail locks (if used) on double-leafed bascule spans, and the end locks on single-leaf bascule bridges, swing bridges, and vertical lift bridges. Note whether there is excessive deflection at these joints or vibration on the bridge. Inspect the locks for fit and for movement of the span or leaf (or leaves). Check lubrication and for loose bolts. Verify that the lock housing and its braces have no noticeable movement or misalignment. The paint adjacent to the locks will have signs of paint loss or wear if there is movement. Check lock bars, movable posts, linkages, sockets, bushings, and supports for damage, cracks, wear, and corrosion.

Check all rear locks in the withdrawn position for clearance from the path of the moving leaf as it opens and for full engagement when the leaf is closed. Measure the gap, if any, between the lock plate and the moving leaf bearing plate. Check each rear lock hydraulic drive unit for leakage of oil and operation for correct length of movement of the lock.

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

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

Live Load Shoes and Strike Plates Inspect the fasteners and structure for deficiencies and corrosion. Note contact surface conditions. Check for alignment and movement under load.

Air Buffer Cylinders and Shock Absorbers Note indications of lack of pressure or stickiness during operation. Check piston rod alignment with strike plate. Note the condition of the rod and housing, and verify if hydraulic leakage is present. Check the air filter and function of any pressure reading or adjusting devices and the operating pressure, if possible. Verify that the air buffers have freedom of movement and development of pressure when closing. Inspect the fully open bumper blocks and the attaching bolts for cracks in the concrete bases.

Machinery Frames, Supports, and Foundations Check that there is no cracking in the steel or concrete. Note corrosion and damage. Check for deflection and movement under load. Ensure that the linkages and pin connections have the proper adjustment and are in functional condition. Check motor mounting brackets to ensure secure mounting.

Fasteners Inspect the fasteners for corrosion, loss of section, and tightness.

Wedges Check the wedges and the outer bearings at the rest piers for alignment and amount of lift. This can be recognized by excessive vibration of span or uplift when load comes upon the other span.

Examine the live load bearings and wedges located under the trusses or girders at the pivot pier for proper fit alignment and amount of lift.

Special Machinery for Swing Bridges Check center bearings for proper and adequate lubrication, oil leaks, and noise. Examine the housing for cracking, pitting, fit of joints, and note indications of span translation (irregular rotation) at racks and track. Measure for proper clearance of balance wheels above track. Verify that the tracks and balance wheels are free of wear, pitting, and cracking. Check for proper and adequate lubrication at all lubrication points.

Note balance characteristics as indicated by loads taken by balance wheels, and by drag on the rest pier rail.

Check the rim bearing for wear on tracks and rollers, particularly at rest positions where the bridge is carrying traffic. Examine the center pivots and guide rings for proper fit, and for wear, pitting, and cracking. Check for proper and adequate lubrication at all lubrication points.

Examine the center (live load) wedges located under the trusses or girders at the pivot pier for proper fit (no lifting) and alignment. Check end wedges and bearings at the rest piers for alignment and amount of lift. This can be recognized by excessive vibration of the span or uplift when live load crosses the other span. Inspect the end lift jacks, shoes, and all linkages for wear, proper bearing under load, and proper adjustment.

Note the condition of end latches, including any modification that adversely affects their functional design.

Special Machinery for Bascule Bridges

On rolling lift bascule bridges, check the segmental and track castings and their respective supporting track girders (if used) for wear on the sides of track teeth due to movement of sockets on segmental castings. Inspect the trunnion assemblies for deflection, buckling, lateral slip, and loose bolts. Examine the trunnions for any signs of corrosion, pitting, or cracking, particularly at stress risers. Laser leveling may be used during the inspection of trunnions. Check the balance of each leaf. Compare all wear patterns for indications of movement of the leaves. Check for cracking at the fillet of the angles forming the flanges of the segmental and track girders, cracking in the flanges opposite joints in the castings, and cracking of the concrete under the track. Inspect rack support for lateral movement when bridge is in motion.

Check trunnion bearings for lubrication of the full width of the bearing. Verify that extreme pressure (EP) lubrication oil of the proper grade is used.

Special Machinery for Vertical Lift Bridges

The condition of wire ropes and sockets, including wire rope lubrication, is important. Look for flattening or fraying of the strands and deficiencies between them. This is reason for replacement. Similarly, check the up-haul and down-haul ropes to see if they are winding and unwinding properly on the drums. Note any need for tension adjustments in up-haul and down-haul ropes. Determine whether ropes have freedom of movement and are running properly in sheave grooves. Look for any obstructions to prevent movement of the ropes through the pulley system, and check the supports on span drive type bridges. Check rope guides for alignment, proper fit, free movement, wear, and structural integrity of the longitudinal and transverse grooved guide castings. Inspect the grooved guide castings closely for wear in the grooves. Examine the cable hold-downs, turnbuckles, cleats, guides, clamps, splay castings, and the travel rollers and their guides.

Check that balance chains hang freely, that span leveling devices are functioning, and that span and counterweight balance closely. Observe if span becomes "out of level" during lifting operation. Inspect spring tension, brackets, braces, and connectors of power cable reels.

Check for damage, including cracking, at drums and sheaves. Note the condition and alignment of span guides.

16.2.15 Electrical Inspection Considerations

An available electrical specialist is required for the inspection of the electrical equipment. For this inspection, use current AASHTO guidance on inspection of movable bridges. Observe the functional operation of the bridge and look for abnormal performance of the equipment. Check the operational methods and safety features provided. Evaluate the maintenance methods being followed and check the frequency of services performed.

Power Supplies

Examine the normal power supply, standby power supply, and standby generator set (for emergency operation of bridge and service lighting) and note the following:

- Take megger readings on the cable insulation values, noting the weather conditions, namely temperature and humidity.
- Make sure all cable connections are properly tightened.
- Measure the voltage and the current to the motors at regular intervals during the operation of the bridge.
- Check the collector rings and windings on the generator set.
- Test starting circuitry for automatic starting and manual starting.
- See if the unit is vibrating while running under load.

If the power cable has been repaired with a splice, note the condition of the splice box seal.

If no standby power supply has been provided, determine whether a portable generator could be used. A manual transfer switch would be a convenient way of connecting it.

Motors

Examine span drive motors, lock motors, brake thrustor motors, and brake solenoids for the same items as given for power supplies.

Transformers

Check dry transformer coil housings, terminals, and insulators, including their temperature under load. Observe the frames and supports for rigidity to prevent vibration. Check the liquid filled transformer in the same way, along with checking the oil level while looking for leakage. Examine oil insulation test records.

Circuit Breakers

Check circuit breakers (e.g., air, molded case, and oil) and fuses, including the arc chute, contact surfaces, overload trip settings, insulation, and terminal connections. Examine oil insulation test records, and observe the closing and tripping operation. Record all fuse types and sizes being used.

Wires and Cables

Examine the wiring and cables for both power and control. Note whether the submarine cables are kinked, hooked, or deteriorated, especially at the exposed area above and below the water. In tidal areas, look for marine and plant growth. Note if the ends of the cable have been protected from moisture. Record the insulation value of each wire as measured by megger. Look for cracking, overheating, and deterioration of the insulation. Check for wear against surfaces and especially sharp edges. Check the adequacy of supports and that dirt and debris do not accumulate against the conduit and supports. Check terminal connections, clamps, and securing clips for tightness, corrosion, and verify that there are wire numbers on the end of each wire. The weight of the wires or cables will be carried by the clamps and not by the wire connections at the terminal strips.

Cabinets

Examine the programmable logic controller (PLC) cabinets, control consoles and stations, switchboards (see Figure 16.2.65), relay cabinets, motor control centers (MCC), and all enclosures for deficiencies, debris inside, drainage, operations of heater to prevent condensation, and their ability to protect the equipment inside. Check the operation of all traffic signals, traffic gates, traffic barriers, and navigation lights. Verify that the bridge is open to provide the clearance shown on the permit drawing before the green span light turns on. Check the traffic warning equipment and control circuits, including the advanced warning signals (if used), traffic lights/signals, gates, barriers, and the public address and communication equipment.

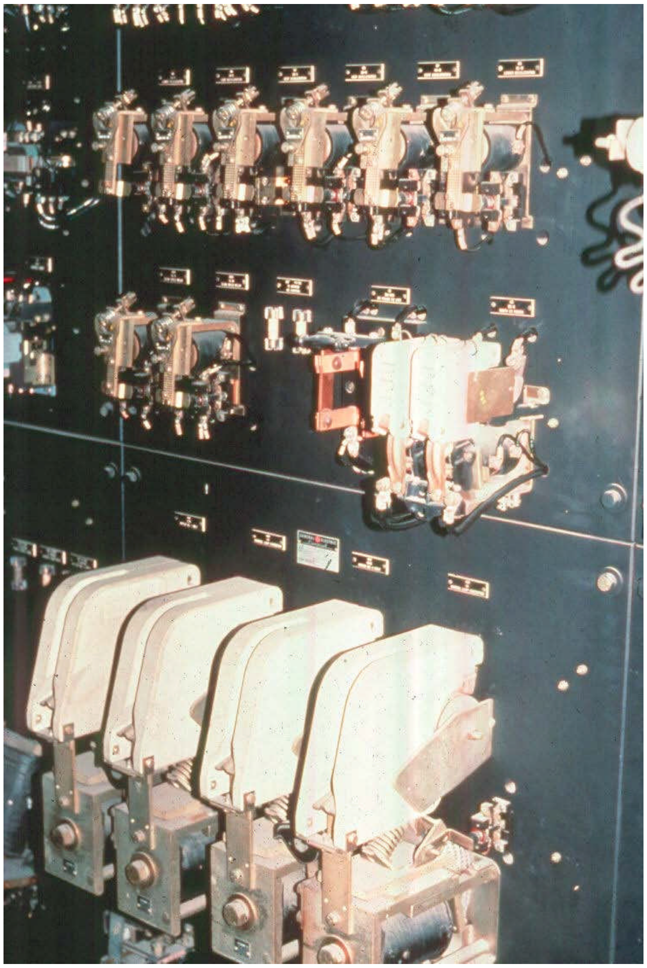

Figure 16.2.65 Open Switchboard

Conduit

See if conduit is far enough away from all surfaces to avoid debris from collecting against it. Note if it is adequately supported and pitched to drain away from junction boxes and pull boxes, so that water is not trapped within. Also, note if all conduits have covers with seals. Report deteriorated conduit so that it can be replaced with new conduit. Seal and re-coat the connectors at the ends of all PVC coated conduit after all fittings are installed.

Junction Boxes	Examine the covers on all junction boxes (JBs) for an effective seal, dry interior, functioning breather-drains, heaters having enough power to prevent condensation inside, and terminal strips all secured to the bottom of horizontal JBs or to the back of vertical JBs.
Meters	Observe if all voltmeters, ammeters, and watt meters are freely fluctuating with a change in load. Check that all switches and meters are operable.
Control Starters and Contactors/Relays	Check the operation of this equipment under load, and watch for arcing between contacts, snap action of contacts, deterioration of any surfaces, and drainage of any moisture. Look for signs of corrosion and overheating.
Limit Switches	Set all limit switches so they do not operate until they are intended to stop the equipment or complete an interlock. Verify that the interior is clean and dry, with all springs active.
Selsyn Transmitters and Receivers	Check for power to the field and signal being sent from the transmitter to the receiver. Observe the receiver tracking the rotation of the bridge as it operates. Observe the mechanical coupling between the driving shaft and the transmitter, checking for damage and misalignment.
Service Light and Outlet	Check to see if power is going to each light and outlet. Note if there is a shield or bar for protecting each bulb and socket. It is desirable to have service lights available when power is removed from all movable bridge controls and equipment.

16.2.16 Hydraulic Inspection Considerations

A hydraulic power specialist is required for the inspection of the hydraulic equipment (see Figure 16.2.66). Observe the functional operation of the bridge and look for abnormal performance of the equipment. Check the safety features provided and evaluate the maintenance methods being followed, checking the frequency of services performed. Due to the inter-related function of components, the requirements for fluid cleanliness, and the need for personnel safety, do not open the reservoir or hydraulic lines. In addition, do not shut off or adjust any component or part of the power circuit without complete understanding of their function and knowledge of the effect such action will have upon the system. Items which are checked during a hydraulic inspection include the following:

- Note leakage anywhere in the system. Significant leakage is immediately brought to the attention of the bridge authority.
- Check for corrosion of reservoir, piping, and connections.
- Inspect sight gauges for proper fluid level in reservoir. Note gauges with low fluid levels or gauges which cannot be read.
- Note unusual noises from any part of the system.
- Check filter indicators to make sure filters are clean.
- Collect a sample of the hydraulic fluid for analysis by a testing laboratory during periodic inspections.

Figure 16.2.66 Hydraulic Power Specialists

16.2.17 Recordkeeping and Documentation

General

The owner of a movable bridge keeps a complete file available for the engineer who is responsible for the operation and maintenance of the bridge. See Topic 4.4 for general record keeping and documentation. The file includes (if applicable), but not be limited to, the following:

- Copy of the latest approved permit drawing
- Complete set of design plans and special provisions
- "As-built" shop plans for the structural steel, architectural, mechanical, electrical, and hydraulic
- Machinery Maintenance Manual
- Electrical Maintenance Manual
- Hydraulic Maintenance Manual
- Copy of maintenance methods being followed
- Copy of the latest Operator's Instruction being followed
- Copies of all inspection reports
- Copy of all maintenance reports
- Copy of all repair plans
- Up-to-date running log on all spare parts that are available, on order, or out of stock

Review inspection and maintenance reports with preventative maintenance measures in mind. An example would be the "megger" readings on wiring insulation; especially those taken on damp rainy days when moisture could influence (reduce) the values. An acceptable minimum reading is usually 1 megaohm. If the value on a wire is decreasing on progressive reports, preventative maintenance may save a "short" that could burn out equipment and put the bridge out of operation.

Inspection and Maintenance Data

Examples of inspection and maintenance records are shown in Figures 16.2.67 through 16.2.73.

South Tower — Differential Assembly GEARS - General — 1.

Gear	General Condition	Lubrication	Keys	Alignment: Center Distance	Alignment: Axial	Alignment: Parallel
Pinion P5	Very Good. Tooth profiles show normal wear	Very Good	Good	Good. Pitch Lines Tangent	Good	Good
Gear I5	Very Good. Tooth profiles normal.	Very Good	Good	No Pitch Line on G5. Looks good. Measured backlash.		
Gear G5	Very Good. Tooth profiles normal	Very Good	Good			
Pinion P4	Very Good. Tooth profiles normal.	Very Good	Integral with shaft	No pitch line on P4. Center distance looks. Looks good. Measured backlash.	Good	Good
Gear G4	Very Good. Tooth profiles normal.	Very Good	Not keyed to shaft. Clutch locks G4 to shaft.			
Bevel Gears BG3 (2)	Very Good. Tooth profiles normal.	Very Good	Integral with sleeves.	Good. Pitch Lines 1/16" to 1/8" apart.	Good	Good
Bevel Pinions BP3 (2)	Very Good. Tooth profiles normal.	Very Good	Integral with shafts.			

Figure 16.2.67 Example of Notes on Operating Machinery (Gears-General)

South Tower Differential Assembly GEARS - Teeth 2.

Gear	Chordal Thickness		Backlash		Condition of Teeth					
					Normal	Pitting	Rolling-Peening	Abnormal		
	Original	Measured	Original	Measured				Scor-ing	Inter-ference	Rust & Corr.
Pinion P5	.625"	Did not measure	.011" min to .020" max.	Did not measure. Pitch lines indicate good backlash.	✓					
Gear I5	.625"		.011" min to .020" max.	.0135" Good.	✓					
Gear G5	.625"				✓					
Pinion P4	.625"		.011" min to .020" max	.020" Good	✓					
Gear G4	.625"				✓					
Bevel Gears BG3 (2)	.875" at large end of teeth		.015" min to .029" max	Did not measure. Pitch lines indicate good backlash.	✓					
Bevel Pinions BP3 (2)	.875" at large end of teeth				✓					

Figure 16.2.68 Example of Notes on Operating Machinery (Gears-Teeth)

South Tower Differential Assembly	BEARINGS				3
Bearing	General Condition	Clearance		Bolts	Lubri-cation
		Original	Measured		
West end Emer. Motor Shaft	Good. Fairly clean, paint good. Bearing has 45° angle lube fitting w/dust cap.	.0025" min. to .0073" max.	.006" Good	Good. Nuts tight. Clean, paint good.	Good.
East end Emer. Motor Shaft		.0025" min. to .0073" max.	.006" Good		
West end Intermediate Shaft		.0025" min. to .0073" max.	.007" Good		
East end Intermediate Shaft		.0025" min. to .0073" max.	.005" Good		
West end Normal Motor Shaft		.0025" min. to .0073" max.	.007" Good		
East end Normal Motor shaft		.0025" min to .0073" max	.009" Fair		

Figure 16.2.69 Example of Notes on Operating Machinery (Bearings)

South Tower Differential Assembly	MECHANICAL COMPONENTS 4.
Item	General Condition
Housing Cover	Very good condition. Cover has four hinged maintenance panels, secured with studs and wingnuts. Cover bolted to lower supports with 20 bolts.
Normal (Main) Drive Clutch Cone	Very good condition. No slippage during span operation, starting or stopping. Clutch cone is inside differential assembly and impossible to inspect without disassembly of differential.
Emergency Drive Clutch Cone Assembly	Very good condition. Design plans show cone type clutch. Actually have jaw type clutch.
Differential Clutch Operating Linkage	Very good condition. Well lubricated. Linkage operates smooth and quiet.
Emergency Drive Clutch Operating Linkage	Very good condition. Well lubricated. Linkage operates smooth and quiet.
Gear Motor for operation of Differential Clutch	Good condition. Operates smoothly. Operated with hand crank, turned fairly easy. GE AC Gearmotor, Model KY3AC2345, Motor 1800 rpm, 1/8 HP, 250:1 ratio
Support for above Gear Motor	Good. Some debris and oil on support.
Gear Motor for operation of Emer. Drive Clutch	Good. Operates smoothly. Turned easily with hand crank. Same gearmotor as at differential clutch
Support for above Gear Motor	Good. Some debris and oil on support.
Housing Support	Good condition. Some debris and oil on support and floor. Paint good. 2 lights attached to supports inside

Figure 16.2.70 Example of Notes on Operating Machinery (Mechanical Components)

Electrical Equipment 125HP, 600RPM, 3φ, 60H

Motor A (Normal-Traction) Tower South-Side W

General Items	General Condition
Stiffness of Supports	Good
Connection to "	Bolts tight
Condition of Frame	Dirty & Dusty Inside & out
Inspection Covers	Wire Mesh, 2 on Top (2 on Bott. missing)
Gaskets on "	None
Bolts on "	Tight
Ventilation	Open Ends
Operation-Noise	Normal
" -Vibration	Minimal
" - -Bearings	Normal wear
Lubrication	Needs normal application
Oil-Dirt Build-Up	None (Except at couplings)
Insulation	See Megger test
Cable Connections	Good

Wound Rotor Motors	Wire No.	Raising Span Amps.	Lowering Span Amps.	
Motor Current - φ A	T1A	10-25-80 122	91	
B	T3A	124	93	
C	T2A	124	92	
Motor Voltage - A-B				460V
A-C				
B-C				
Rings-Surface	Normal wear			
" -Arcing	None Visible			
Brushes-Contact	Good			
" -Spring Pressure	Good, Springs Rusty			
" -Condition	Good, 2¼" length			
Wiring-Connection	Tight, Bolts Rusty			
" -Insulation	Good			
Rotor Current 3 φ A	M1A	10-25-80 50	31	
B	M3A	48	32	
C	M2A	50	32	

Figure 16.2.71 Example of Notes on Electrical Equipment (Motors)

Megger Insulation Test Temp 60's Weather Dry

Rotating Cam - Normal Height Limit Switch.
Contacts shown for Bridge Closed. Tower South Side W

Bottom Connection			Gear	Top Connection		
Remarks	500V MΩ to Ground	Wire No. Taged U.N.	Drive End North Contacts	Wire No.	500V MΩ to Ground	Remarks
	0.2	1084	1	1081	10.	
	0.2	1085	2			
	16.	No Tag 1083	3	1003	8.	
	18.	1105	4	1010.	0.2	
	20.	No Tag 1110	5			
	18.	1117	6			
	18.	1125	7			
	0.2	2051	8	2022	0.2	
	0.2	2052	9			
Spare		No Wires	10			

Remarks: Cover has probably been left OFF for a period of time. No gaskets, clips on some switches not hooked. Connection screws inside all rusty on the bottom. Springs rusty but still springy. Contacts are clean with fair contact alignment.

Figure 16.2.72 Example of Notes on Electrical Equipment (Limit Switch)

Megger Insulation Test of the Submarine Cables		Temp 50°s Weather Dry					
Equipment Being Controlled	Wire No. on Plans	Emergency Cables			Normal Cables		
		No. in Cable	500V M-Ω	Remarks	No. in Cable	500V M-Ω	Remarks
North Tower Elev.	261	1	6		2	500	
	261	3	6		4	500	
	263	5	1.5		6	<.2	>20K-Ω
	263	7	1.5		8	.1	
	262	9	.9		10	.1	
	262	11	.9		12	.1	
Service Brake C	447	13	2.0		14	1000	
	446	15	40.		16	1000	
	448	17	15.		18	1000	
Service Brake D	467	19	2.		20	1000	
	466	21	25.		22	1000	
	468	23	5.		24	1000	
Drag Brake L	519	25	20.		26	1000	
	516	27	35.		28	1000	
	520	29	5.		30	1000	
Drag Brake M	529	31	4.		32	1000	
516	526	33	5.		34	1000	
	535	35	1.		36	1000	
North Lock Motor	617	37	0.8		38	1000	
	616	39	10.		40	1000	
	618	41	0.2		42	1000	
North Barrier Gate Motor	647	43	12.		44	1000	
	646	45	.7		46	1000	
	648	47	90		48	∞	
N.W. Traffic Gate Motor	687	49	.2		50	1000	
	686	51	35.		52	∞	
	688	52	100.		54	∞	
N.E. Traffic Gate Motor	697	55	9.		56	1000	
	696	57	6.		58	1000	
	698	59	3.		60	1000	

Figure 16.2.73 Example of Notes on Electrical Equipment (Megger Insulation Test of the Submarine Cables)

16.2.18 Evaluation

State and Federal rating guideline systems have been developed to aid in the inspection of movable bridges. The two major rating guideline systems currently in use are the FHWA's *Recording and Coding Guide for the Structural Inventory and Appraisal of the Nation's Bridges* used for the National Bridge Inventory (NBI) component condition rating method and the AASHTO *Guide Manual for Bridge Element Inspection* for element level condition state assessment.

NBI Component Condition Rating Guidelines

Using the NBI component condition rating guidelines, a one-digit code on the Federal Structure Inventory and Appraisal (SI&A) sheet indicates the condition of the superstructure. Component condition rating codes range from 9 to 0 where 9 is the best rating possible. See Topic 4.2 (Item 59) for additional details about NBI component condition rating guidelines.

Consider previous inspection data along with current inspection findings to determine the correct component condition rating.

Element Level Condition State Assessment

In an element level condition state assessment of a movable bridge, possible AASHTO National Bridge Element (NBEs) and Bridge Management Elements (BMEs) are:

NBE No.	Description
Superstructure	
	Box Girder
102	Steel Closed Web/Box Girder
	Floor System
107	Steel Open Girder/Beam
113	Steel Stringer (Stringer-Floorbeam System)
152	Steel Floorbeam (Stringer-Floorbeam System)
	Steel Truss
120	Steel Truss
162	Steel Gusset Plate
	Steel Arch
141	Steel Arch
	Cable
147	Steel Main Cable (not embedded in concrete)
148	Steel Secondary Cable (not embedded in concrete)

BME No.	Description
Wearing Surfaces and Protection Systems	
515	Steel Protective Coating

The unit quantity for the superstructure elements is feet. The total length is distributed among the four available condition states depending on the extent and severity of the deficiency. The unit quantity for gusset plates is each, with each gusset plate element placed in one of the four available condition states depending on the extent and severity of the deficiency. The unit quantity for protective coating is square feet, and the total area is distributed among the four available condition states depending on the extent and severity of the deficiency. The sum of all condition states equals the total quantity of the National Bridge Element or Bridge Management Element. Condition State 1 is the best possible rating. See the *AASHTO Guide Manual for Bridge Element Inspection* for condition state descriptions.

For mechanical, electrical, and hydraulic movable bridge members, individual bridge owners may choose to create their own Agency Developed Elements (ADEs).

The following Defect Flags are applicable in the evaluation of movable bridges:

Defect Flag No.	**Description**
356	Steel Cracking/Fatigue
357	Pack Rust
362	Superstructure Traffic Impact (load capacity)
363	Steel Section Loss
364	Steel out-of-plane (compression members)

See the AASHTO *Guide Manual for Bridge Element Inspection* for the application of Defect Flags.

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Chapter 16
Complex Bridges

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Topic 16.3 Floating Bridges

16.3.1 Introduction

Although uncommon, some states have floating bridges that are not supported by a substructure. Instead, they are supported by, or float on the water. The bridge elevation will change as the water level fluctuates (see Figure 16.3.1).

Floating bridges are cost-effective solutions for crossing large bodies of very deep water with a very soft bottom where conventional piers are impractical. For a site with a 100- to 200-foot deep water and a very soft bottom extending another 100 to 200 feet, a floating bridge is estimated to cost three to five time less than a conventional multi-span fixed bridge or a tunnel.

Floating bridges perform well in areas subjected to high winds, moderate currents and moderate waves. They also have low environmental impact and perform well in seismic events.

Washington State is known for its floating bridges with four of the longest and heaviest floating bridges. They are the SR 520 Evergreen Point Bridge, the I-90 Lacey V. Murrow Bridge, the I-90 Homer M. Hadley Bridge, and the SR 104 Hood Canal Bridge.

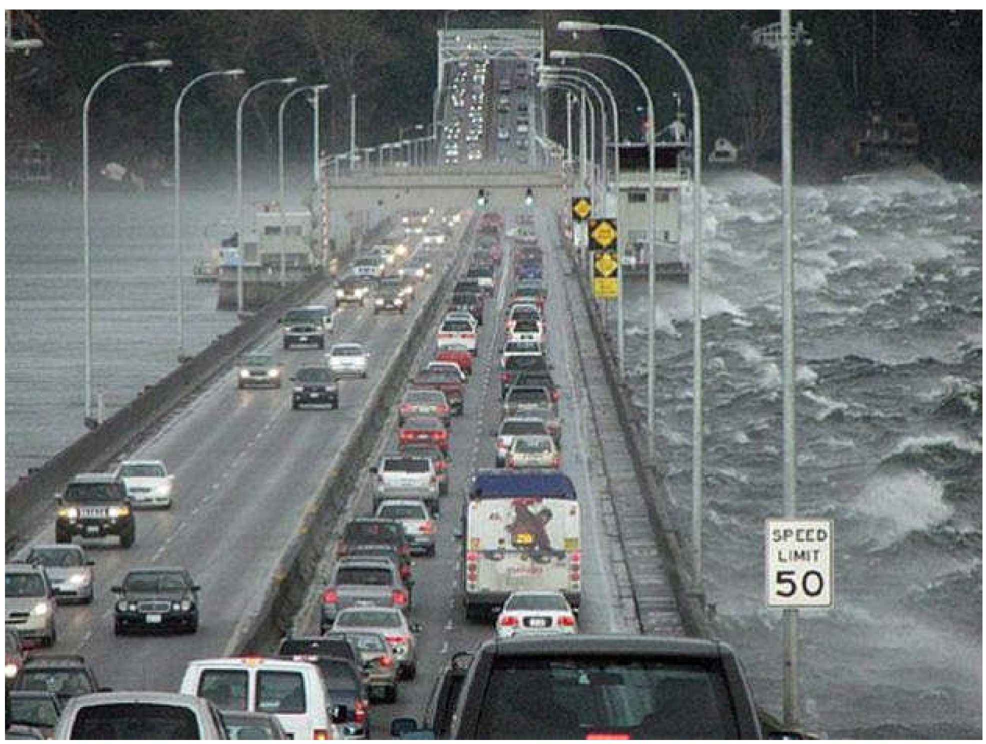

Figure 16.3.1 Floating Bridge, SR 520 Evergreen Point Bridge, Seattle, WA During Stormy Weather

16.3.2 Design Characteristics

Floating bridges take advantage of the natural law of buoyancy of water to support the loads. This is achieved through the use of giant pontoons secured into place by an anchoring system. Conventional piers and foundations are not used.

Since a floating bridge "sits" on the water, the bridge itself creates an obstacle to vessels attempting to cross the waterway. For this reason, many floating bridges employ a movable bridge section for vessels to pass through, or an elevated span for vessels to pass under (see Figures 16.3.2 and 16.3.3).

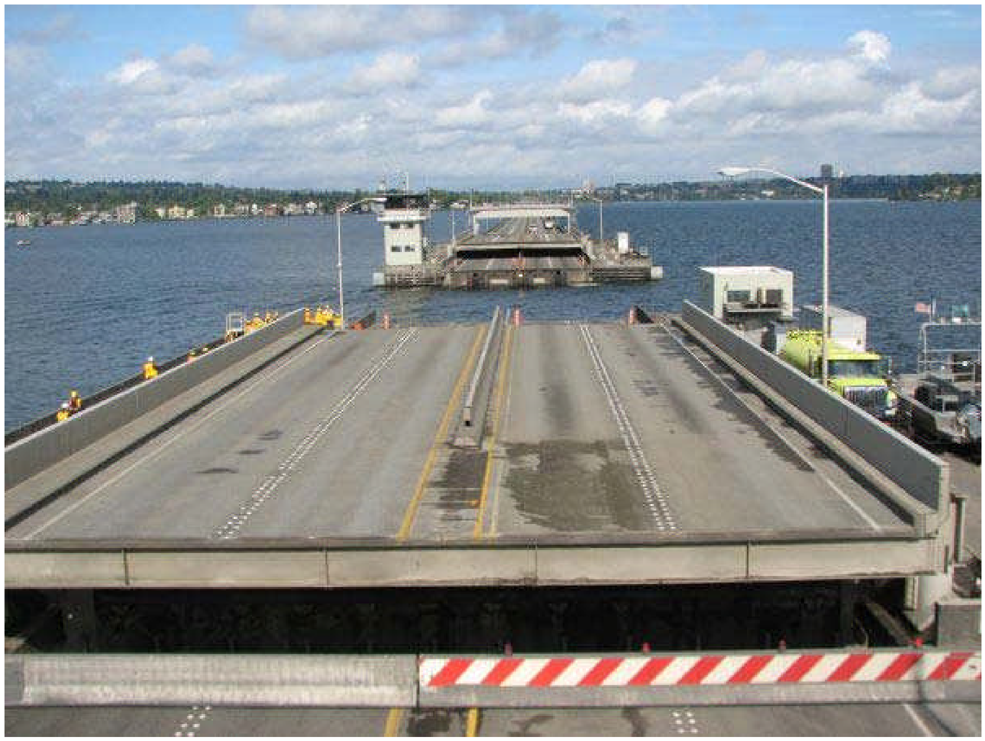

Figure 16.3.2 Movable Bridge Section of Evergreen Point Bridge, Seattle, WA

Figure 16.3.3 Elevated Section of Evergreen Point Bridge, Seattle, WA

Pontoons

Floating bridges may be constructed of wood (see Figure 16.3.4), concrete, steel, or a combination of materials depending on the design requirements although concrete pontoons are generally used in the newer bridges.

The pontoons are large water-tight chambers constructed off site and floated into place (see Figures 16.3.5 and 16.3.6). Despite their heavy concrete composition, the weight of the water displaced by the pontoons is equal to the weight of the structure (including all traffic), which allows the bridge to float. They may be prestressed concrete or reinforced concrete and are classified as either continuous pontoon type or separate pontoon type. The pontoons are held into place by huge steel cables anchored deep in the soil below water.

Figure 16.3.4 Brookfield, Vermont, Floating Bridge Constructed from Timber

Figure 16.3.5 Concrete Pontoons Under Construction

Figure 16.3.6 Concrete Pontoons Transported for Hood Canal Project

To control water leaking into the interior of the pontoons and ultimately sinking the bridges, each pontoon contains several water tight cells. This confines any flooding to a small area of the bridge. Access doors to the interior cells are watertight. Each cell may be equipped with water sensors for early detection of any leaks in the pontoons and a bilge pumping system to pump out water.

Bridge pontoons are designed to safely withstand wind and wave forces, major storms and vessel collisions.

Continuous Pontoons

Continuous pontoon bridges are made of individual pontoons, longitudinally connected to each other. The top of the pontoons may be the roadway or a superstructure may be built on top of the pontoons. The size of each pontoon is determined by design requirements as well as constraints imposed by the constructions facilities and the transportation route to the bridge site.

The floating bridges in use today in Washington State are of the continuous type (see Figure 16.3.7).

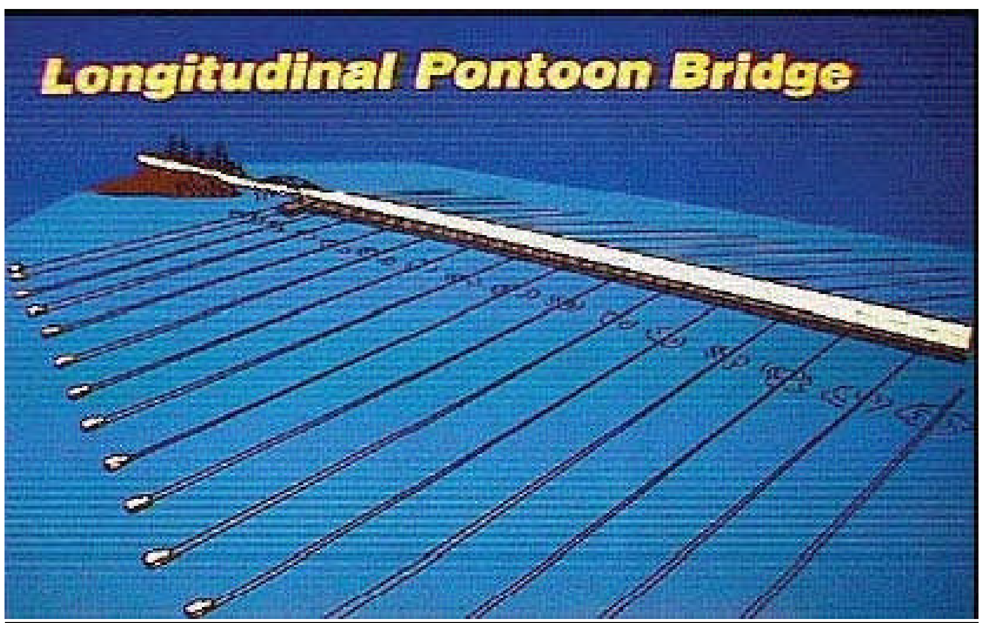

Figure 16.3.7 Continuous Pontoon-Type Structure

Separate Pontoons

A separate pontoon type of floating bridge consists of individual pontoons. These pontoons are placed transversely to the structure and are spanned by a steel or concrete superstructure (see Figures 16.3.8 and 16.3.9). The superstructure needs to be strong enough and rigid enough to maintain the position of the separated pontoons. A series of cables are attached to each pontoon and are anchored deep in the soil below water.

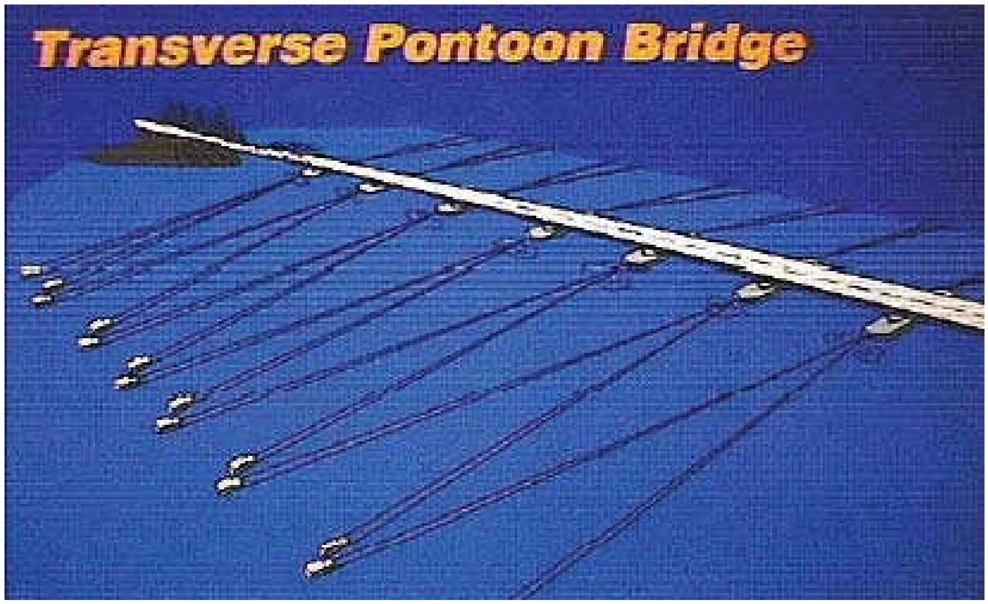

Figure 16.3.8 Separate Pontoon Type Structure

Figure 16.3.9 Bridge Constructed with Separate Pontoons

Anchoring Systems

Floating bridges are held in place in various ways such as a system of piles, caissons, cables, anchors and fixed guide structures. The most common type of system consists of cables and anchors. Anchor cables are normally two and one half inches in diameter and consist of dozens of individual steel strands (see Figure 16.3.10).

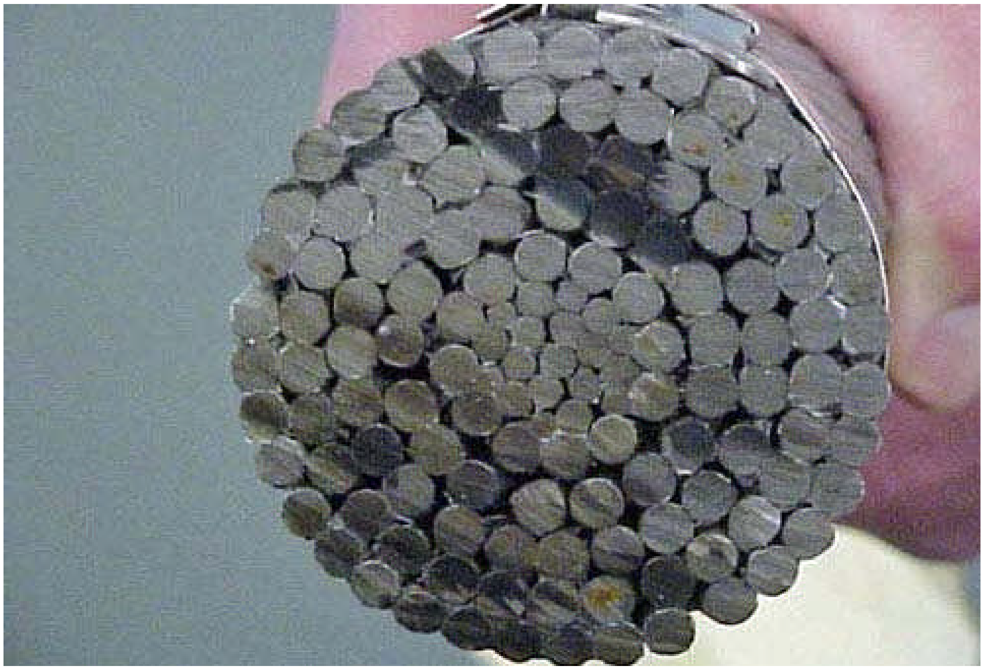

Figure 16.3.10 Cross-Section of Anchor Cable

Anchor cable saddles are used within the pontoon to guide and hold the cable in place (see Figure 16.3.11). Hydraulic jacks inside the pontoon tighten or release the pressure on the cables as the water level fluctuates under the bridge.

Figure 16.3.11 Anchor Cable Saddle

Types of Anchoring Systems

Depending on the depth of the water and the soil conditions, there are four primary types of anchoring systems used on the floating bridges: precast concrete fluke style anchor, pile anchor, open-cell gravity block anchor, and solid gravity slab anchor (stackable).

Precast Concrete Fluke Style Anchor

Precast concrete fluke style anchors are used in deep water with very soft soil conditions. Anchors weighing 60 to 86 tons are lowered to the soil below water. Water jets are turned on allowing the anchors to sink to the proper depth (see Figure 16.3.12).

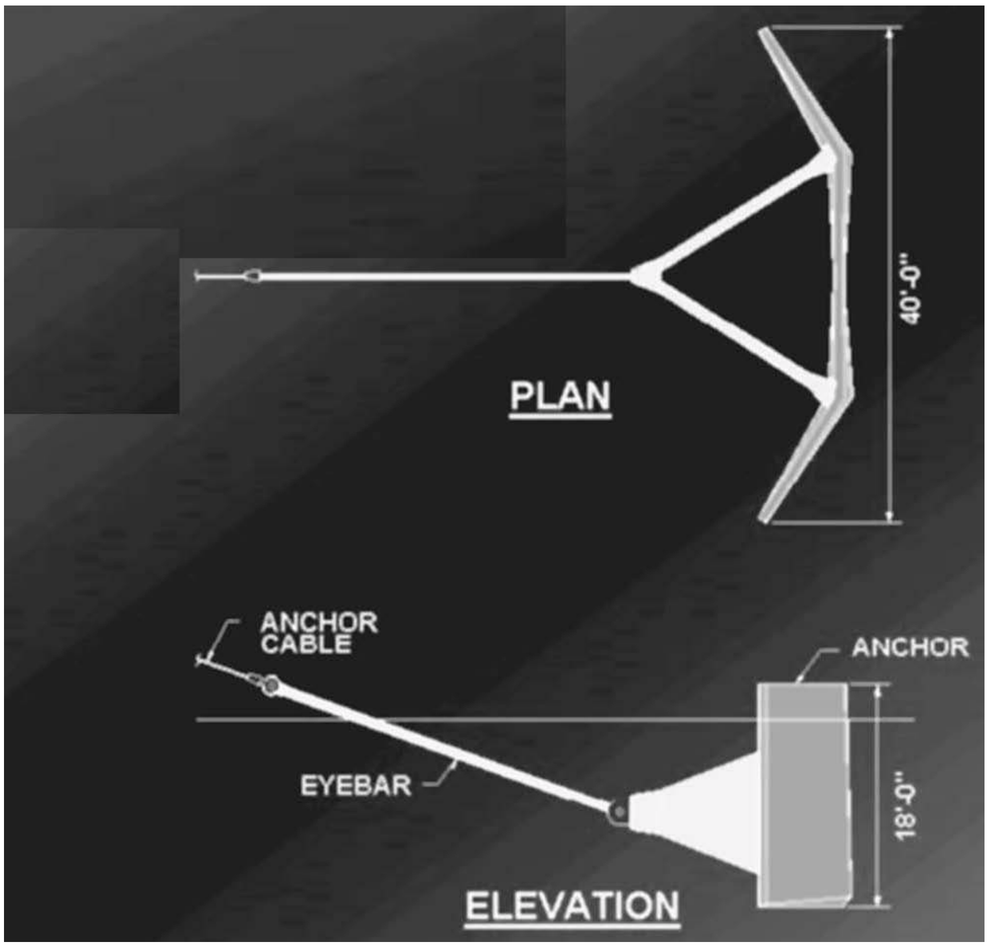

Figure 16.3.12 Precast Concrete Fluke Style Anchor

Pile Anchor

Pile anchors are designed for use in water depths less than 88 feet and with hard soil. Piles are driven into the surface to a specified depth and tied together to increase capacity (see Figure 16.3.13).

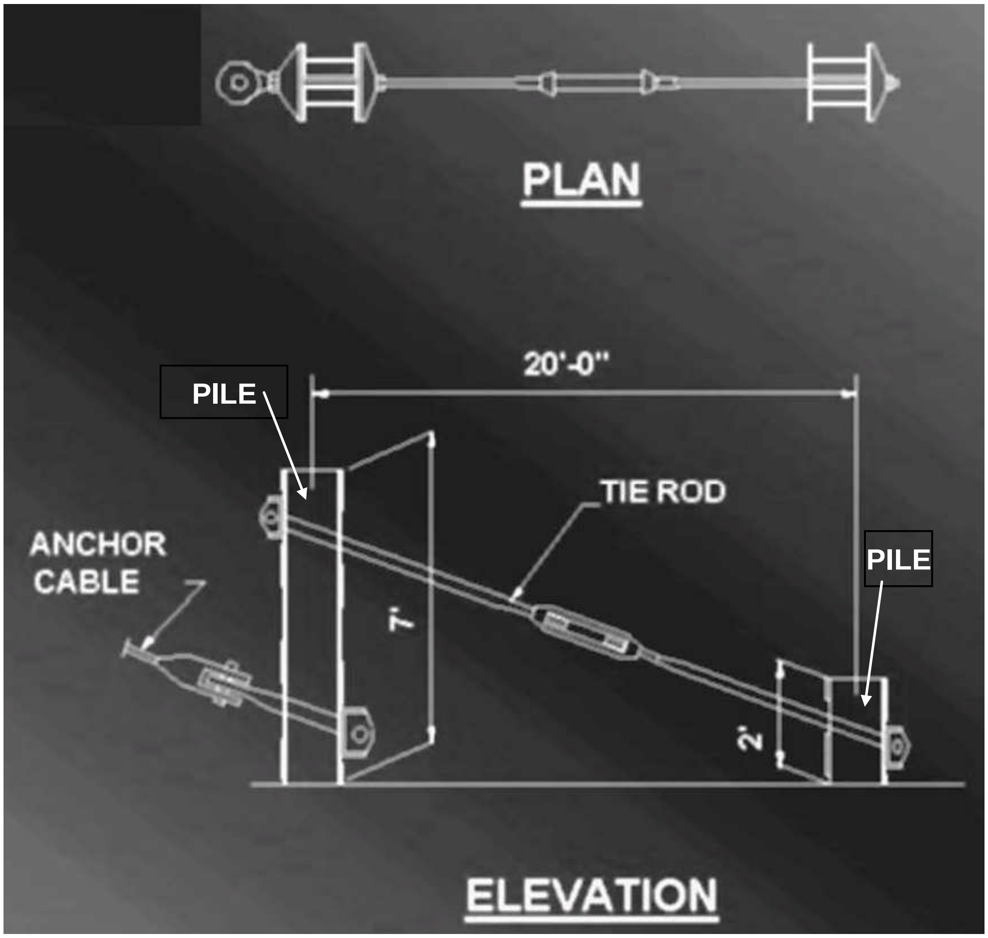

Figure 16.3.13 Pile Anchor

Open-Cell Gravity Block Anchor

Open-cell gravity block anchors are a gravity type of anchor. They are reinforced concrete boxes with an open top that are lowered into position and filled with gravel to a predetermined weight. This type or anchor is used in deep water where the soil is hard (see Figure 16.3.14).

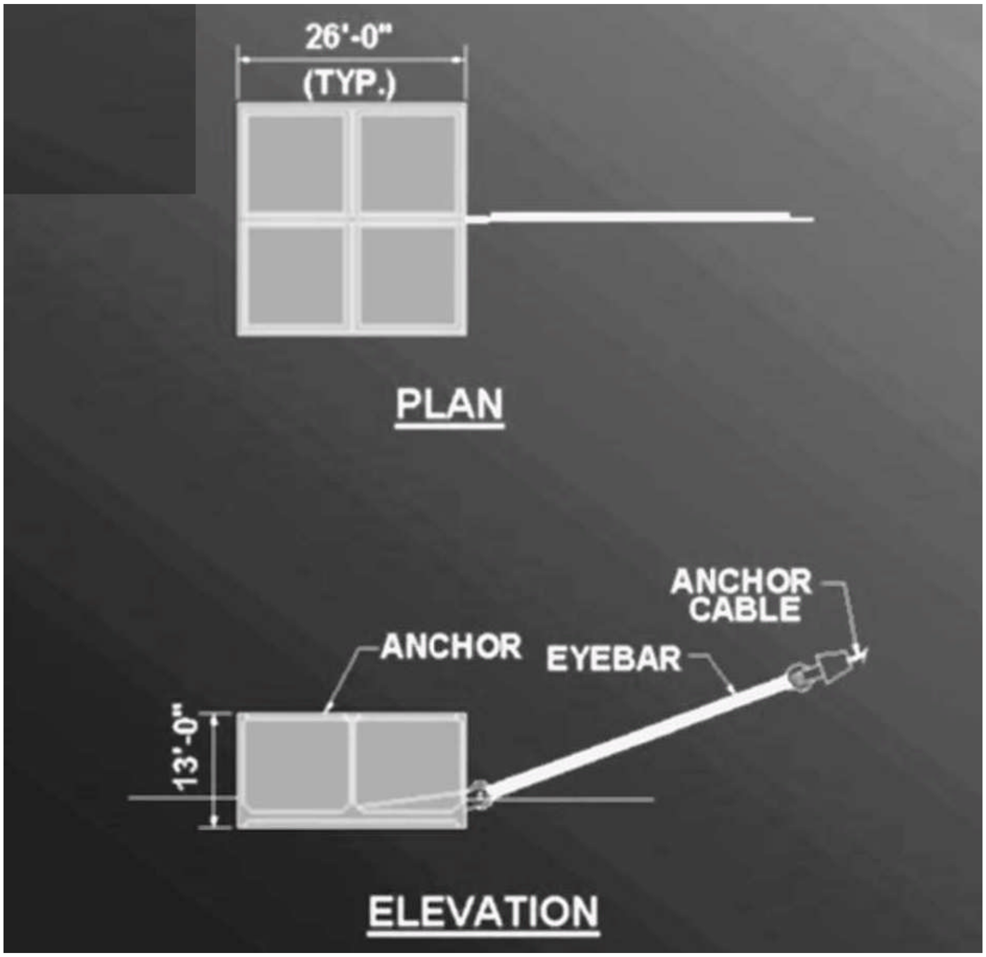

Figure 16.3.14 Open-Cell Gravity Block Anchor

Solid Gravity Slab Anchor (Stackable)

Solid gravity slab anchors are a gravity type of anchor. They can be used in either shallow or deep water where the soil is hard. These anchors are solid reinforced concrete slabs weighing up to 270 tons each. The first slab is lowered into position, and then additional slabs are added until the required anchoring capacity has been reached. Solid gravity slab anchors are the preferred anchor type because they are easy to cast and can be placed quickly (see Figure 16.3.15).

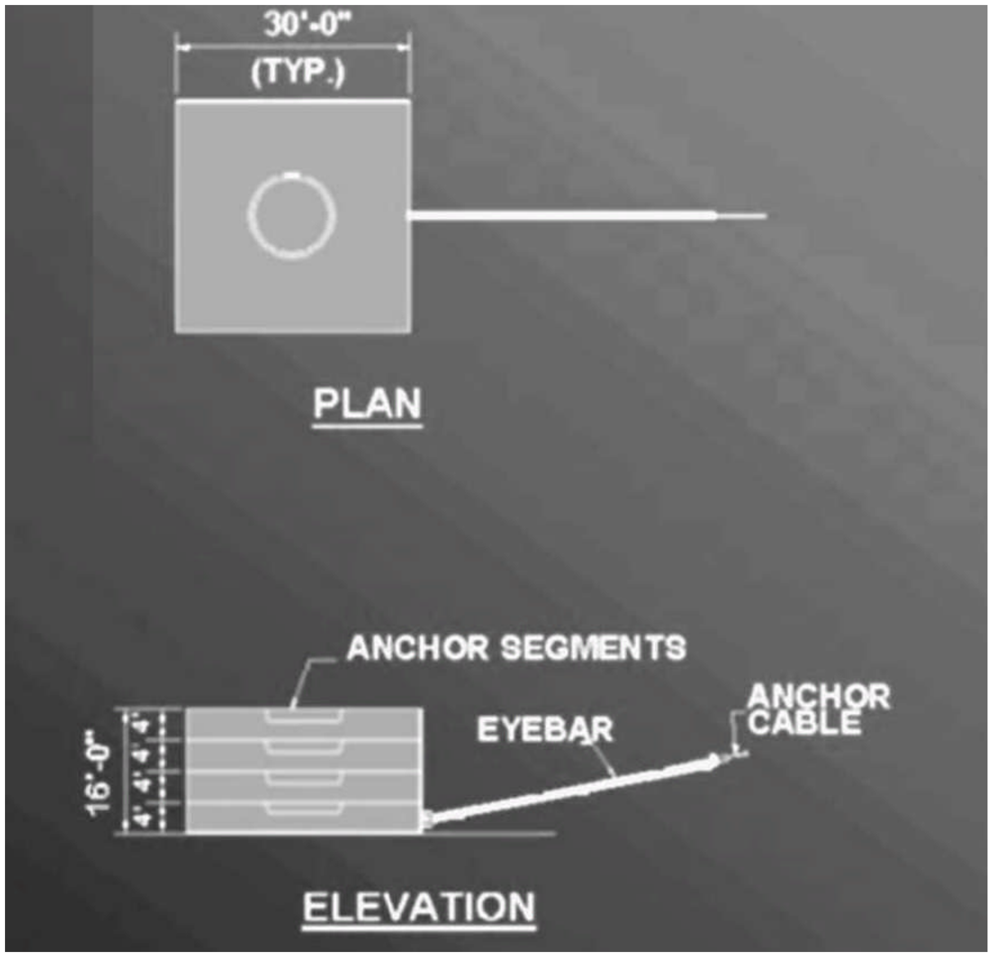

Figure 16.3.15 Solid Gravity Slab Anchor

16.3.3 Overview of Common Deficiencies

Common deficiencies that occur on floating bridges are:

- Corrosion of anchor cables
- Fatigue cracking
- Overloads
- Collision damage
- Water infiltration

Floating bridges may be constructed from steel, concrete or timber. Therefore, deficiencies will depend on the material used to construct the bridge. See Topics 6.1 (Timber), 6.2 (Concrete), and 6.3 (Steel) for specific information regarding deficiencies of each material type.

16.3.4 Inspection Locations and Methods

Because of their uniqueness and depending on the material used, floating bridges can prove challenging to an inspector. Floating bridges can be constructed of steel, concrete or timber, therefore a variety of inspection methods are utilized to thoroughly inspect the bridge. Additionally, since many floating bridges include an elevated conventional bridge structure or a moveable bridge section, those inspection methods and locations are to be considered by the inspection team.

See Chapter 6 for detailed description of anticipated modes of deterioration for common bridge materials. See Chapters 8 through 12 for the inspection and evaluation of timber superstructures, concrete superstructures, steel superstructures, bearings and substructures. See Topic 16.2 for detailed information about movable bridges.

Methods

Visual

Visual inspection of each pontoon cell will reveal any cracks or leaks. Pontoons have access hatches to allow for maintenance and inspection (see Figure 16.3.16).

Visually inspect concrete pontoons for the following deficiencies:

- Cracking
- Spalling
- Delamination
- Overload damage
- Collision damage
- Abrasion
- Loss of watertight seals on access doors and hatches
- Damaged cable connections

Visually inspect steel pontoons for the following deficiencies:

- Cracking
- Overload damage
- Collision damage
- Loss of watertight seals on access doors and hatches
- Coating failure
- Corrosion and section loss
- Damaged cable connections

Figure 16.3.16 Inspector Opening Pontoon Access Hatch

Physical

Measure and record the depth of any water found in each cell. The length, location and width of cracks found are to be accurately measured and recorded (see Figure 16.3.17). For steel pontoons and cables, remove corrosion and rust down to bare metal. With calipers or a D-meter, measure and record remaining section thickness. Use a hammer to check for delaminated areas in concrete pontoons.

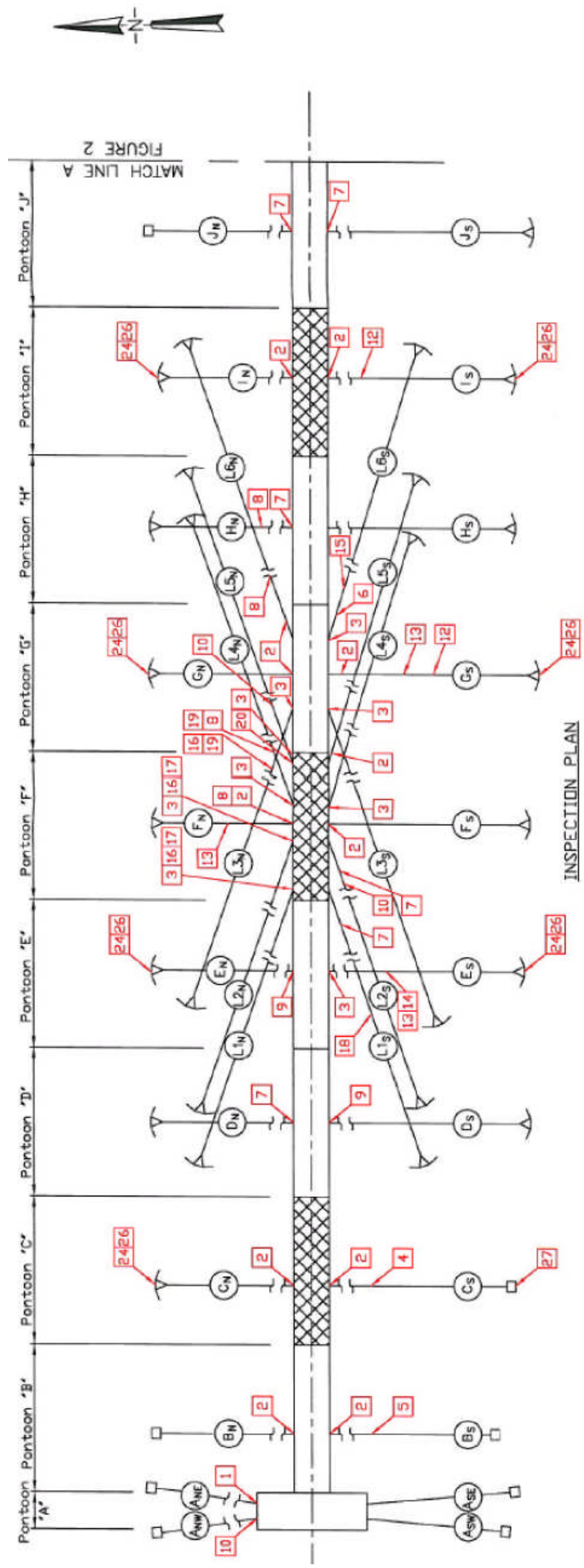

Figure 16.3.17 Sample Pontoon Inspection Plan

Advanced Inspection Methods

Many of the advanced inspection tools used above water have been adopted for underwater use. See Chapter 15 for the advanced inspection methods of timber, steel and concrete.

Anchors may be embedded 100 or more feet below the water surface. Inspection of the anchors will require underwater divers and equipment with the ability to detect any deficiencies present. See Topic 13.3, Underwater Inspection. Underwater cameras, sonar and other specialized equipment can provide access to cables and anchors.

Locations

Pontoons

Examine the floor of each pontoon cell for standing water. Examine pontoon walls and surfaces for cracks. Examine access doors, locks and hatches verifying that they are water tight and in proper working condition. Check the bilge pumping system and verify that it is in working order. Convey any noted problems with the pumping system to specialized maintenance personnel responsible for the system.

Examine the cable ends and anchor cable saddle inside the pontoon. Look at the connections in the pontoons for frayed or broken strands. Verify the presence and functioning of any cathodic protection system on the anchor cables.

Joints

When continuous pontoons are used, inspect the joint between the pontoons. Typically a rubber membrane or grout is used between the pontoons. Examine the alignment of the pontoons across the structure looking for signs of differential movement or distortion. This may indicate water leaking into one of the pontoons or some type of ballast balancing problem within the structure.

Cables

Examine the cable ends at the pontoon portals and check for cable misalignment and fraying. Check for broken wires that may indicate undue stress on the cable securing the pontoon (see Figure 6.3.18). Also check cables for heavy corrosion or section loss (see Figure 6.3.19).

Figure 16.3.18 Frayed Cables Removed from a Floating Bridge

Figure 16.3.19 Typical View of Heavy Corrosion within Pontoon Port

Anchors

Floating bridges are subjected to wind, tides and wave forces that are unpredictable and always changing. This exerts high levels of strain and stress on the cables and the anchors. Inspection of the anchors is not easily accomplished. Underwater remote equipment can provide information on each anchor. Look for any indication of anchor movement, misalignment or undermining of the anchor. Check the ballast on open-cell gravity block anchors to verify if there is enough material to keep the anchors in place.

16.3.5 Evaluation

State and Federal rating guideline systems have been developed to aid in the inspection of floating bridges. The two major rating guideline systems currently in use are the FHWA's *Recording and Coding Guide for the Structural Inventory and Appraisal of the Nation's Bridges* used for the National Bridge Inventory (NBI) component condition rating method and the AASHTO *Guide Manual for Bridge Element Inspection* for element level condition state assessment.

NBI Component Condition Rating Guidelines

Using the NBI component condition rating guidelines, a one-digit code on the Federal Structure Inventory and Appraisal (SI&A) sheet indicates the condition of the superstructure. Component condition rating codes range from 9 to 0 where 9 is the best rating possible. See Topic 4.2 (Item 59) for additional details about NBI component condition rating guidelines.

Consider previous inspection data along with current inspection findings to determine the correct component condition rating.

Element Level Condition State Assessment

In an element level condition state assessment of a floating bridge, possible AASHTO National Bridge Elements (NBEs) and Bridge Management Elements (BMEs) are:

NBE No.	Description
Superstructure	
107	Steel Girder/Beam
102	Steel Closed Web/Box Girder
113	Steel Stringer
152	Steel Floorbeam
147	Steel Cables
109	Prestressed Concrete Girder/Beam
104	Prestressed Concrete Closed Web/Box Girder
115	Prestressed Concrete Stringer
154	Prestressed Concrete Floorbeam
110	Reinforced Concrete Girder/Beam
105	Reinforced Concrete Closed Web/Box Girder
116	Reinforced Concrete Stringer
155	Reinforced Concrete Floorbeam
111	Timber Girder/Beam
117	Timber Stringer
156	Timber Floorbeam
Substructure	
310	Elastomeric Bearing
311	Moveable Bearing (roller, sliding, etc)
312	Enclosed/Concealed Bearing
313	Fixed Bearing
314	Pot Bearing
315	Disk Bearing

BME No.	**Description**
Wearing Surfaces and Protection Systems	
510	Wearing Surfaces
515	Steel Protective Coating
525	Concrete Protective Coating

The unit quantity for the superstructure elements is feet. The total length is distributed among the four available condition states depending on the extent and severity of the deficiency. The unit of quantity for bearings is each, with each bearing element placed in one of the four available condition states depending on the extent and severity of the deficiency. The unit quantity for wearing surfaces and protective coatings is area, and the total area is distributed among the four available condition states depending on the extent and severity of the deficiency. The sum of all condition states equals the total quantity of the National Bridge Element or Bridge Management Element. Condition State 1 is the best possible rating. See the *AASHTO Guide Manual for Bridge Element Inspection* for condition state descriptions.

The following Defect Flags are applicable in the evaluation of floating bridges:

Defect Flag No.	**Description**
356	Steel Cracking/Fatigue
357	Pack Rust
358	Concrete Cracking
359	Concrete Efflorescence
360	Settlement
361	Scour
362	Superstructure Traffic Impact (load capacity)
363	Steel Section Loss
364	Steel out-of-plane (Compression Member)

See the AASHTO *Guide Manual for Bridge Element Inspection* for the application of Defect Flags.