Table of Contents

Section 8
Inspection and Evaluation of Common Steel Superstructures

Topic 8.7 Steel Eyebars

8.7.1 Introduction

Eyebars are tension only members that require pins to make their end connections. Eyebars are predominantly found on older truss bridges, but can also be found on suspension chain bridges and as anchorage bars embedded within the substructures of long span bridges (see Figures 8.7.1 to 8.7.4).

Figure 8.7.1 Typical Eyebar Tension Member on a Truss

Figure 8.7.2 Eyebar Cantilevered Truss Bridge (Queensboro Bridge, NYC)

Figure 8.7.3 Eyebar Chain Suspension Bridge

Figure 8.7.4 Anchorage Eyebar

Heat treated steel eyebars have been used in bridges all over the world. One of these eyebars failed on December 15, 1967, sending the Point Pleasant Bridge (Silver Bridge), built in 1928, into the Ohio River between Point Pleasant, West Virginia and Kanauga, Ohio (see Figure 8.7.5). Forty-six people died and nine were injured due to the fracture of an eyebar in the north suspension chain on the Ohio side.

Figure 8.7.5 Collapsed Silver Bridge

Since the collapse of the Silver Bridge, there has been considerable public and professional concern over the safety of existing bridges, especially those containing eyebars. Many of these structures have been inspected and analyzed (see Figure 8.7.6). As a result, costly structural modifications and retrofits were made to many of these bridges (see Figure 8.7.7), while some others have been demolished. Eyebars are rarely used in new bridge designs but are present on many existing bridges.

Figure 8.7.6 Inspection of Eyebars

Figure 8.7.7 Retrofit of Eyebars to Add Redundancy

The design of the eyebar connections does not allow for inspection by common techniques. These connections collect water and promote corrosion at the critical point on the eyebar head (see Figure 8.7.8).

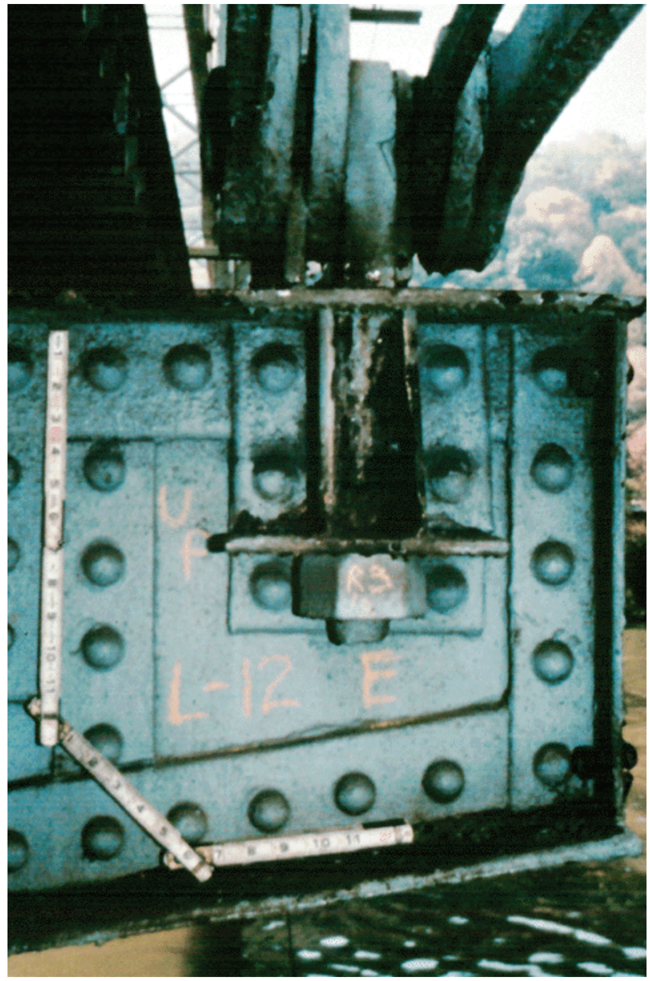

Figure 8.7.8 Eyebar Connection with Corrosion

8.7.2 Design Characteristics

Development of Steel Eyebars

In the late 1800's and early 1900's bridge spans began to increase in length, providing a need for higher strength steel. Prior to this time eyebars were made of wrought iron. The Eads Bridge in St. Louis, completed in 1874, was the first major steel bridge in America and the first in the world to use alloy steel. (see Figure 8.7.9).

Figure 8.7.9 Eads Bridge, St. Louis

Nickel alloy steel eyebars were developed around 1900. Nickel steel showed high physical properties with a yield point of 380 MPa (55,000 psi) and an ultimate strength of 620 MPa (90,000 psi). The major disadvantage of this steel was that it cost 2-1/2 cents per pound more than common carbon steel. Nickel steel was also difficult to roll without surface defects.

Sometime around 1915 mild grade heat treated steel eyebars (basically a "1035" steel) were developed with an ultimate strength of 550 MPa (80,000 psi) and a yield point of 345 MPa (50,000 psi). These eyebars were only 1 cent more per pound than common carbon steel.

In 1923 a high tension, mild grade heat treated steel eyebar was developed. The guaranteed minimum ultimate strength of 725 MPa (105,000 psi) and minimum yield point of 515 MPa (75,000 psi) made these bars equal to wire cable with added stiffness but no added cost. These "1060" steel eyebars were used on the Silver Bridge.

These heat treated alloy steels were extremely strong and contributed to substantial cost savings, but they could not be easily welded.

Forging

The ends of the eyebar shanks are connected by forging. Forging is a method of hot working to form steel by using hammering or pressing techniques.

Hammering

Hammering was the first method employed in shaping metals. An early form of the eyebar, shaped in this manner, is known as a loop rod (see Figures 8.7.10 and 8.7.11). Loop rods were first made of wrought iron, and later steel, by forging a heated bar around a pin, pounding the bar until a closed loop was formed.

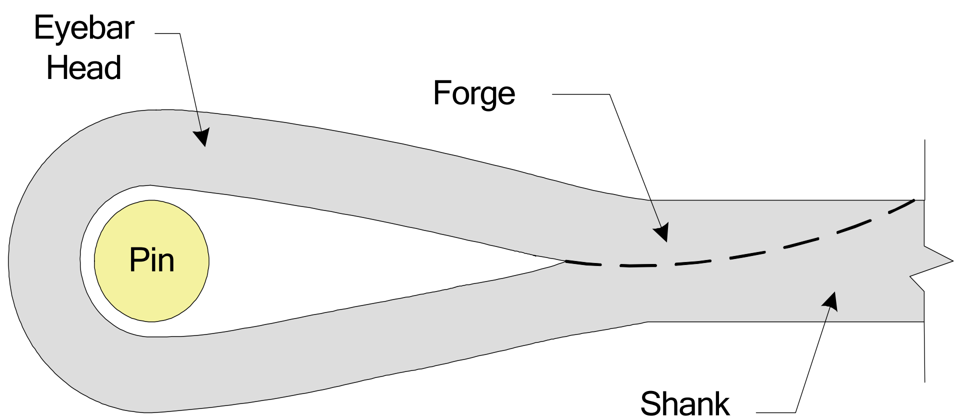

Figure 8.7.10 Forged Loop Rod

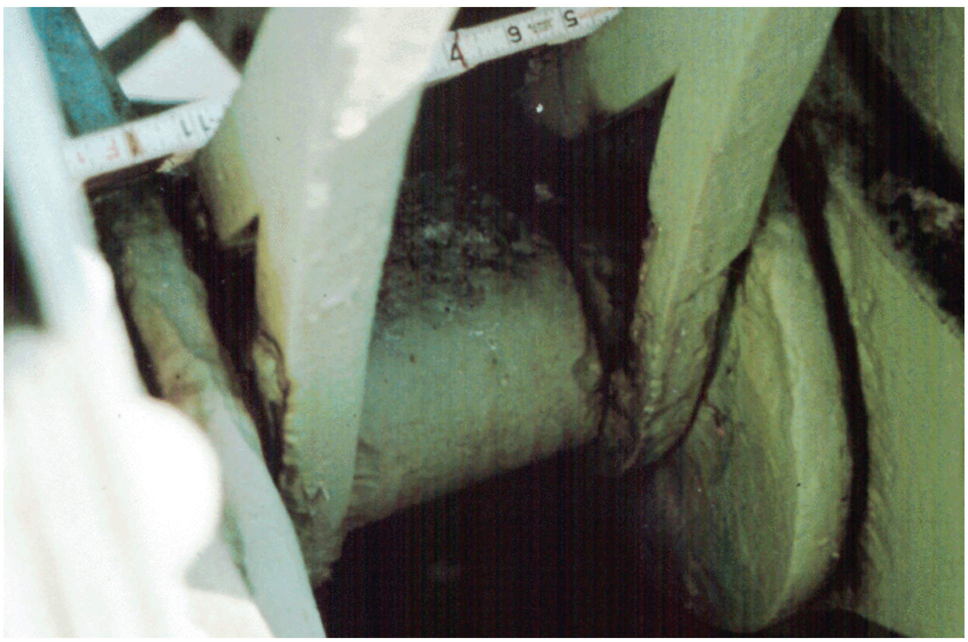

Figure 8.7.11 Close-up of the End of a Loop Rod

Pressing

Steel eyebars were also formed with a special type of mechanical forge press called an upsetting machine. The eyebar consists of the two heads (formed by casting) joined to the ends of the shaft. The upsetting machine clamps the eyebar pieces between two dies with vertical faces. The eyebar is then forged and shaped by the horizontal action of a ram operated by a crankshaft (see Figure 8.7.12). Most other forging presses operate with vertical rams.

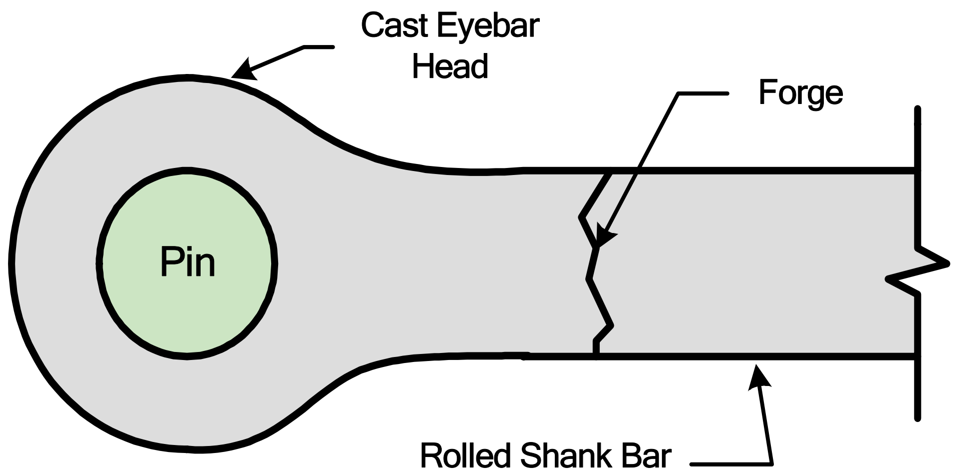

Figure 8.7.12 Forged Eyebar

Pin Hole

The pin hole in the enlarged head of the eyebar is commonly formed by boring. To fabricate the hole, flame cutting is permitted to within 50 mm (2 inches) of the pin diameter (see Figure 8.7.13).

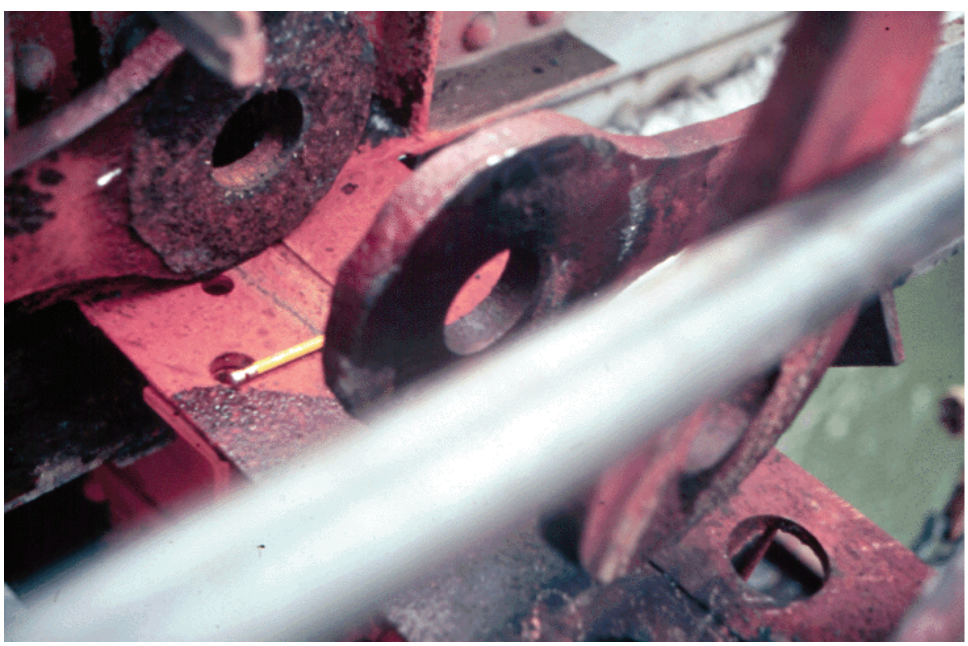

Figure 8.7.13 Eyebar Pin Hole (Disassembled Connection)

Heat Treating and Annealing

The inspector may find the terms "heat treated" and "annealed" on bridge plans to describe eyebars. Heat treating of steel is an operation in which the steel is heated and cooled, under controlled conditions according to a predetermined schedule, for the purpose of obtaining certain desired properties.

Through heat treatment various characteristics of steel can be enhanced. If steel is to be formed into intricate shapes, it can be made very soft and ductile by heat treatment. On the other hand, if it is to resist wear, it can be heat treated to a very hard, wear-resisting condition.

Annealing is a term used to describe several types of heat treatment which differ greatly in procedure yet all accomplish one or more of the following effects:

- Remove internal stresses
- "Soften", by altering mechanical properties
- Redefine the grain structure
- Produce a definite microstructure

More than one of these effects can often be obtained simultaneously.

Dimensions

The dimensions of a typical eyebar are as follows:

- Thickness - usually 25 to 50 mm (1 to 2 inches)
- Width - usually 200 to 400 mm (8 to 16 inches)
- Length - varied with bridge design

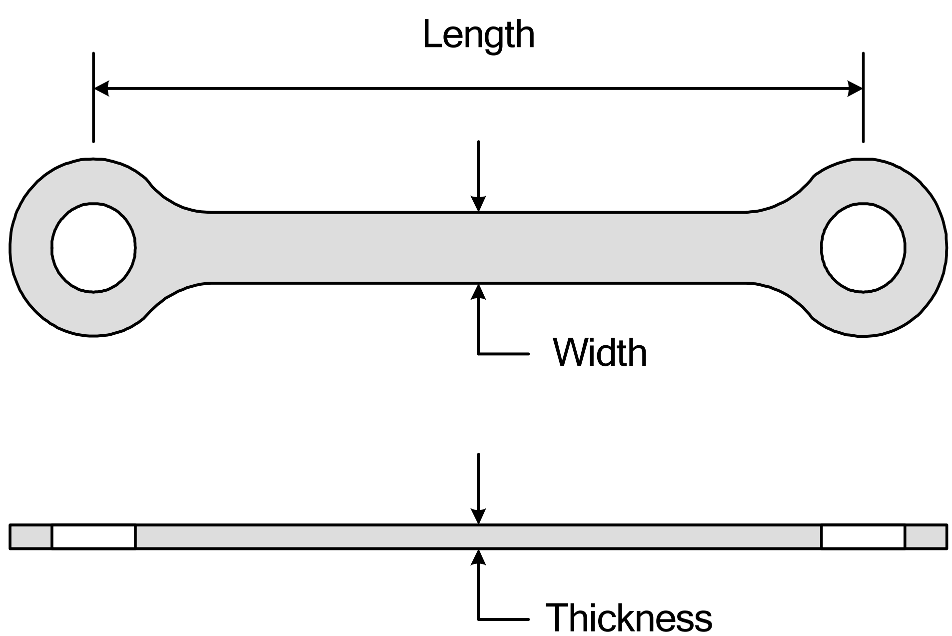

Figure 8.7.14 Eyebar Dimensions

The eyebars on the Silver Bridge were between 13.7 to 16.8 m (45 and 55 feet) in length, 300 mm (12 inches) wide, and varied in thickness.

Packing

Packing is the term used to describe the arrangement of all the eyebars at a given point. Eyebars may be tightly packed together or spread apart (see Figures 8.7.15 and 8.7.16). The packing should be symmetrical about the center-line of the member.

Figure 8.7.15 Loosely Packed Eyebar Connection

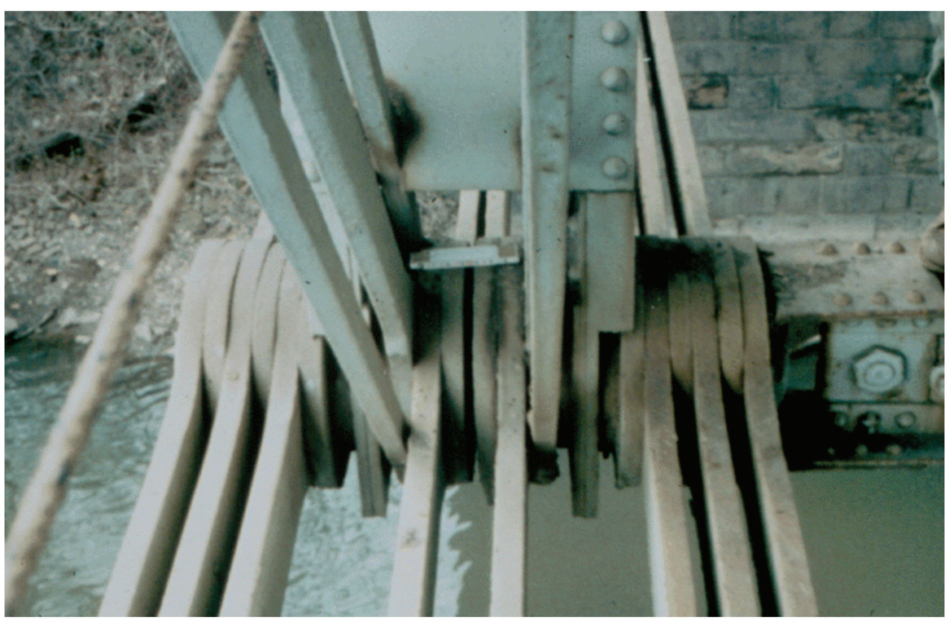

Figure 8.7.16 Tightly Packed Eyebar Connection

Spacers

Spacers or steel filling rings are often wrapped around the pin to prevent lateral movement within the eyebar pack (see Figure 8.7.17).

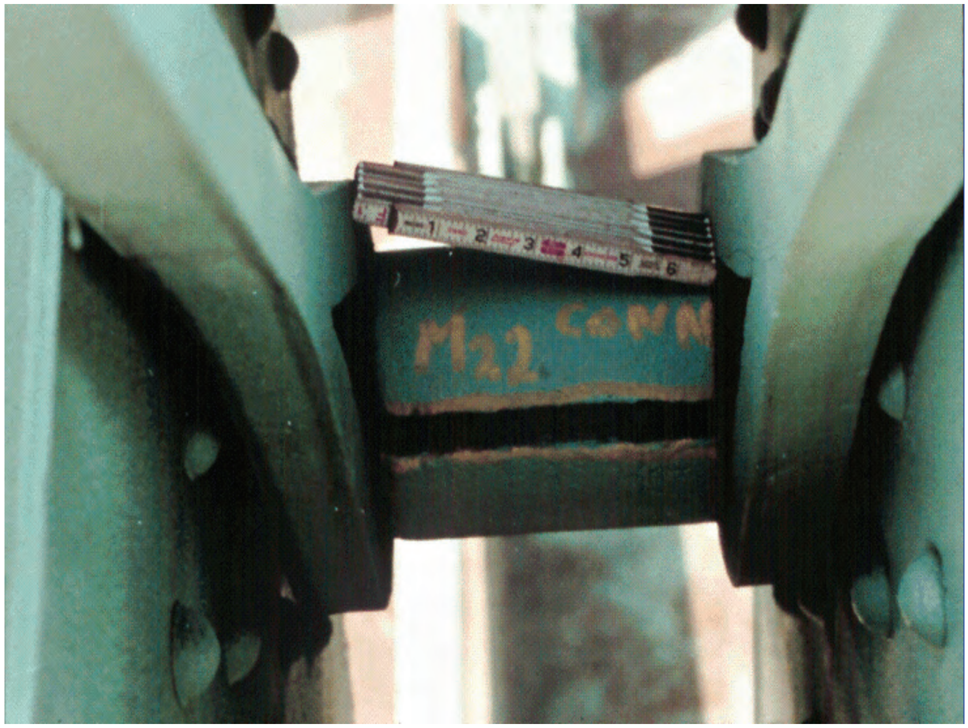

Figure 8.7.17 Steel Pin Spacer or Filling Ring

Redundancy

An internally redundant eyebar member will consist of three or more eyebars. Many eyebar members are internally non-redundant, having only one or two eyebars per member (see Figure 8.7.18).

The collapse of the Silver Bridge is attributed to the failure of an eyebar within a nonredundant eyebar member. When the first eyebar failed, the second eyebar was unable to carry the load due to lack of internal redundancy. The Silver Bridge was also not load path redundant which contributed to the complete collapse of the structure. Load path and internal (member) redundancy are discussed in detail in Topics P.2 and 8.1.

Figure 8.7.18 Nonredundant Eyebar Member

8.7.3 Overview of Common Defects

Common defects that occur on steel multi-beam and fabricated multi-girder bridges are:

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

See Topic 2.3 for a detailed presentation of the properties of steel, types and causes of steel deterioration, and the examination of steel. Refer to Topic 8.1 for Fatigue and Fracture in Steel Bridges.

8.7.4 Inspection Procedures and Locations

Inspection procedures to determine other causes of steel deterioration are discussed in detail in Topic 2.3.8.

Procedures

Visual

The inspection of steel bridge members for defects is primarily a visual activity.

Most defects in steel bridges are first detected by visual inspection. In order for this to occur, a hands-on inspection, or inspection where the inspector is close enough to touch the area being inspected, is required. More exact visual observations can also be employed using a magnifying unit after cleaning the paint from the suspect area.

Physical

Removal of paint can be done using a wire brush, grinding, or sand blasting, depending on the size and location of the suspected defect. The use of degreasing spray before and after removal of the paint may help in revealing the defect.

When section loss occurs, use a wire brush, grinder or hammer to remove loose or flaked steel. After the flaked steel is removed, measure the remaining section and compare it to a similar section with no section loss.

The usual and most reliable sign of fatigue cracks is the oxide or rust stains that develop after the paint film has cracked. Experience has shown that cracks have generally propagated to a depth between one-fourth and one-half the plate thickness before the paint film is broken, permitting the oxide to form. This occurs because the paint is more flexible than the underlying steel.

Smaller cracks are not likely to be detected visually unless the paint, mill scale, and dirt are removed by carefully cleaning the suspect area. If the confirmation of a possible crack is to be conducted by another person, it is advisable not to disturb the suspected crack area so that re-examination of the actual conditions can be made.

Once the presence of a crack has been verified, the inspector should examine all other similar locations and details.

Advanced Inspection Techniques

Several advanced techniques are available for steel inspection.

Nondestructive methods, described in Topic 13.3.2, include:

- Acoustic emissions testing
- Computer programs
- Computer tomography
- Corrosion sensors
- Smart paint 1
- Smart paint 2
- Dye penetrant
- Magnetic particle

- Radiographic testing
- Robotic inspection
- Ultrasonic testing
- Eddy current

Other methods, described in Topic 13.3.3, include:

- Brinell hardness test
- Charpy impact test
- Chemical analysis
- Tensile strength test

Locations

Forge Zone

Inspect carefully the forged area around the eyebar head and the shank for cracks. Check the loop rods for cracks where the loop is formed (see Figure 8.7.19). Most eyebar failures are likely to occur in the forge zone.

Figure 8.7.19 Close-up of the Forge Zone on an Eyebar (Arrow denotes crack)

Tension Zone

Since an eyebar carries axial tension, the entire length must be closely examined for deficiencies that can initiate a crack. These deficiencies include notch effects due to mill flaws, corrosion or mechanical damage. The area around the eye and the transition to the shank where stress is the highest is the most critical.

Alignment

Check the alignment of the shank along the full length of the eyebar. Since the eyebar is a tension member, it should be straight. A bowed eyebar indicates that a compressive force has been introduced (see Figure 8.7.20).

Figure 8.7.20 Bowed Eyebar Member

Misalignment due to buckling can also be caused by movement at the substructure or changes in loading during rehabilitation (see Figures 8.7.21and 8.7.22). The eyebars of the same member should be parallel and evenly loaded.

Figure 8.7.21 Buckled Eyebar due to Abutment Movement

Figure 8.7.22 Non-parallel Eyebar Member

Areas That Trap Water and Debris

Areas that trap water and debris can result in active corrosion cells that can cause notches susceptible to fatigue or perforation and loss of section. On eyebar members, check the area between the eyebars especially if they are closely spaced.

Spacers

Examine the spacers on the pins to be sure they are holding the eyebars in their proper position (see Figure 8.7.23).

Figure 8.7.23 Corroded Spacer

Examine closely spaced eyebars at the pin for corrosion build-up (packed rust). These areas do not always receive proper maintenance due to their inaccessibility. Extreme pack rust can deform retainer nuts or cotter pins and push the eyebars off the pins.

Verify the eyebars are symmetrical about the central plane of the spacer (see Figure 8.7.24).

Figure 8.7.24 Symmetry at an Eyebar Connection

Areas Exposed to Traffic

Check underneath the bridge for collision damage if the bridge crosses over a highway, railway, or navigable channel. Document any cracks, section loss, or distortion found. On a suspension bridge using eyebars, investigate the eyebars along the curb lines and at the ends for collision damage.

Load Distribution

Check to determine if any eyebars are loose (unequal load distribution) or if they are frozen at the ends - preventing free rotation (see Figure 8.7.25). Check for panel point pins or eyebar twisting.

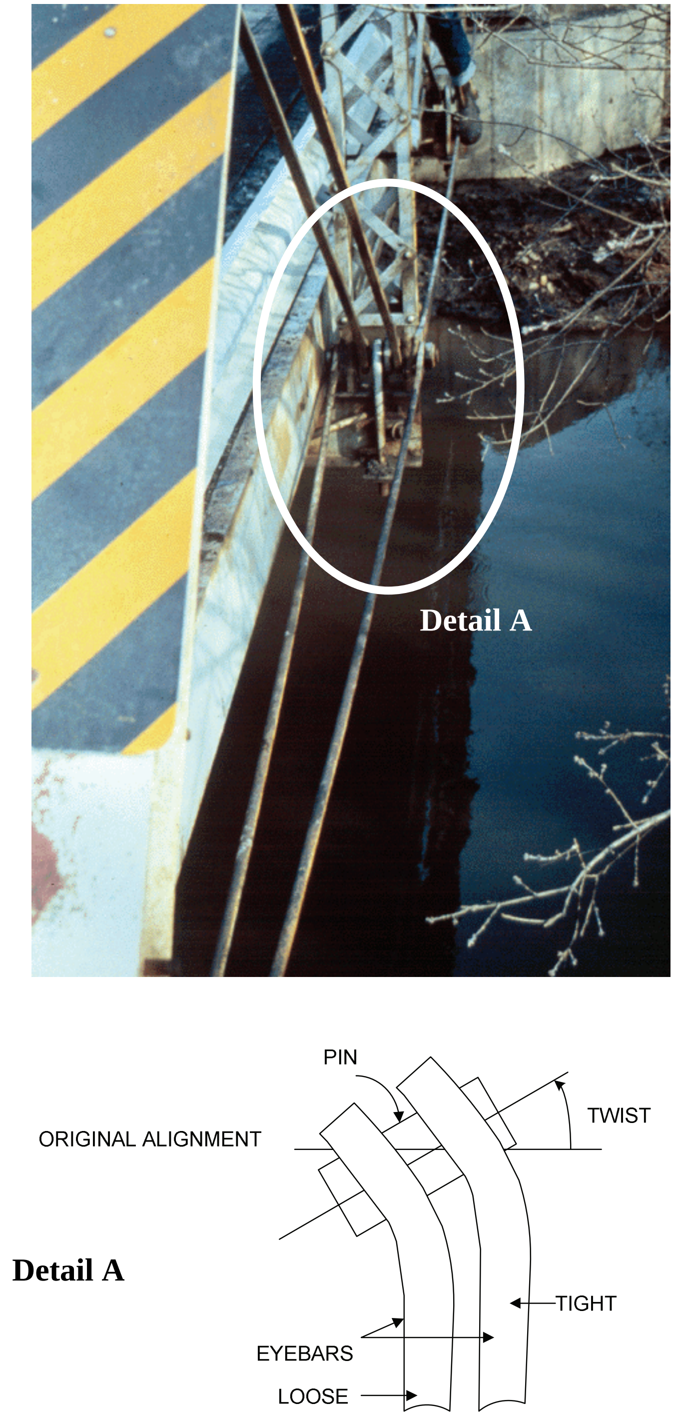

Figure 8.7.25   Eyebar Member with Unequal Load Distribution

Weldments

Evaluate the integrity of any welded repairs to the eyebar (see Figure 8.7.26). Check for any unauthorized welds and include their locations in your report so that the engineer can analyze the severity of their effect on the member (see Figure 8.7.27). Most of these bridges are old and constructed of steel which is considered "unweldable" by today's standards. It is difficult to obtain a high quality "field" weld.

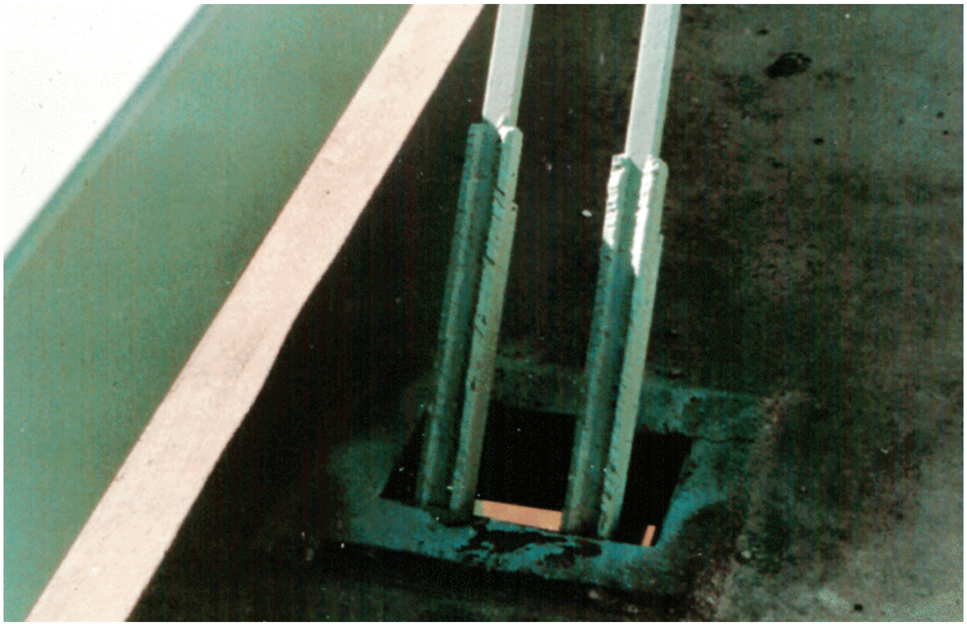

Figure 8.7.26 Welds on Loop Rods

Figure 8.7.27 Welded Repair to Loop Rods

Turnbuckles

Examine any threaded rods in the area of the turnbuckle for corrosion, wear and repairs. Turnbuckles are often located in counter diagonals (see Figures 8.7.28 and 8.7.29).

Figure 8.7.28 Turnbuckle on a Truss Diagonal

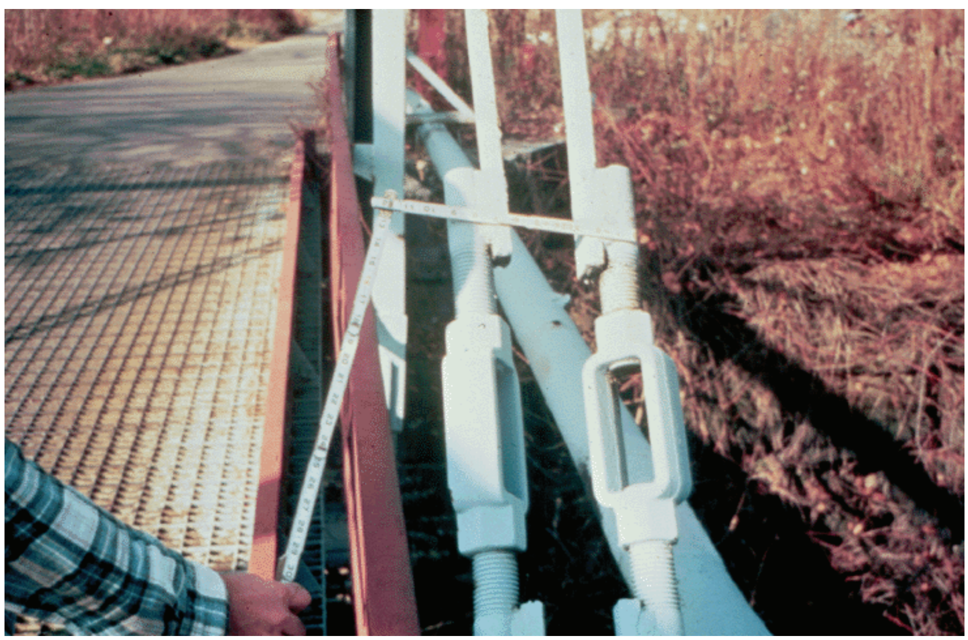

Figure 8.7.29 Welded Repair to Turnbuckles

Pins

Pins should be inspected for signs of wear and corrosion. Nondestructive methods such as ultrasonic inspection are recommended since visual inspection cannot reveal internal material flaws that may exist (see Figure 8.7.30).

Figure 8.7.30 Ultrasonic Inspection of Eyebar Pin

Fracture Critical Members

Eyebars are normally used on truss or suspension bridges. Since these bridge types normally only have two load paths between substructure supports, the bridges are considered non-load path redundant. If a steel eyebar member in tension fails causing a total or partial collapse of the bridge, that eyebar is considered a fracture critical member. Truss members that have three or more eyebars between panel points may be considered internally redundant (see Figures 8.7.31 and 8.7.32). See Topic 8.1 for a detailed discussion on fracture critical members and types of redundancy.

Figure 8.7.31 Fracture Critical Bottom Chord Truss Member: Internally Non-redundant Eyebar

Figure 8.7.32 Fracture Critical Top Chord Truss Member: Internally Redundant Eyebar

8.7.5 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 rating method and the AASHTO element level condition state assessment method

NBI Rating Guidelines

Under the NBI rating guidelines, the steel eyebars are considered part of the superstructure and do not have an individual rating. The rating for the superstructure should take into account the condition of the steel eyebar assembly and may be lowered due to a deficiency in the steel eyebars. The superstructure is still rated as a whole unit but the steel eyebars may be the determining factor in the given rating.

Using the NBI rating guidelines, a 1-digit code on the Federal Structure Inventory and Appraisal (SI&A) sheet indicates the condition of the superstructure. 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 Rating Guidelines.

The previous inspection data should be considered along with current inspection findings to determine the correct rating.

Element Level Condition State Assessment

Element level evaluation does not have specific CoRe elements for steel eyebars. Due to this fact, individual states may choose to create their own non-CoRe elements or use the AASHTO CoRe elements that "best describe" the steel eyebars. In an element level condition state assessment of steel eyebars, the AASHTO CoRe elements that relate closest to a steel eyebar include:

Element No.	Description
	Truss
121	Thru Truss (Bottom Chord) – Painted Steel
126	Thru Truss (Excluding Bottom Chord) – Painted Steel
131	Deck Truss – Painted Steel
	Cable
147	Cable Coated *(for suspension bridges using eyebars)*

The unit quantity for steel eyebars in truss bridges is meters or feet, and the total length must be distributed among the five available condition states for painted steel depending on the extent and severity of deterioration. The unit quantity for steel eyebars used as cables in suspension bridges is each and must be placed in one of the five available condition states for coated steel cables. In both cases, Condition state 1 is the best possible rating. See the *AASHTO Guide for Commonly Recognized (CoRe) Structural Elements* for condition state descriptions.

A Smart Flag is used when a specific condition exists, which is not described in the CoRe element condition state. The severity of the damage is captured by coding the appropriate Smart Flag condition state. The Smart Flag quantities are measured as each, with only one each of any given Smart Flag per bridge.

For damage due to fatigue, the "Steel Fatigue" Smart Flag, Element No. 356, can be used and one of the three condition states assigned. For rust, the "Pack Rust" Smart Flag, Element No. 357, can be used and one of the four condition states assigned. For damage due to traffic impact, the "Traffic Impact" Smart Flag, Element No. 362, can be used and one of the three condition states assigned. For eyebars with section loss, the "Section Loss" Smart Flag, Element No. 363, can be used and one of the four condition states assigned.