Table of Contents

Section 8
Inspection and Evaluation of Common Steel Superstructures

Topic 8.8 Steel Arches

8.8.1 Introduction

Arches are a unique form of bridge in that they look like a half circle or ellipse, turned upside down. Arch bridges have been built since Roman times, but steel arch bridges have only been constructed since the late 1800's. Arch bridges generally need strong foundations to resist the large concentrated diagonal loads.

Arches are divided into three types: deck, through, and tied (see Figures 8.8.1, 8.8.2, and 8.8.3).

Figure 8.8.1 Deck Arch Bridge

Figure 8.8.2 Through Arch Bridge

Figure 8.8.3 Tied Arch Bridge

8.8.2 Deck Arch Design Characteristics

General

Arches are considered to be "simple span" because of the basic arch function, even though many bridges of this type consist of multiple arches. The arch reactions, with their massive horizontal thrusts, are diagonally oriented and transmitted to the foundation.

Like its concrete counterpart, the steel open spandrel arch is designed to resist a load combination of axial compression and bending moment. The open spandrel steel arch is considered a deck arch since the roadway is above the arches (see Figure 8.8.4). The area between the arches and the roadway is called the spandrel.

Open spandrel steel arches receive traffic loads through spandrel bents that support a deck and floor system. Steel deck arches can be used in very long spans, measuring up to 518 m (1700 ft).

Figure 8.8.4 Deck Arch

The arch members are called ribs and can be fabricated into I-girders, boxes, or truss shapes. The arches are classified as either solid ribbed, braced ribbed, or spandrel braced (see Figures 8.8.5 and 8.8.6). The members are fabricated using riveted, bolted, or welded techniques. Most steel deck arches have two arch rib members, although some structures have three or more ribs (see figure 8.8.7).

Figure 8.8.5 Solid Ribbed Deck Arch

Figure 8.8.6 Braced Rib Deck Arch, New River Gorge, WV

Figure 8.8.7 Spandrel Braced Deck Arch with Six Arch Ribs

An arch with a pin at each end of the arch is called a two-hinged arch (see Figure 8.8.8). If there is also a pin at the crown, or top, of the arch, it is a three-hinged arch. One-hinged and fixed arches may exist, although these are very rare. Foundation conditions, in part, dictate the requirements for hinges. Three-hinged arches, for example, are not significantly affected by small foundation movements.

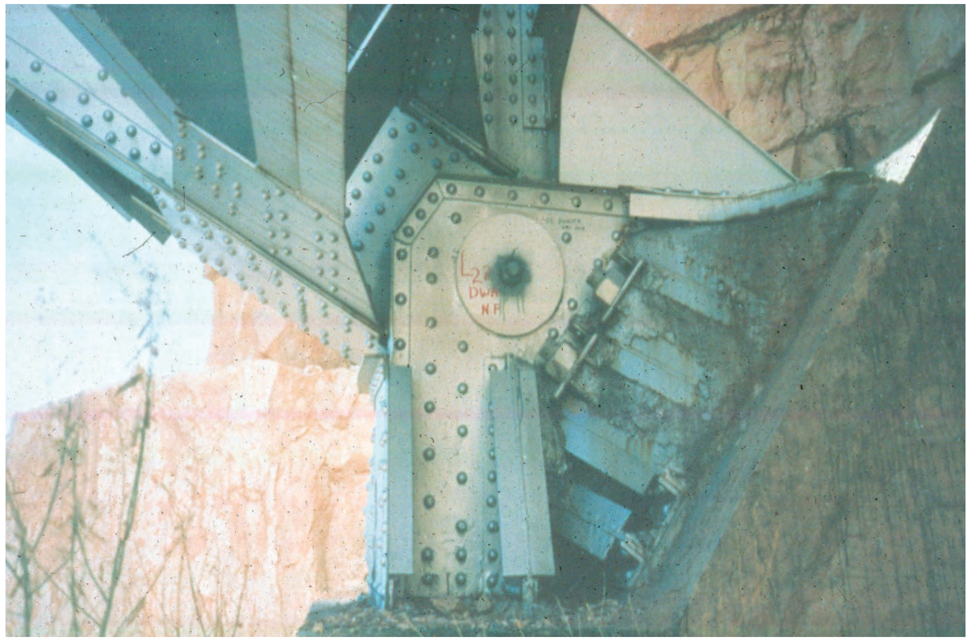

Figure 8.8.8 Hinge Pin at Skewback for Spandrel Braced Deck Arch (Navajo Bridge)

Primary and Secondary Members

The primary members of a deck arch bridge consist of the arches or ribs, spandrel columns or bents, spandrel girders and the floor system. The floor system consists of floorbeams and stringers (if present) (see Figure 8.8.9).

The secondary members of a deck arch bridge consist of the sway bracing and the upper lateral and lower lateral bracing of the arch or floor system (see Figure 8.8.10).

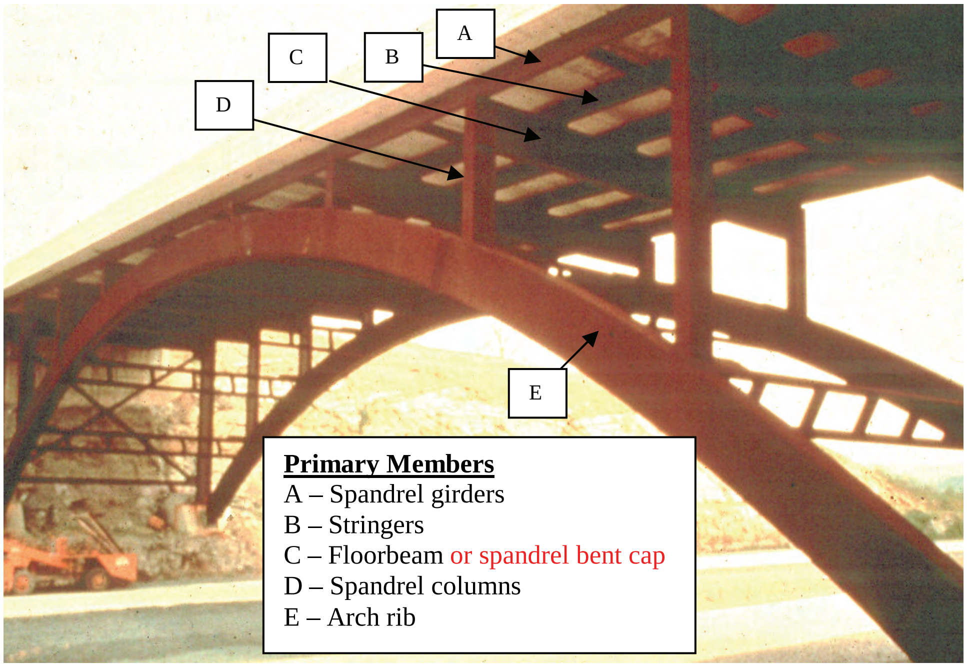

Figure 8.8.9 Solid Ribbed Deck Arch Primary Members

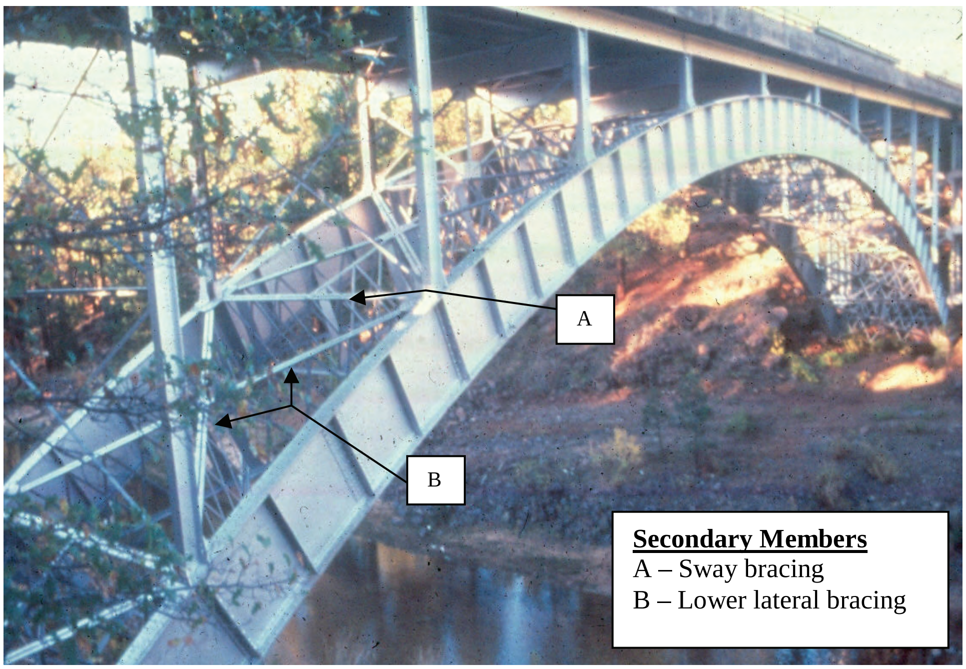

Figure 8.8.10 Solid Ribbed Deck Arch Secondary Members

Load Transfer

Traffic loads are supported by a deck. The load from the deck is transmitted to the stringers (if present) and then the floorbeams. The stringer and floorbeams resist the traffic load in bending and shear. The load is transferred to the spandrel bents and spandrel columns, which are in compression or bending. The arch supports the spandrel column and transfers the compressive load to the ground at the supports.

Fracture Critical Members

The deck arch bridge has two or more main members. However, the arch is not a tension member and is therefore not considered fracture critical. Some members of the floor system and spandrel bent may be considered fracture critical (see Topic 8.3)

8.8.3 Through Arch Design Characteristics

General

Arch bridges are considered simple spans because of the basic arch function, even though many bridges of this type consist of multiple arches. Through arches are typically two or three hinged. The arch reactions, with their massive horizontal thrusts, are diagonally oriented and transmitted to the foundations.

The steel through arch is constructed with the crown of the arch above the roadway and the arch foundations below the roadway (see Figure 8.8.11). The deck is hung from the arch by wire rope cables or eyebars.

Figure 8.8.11 Elevation View of a Braced Ribbed Through Arch

The arch members are called ribs and are usually fabricated box-type members. Steel through arches are known as either solid ribbed or braced ribbed. The solid ribbed arch, which can be any type of arch, has a single curve defining the arch shape, while the braced ribbed arch has two curves defining the arch shape, braced with truss webbing between the curves. The lower curve is the bottom rib chord, and the upper curve is the top rib chord. The rib chord bracing consists of posts and diagonals. The braced ribbed arch is sometimes referred to as a trussed arch and is more common than the solid ribbed through arch.

Primary and Secondary Members

The primary members of a through arch bridge consist of arch ribs (consisting of top and bottom rib chords and rib chord bracing), rib chord bracing, hangers and floor system including floorbeams and stringers (if present) (see Figure 8.8.12).

The secondary members of a through arch bridge consist of sway bracing, lateral bracing (top and bottom rib chords and floor system) (see Figure 8.8.13).

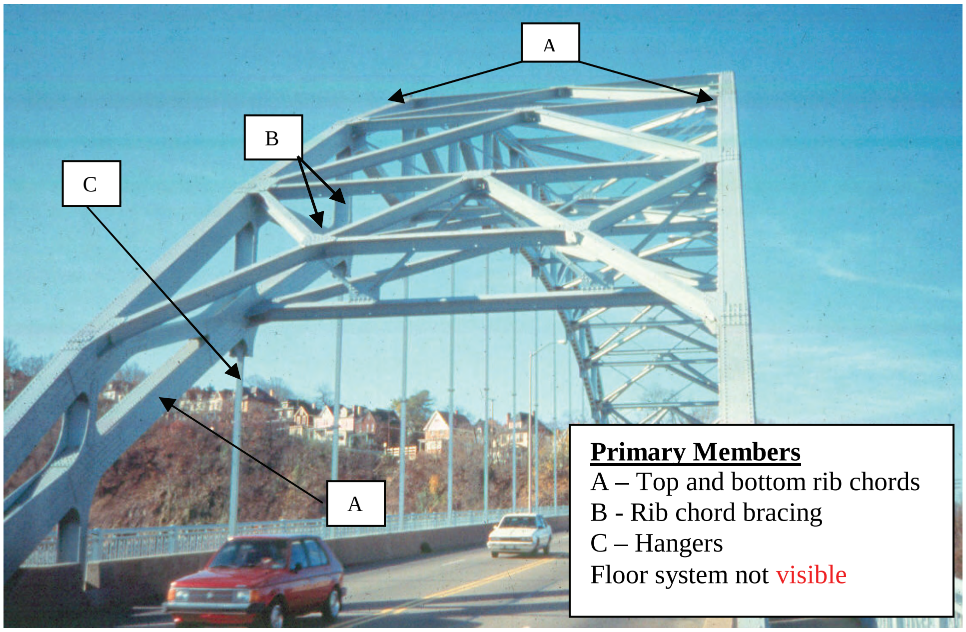

Figure 8.8.12 Through Arch Primary Members

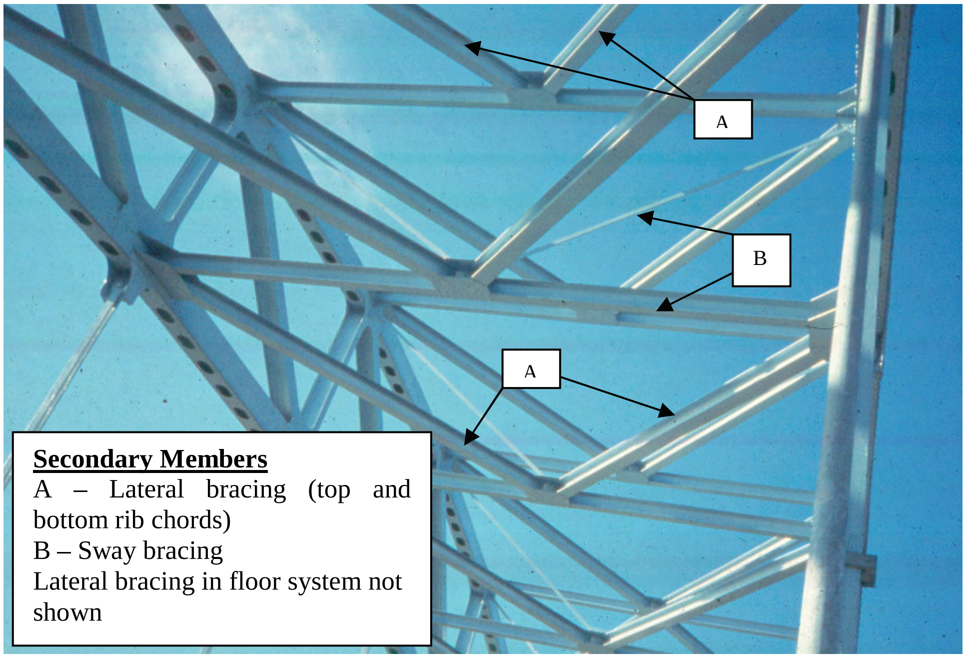

Figure 8.8.13 Through Arch Bracing (Secondary Members)

Load Transfer

Traffic loads are supported by a deck. The load from the deck is transmitted to the stringers (if present) and then the floorbeams. The stringer and floorbeams resist the load in bending and shear. The load is transferred to the hangers, which are in tension. The arch supports the hangers and transfers the compressive load to the ground at the supports.

Fracture Critical Members

The through arch is the main load-carrying member. Since there are typically only two arch ribs, the structure is nonredundant. However, the bridge is not classified as fracture critical because the arches are not tension members. The hangers may be fracture critical, depending on the results of a detailed structural analysis. Some members of the floor system may be fracture critical (see Topic 8.3).

8.8.4 Tied Arch Design Characteristics

General

The tied arch is a variation of the through arch with one significant difference. In a through arch, the horizontal thrust of the arch reactions is transferred to large rock, masonry, or concrete foundations. A tied arch transfers the horizontal reactions through a horizontal tie which connects the ends of the arch together, like the string on an archer's bow (see Figure 8.8.14). The tie is a tension member. If the string of a bow is cut, the bow will spring open. Similarly, if the arch tie fails, the arch will lose its compression and will collapse.

Design plans are generally needed to differentiate between through arches and tied arches. Another guide in correctly labeling through and tied arches is by examining the piers. Since tied arch bridges redistribute the horizontal loads to the tie girders, the piers for tie arch bridges are smaller than the piers for through arch bridges.

Figure 8.8.14 Tied Arch

Arch members are fabricated with either solid rib members, box members or braced ribs.

The tie member is a fabricated box member or consists of truss members. The tie is also supported by hangers, which usually consist of wire rope cable, but can also be eyebars or built-up members.

Primary and Secondary Members

The primary members of a tied arch bridge consist of arch ribs, tie members, rib bracing truss (if present), hangers, and floor system including floorbeams and stringers (if present) (see Figure 8.8.15).

The secondary members of a tied arch bridge consist of sway bracing, lateral bracing (arch rib, top chord and floor system) (see Figure 8.8.16).

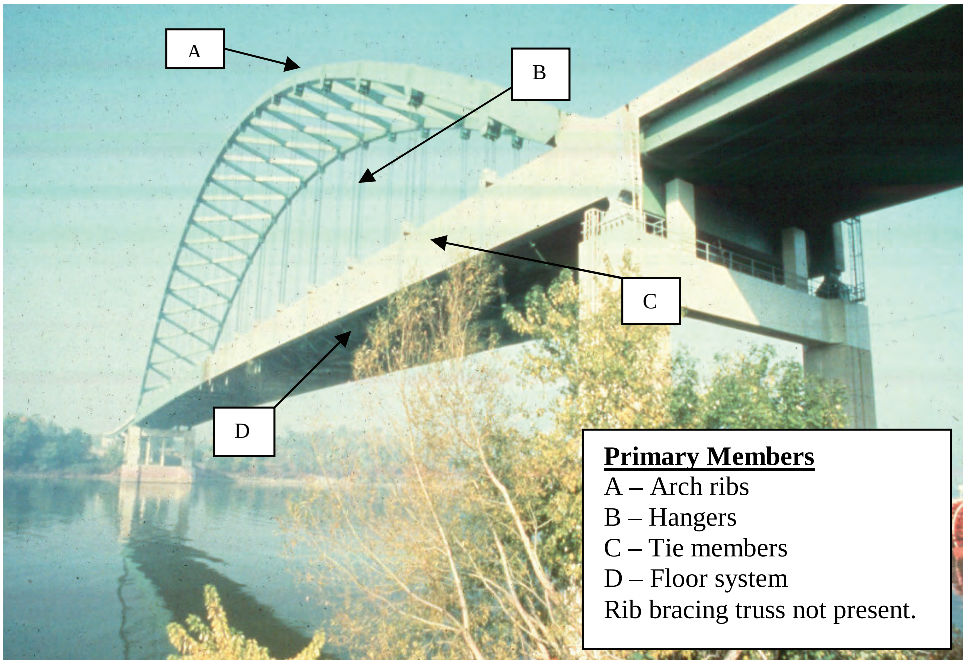

Figure 8.8.15 Tied Arch Primary Members

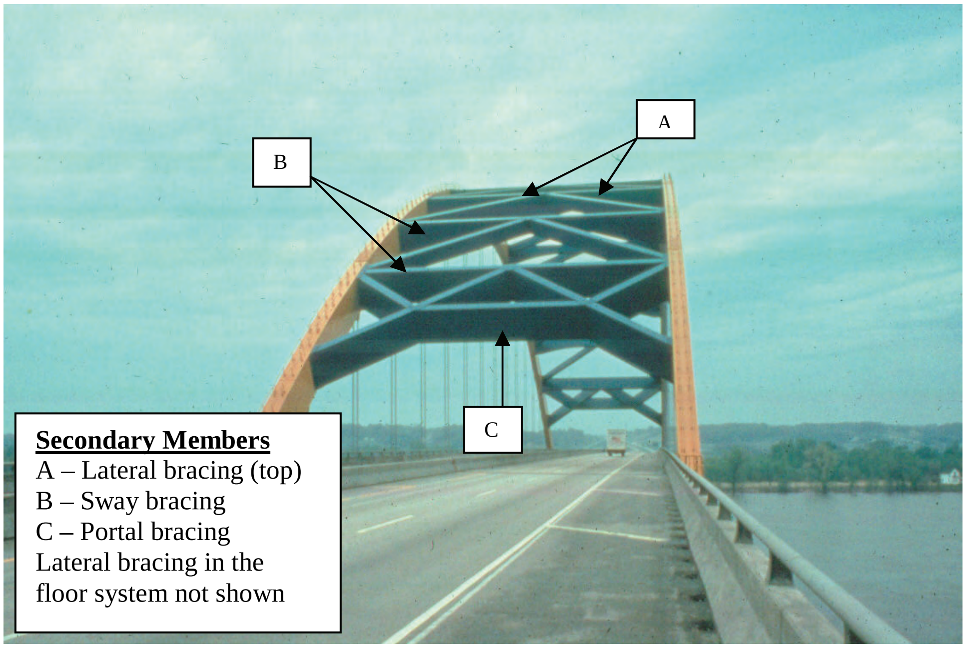

Figure 8.8.16 Tied Arch Secondary Members

Load Transfer

Traffic loads are supported by a deck. The load from the deck is transmitted to the stringers (if present) and then the floorbeams. The stringer and floorbeams resist the load in bending and shear. The load is transferred to the hangers, which are in tension. The arch supports the hangers and transfers the compressive load to the tie girder and the supports.

Fracture Critical Members

With only two load paths, arches are considered non-redundant structures. The arches are not fracture critical since they are subjected to axial compression. The tie girders, on the other hand, are axial tension members and are considered fracture critical.

8.8.5 Overview of Common Defects

Common defects that occur on steel arch 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.

8.8.6 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

Bearing Area

Examine the web areas over the supports for cracks, section loss and buckling. If bearing stiffeners, jacking stiffeners and diaphragms are present at the supports inspect them for cracks, section loss and buckling also.

Examine the bearings on each of the supports for corrosion. Check the alignment of each bearing and note any movement. Report any build up of debris surrounding the bearings that may limit the bearing from functioning properly. Check for any bearings that are frozen due to heavy corrosion. (see Topic 9.1).

Arch Members

Inspect the alignment of the arch and look for signs of buckling and crippling in the arch ribs. Check for general corrosion and deterioration Examine any pins for corrosion and wear. Check the arch rib splice plates and the connections for hangers or spandrel bents.

Inspect steel arch girder type bridges as described in Topic 8.2. Inspect steel arch box girder type bridges as described in Topic 8.5. Inspect steel braced ribbed arch type bridges as described in Topic 8.6 (see Figure 8.8.17).

Figure 8.8.17 Through Truss Arch Members

Bracing (Through and Tied Arches)

Inspect the web members (posts and diagonals) in a manner similar to any other truss as described in Topic 8.6. Depending on the truss design (e.g., Pratt or Warren, etc.), the web members will either be designed for tension, compression, or both.

Spandrel Members (Deck Arch)

Examine the end connections of the spandrel bents, spandrel columns and spandrel girders for cracks and loose fasteners. Check the spandrel girders/caps/columns for flexure, section loss, and buckling damage (see Figure 8.8.18).

Figure 8.8.18 Solid Ribbed Deck Arch Showing Spandrel Columns

Hangers (Through and Tied Arches)

Check the connections at both ends of the hangers, and look for corrosion and cracks. Examine the alignment of the hangers; the hangers may be near traffic, so inspect for collision or fire damage (see Figures 8.8.19 and 8.8.20). Check the hangers for any welded attachment; examine the welds between the attachment and the hanger for cracks

Figure 8.8.19 Hanger Connection on a Through Arch

Figure 8.8.20 Performing Baseline Hardness Test on Fire Damaged Arch Cables

Floor System

The floor system, consisting of floorbeams and possibly stringers, should be inspected in the same manner as previously described in Topic 8.3, Steel Two-girder Systems & Steel Through Girder Systems (see Figure 8.8.21).

Tied Arches

Tied arches are subjected to axial compression in addition to bending caused by the hanger connections. Check floorbeam to tied member connection for distortion caused by fatigue or horizontal floorbeam displacement in the webs of the floorbeams when the stringers are placed above the floorbeams.

Figure 8.8.21 Floor System on a Through Arch

Tied Girder

Determine if back-up bars were used to make corner welds in the tie box. If so, the back-up bars should be carefully examined to determine if they are continuous. Weld cracks can occur at points where the bars are discontinuous. Check all welds, and examine the ends of any cover plates. Especially check welds connecting internal diaphragms to the tie box. Inspect the floorbeam connections and the corner welds of the tie box (see Figure 8.8.22).

Fatigue Prone Details

Check the welds on tension members such as tie girders, floorbeams or stringers. Look at welds for stiffeners/diaphragms/connection plates.

If cover plates are present, look at the welded ends for cracking. Back-up bars may be used between the webs and flanges and are susceptible to cracking.

Check the web gap area between the flanges and the connection plates. Closely inspect tack welds, intersecting welds and discontinuous or intermittent welds.

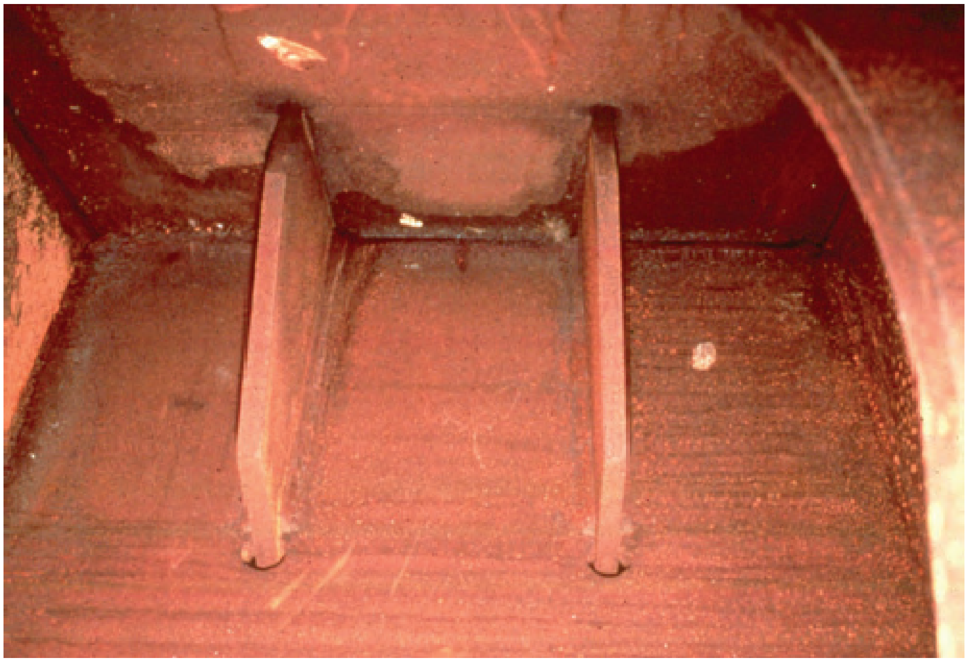

Figure 8.8.22 Tie Girder Interior

Out-of-plane Distortion

Investigate the girders at the floorbeam connection for cracks in the webs due to out-of-plane distortion. Investigate for fatigue cracks due to web-gap distortion. This is a major source of cracking when floorbeams frame into girders. For additional information on out-of-plane distortion, see Topic 8.3.

Out-of-plane distortion can also crack the tie girder webs at partial depth diaphragm connection with floorbeams (see Figure 8.8.23). The diaphragms stiffen the tie girders. However, the small, unstiffened regions of the webs do not have sufficient rigidity against lateral, out-of-plane distortion. The situation is analogous to that of webs at unattached ends of floorbeam or diaphragm connection plates. Fatigue cracks can develop at the ends of the diaphragm plates. The ends of all partial depth diaphragms in a box tie girder should be closely inspected.

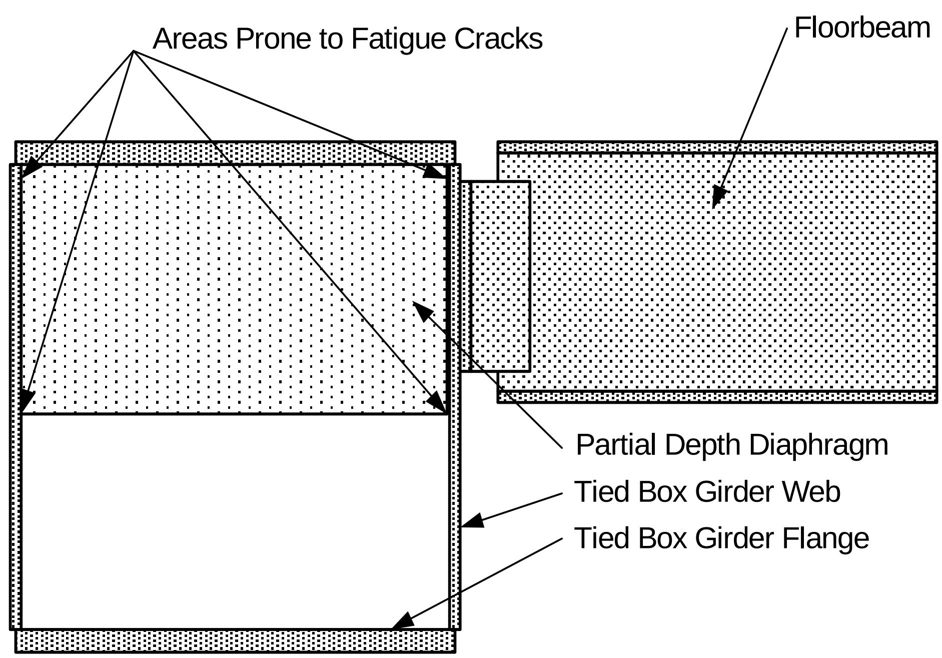

Figure 8.8.23 Partial Depth Diaphragm in a Tied Box Girder

Secondary Members

The secondary members should be inspected using methods similar to those detailed in Topics 8.3, 8.5, and 8.6 (see Figure 8.8.24). In addition:

Investigate the alignment of the bracing elements. Check horizontal connection plates, which can trap debris and moisture and are susceptible to a high degree of corrosion and deterioration. Examine the end connections for cracks, corrosion, and loose fasteners.

Misalignment of secondary members may be an indication of differential structure movement or substructure settlement.

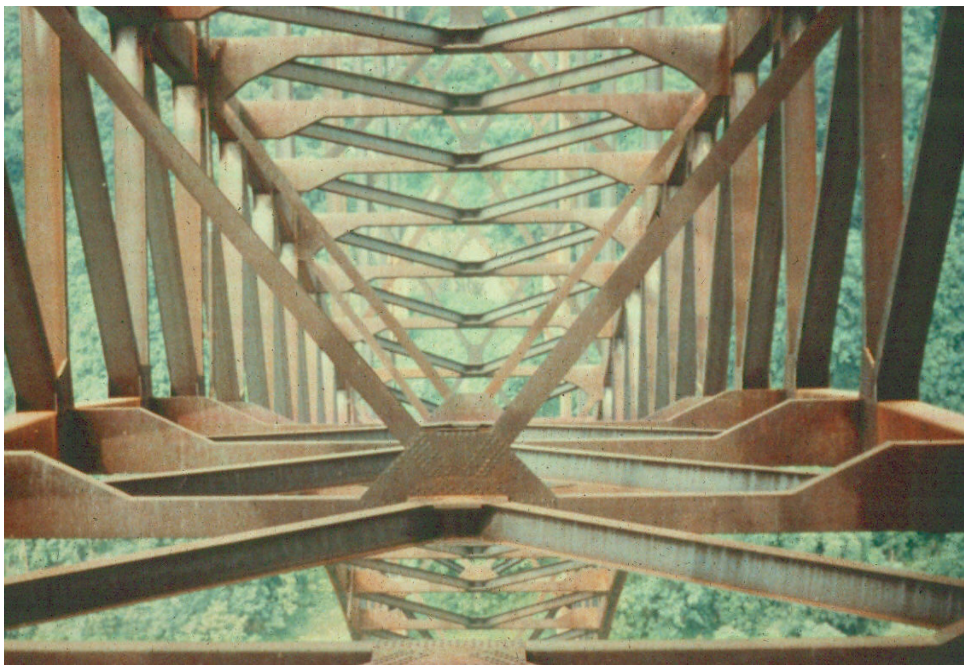

Figure 8.8.24 Bracing Members (New River Gorge Bridge)

Areas Exposed to Traffic

Inspect any areas exposed to traffic for collision damage (see Figure 8.8.25). If collision damage is found, document the location and dimensions and reference with photographs or sketches.

Figure 8.8.25 Areas Exposed to Traffic

Areas Exposed to Drainage

The areas that trap water and debris result in active corrosion cells, which cause loss of section and notches susceptible to fatigue. On arch bridges check lateral bracing gusset plates, pockets created by floor system connections, and areas exposed to drainage runoff.

8.8.7 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

Using 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

In an element level condition state assessment of a steel arch bridge, the AASHTO CoRe elements may be:

Element No.	Description
	Box Girder
101	Unpainted Steel Closed Web/Box Girder
102	Painted Steel Web/Box Girder
	Floor System
106	Unpainted Steel Open Girder/Beam
107	Painted Steel Open Girder/Beam
112	Unpainted Steel Stringer (Stringer Floorbeam System)
113	Painted Steel Stringer (Stringer Floorbeam System)
	Steel Arch
140	Unpainted Steel Arch
141	Painted Steel Arch
	Hanger
146	Cable (not embedded in concrete) Uncoated
147	Cable (not embedded in concrete) Coated
	Floor System
151	Unpainted Steel Floorbeam
152	Painted Steel Floorbeam
	Pin and Hanger
160	Unpainted Steel Pin and Hanger Assembly
161	Painted Steel Pin and Hanger Assembly
	Spandrel Columns
201	Unpainted Steel Columns
202	Painted Steel Columns

The unit quantity for the arch is meters or feet and the total length of the arch ribs must be distributed among the four available condition states for unpainted and five available condition states for painted structures depending on the extent and severity of deterioration. The unit quantity for the floor system is meters or feet and the total length of floor beams and stringers must be distributed among the 4 or 5 available condition states. The unit quantity for columns, cables or hanger assemblies is each and the total quantity must be placed in one of the four available condition states for unpainted and five available condition states for painted. 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 between riveted members, 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 steel arches with section loss due to corrosion, the "Section Loss" Smart Flag, Element No. 363, can be used and one of the four condition states assigned.