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Section 7
Inspection and Evaluation of Common Concrete Superstructures

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Section 7

Inspection and Evaluation of Common Concrete Superstructures

Topic 7.1 Cast-in-Place Slabs

7.1.1 Introduction

The cast-in-place slab bridge is the simplest type of reinforced concrete bridge and was a common choice for construction in the early 1900's (see Figures 7.1.1 and 7.1.2). Sometimes the terms "deck" and "slab" are used interchangeably to describe the same bridge component. However, this is incorrect. A deck is supported by a superstructure unit (beams, girders, etc.), whereas a slab is a superstructure unit supported by a substructure unit (abutments, piers, bents, etc.). A deck can be loosely defined as the top surface of the bridge, which carries the traffic. A slab serves as the superstructure and the top surface that carries the traffic. Even though slabs are defined differently than decks, many of the design characteristics, wearing surfaces, protective systems, inspection procedures and locations and, evaluation, are similar. See Topic 5.2 for further details.

Figure 7.1.1 Typical Simple Span Cast-in-Place Slab Bridge

Figure 7.1.2 Typical Multi-span Cast-in-Place Slab Bridge

7.1.2

Design Characteristics

General

The slab bridge functions as a wide, shallow superstructure beam that doubles as the deck. This type of bridge generally consists of one simply supported span and is typically less than 9 m (30 feet) long. Simple and continuous multi-span slab bridges are also common.

Primary Members and Secondary Members

The only primary member in a cast-in-place slab bridge is the slab itself. There are no secondary members.

Steel Reinforcement

For simple spans, the slab develops only positive moment; therefore, the primary, or main tension reinforcement is located in the bottom of the slab. The reinforcement is placed longitudinally, or from support to support, parallel to the direction of traffic. For continuous spans, additional primary reinforcement is located longitudinally in the top of the slab over the piers to resist negative bending moments.

Secondary reinforcement, known as temperature and shrinkage steel, is located transversely throughout the top and bottom of the slab. In simple span slabs, secondary reinforcement is also located longitudinally in the top of the slab. In continuous span slabs, the primary reinforcement is often placed the full structure length, negating the need for longitudinal secondary reinforcement.

Nearly all slab bridges have a grid or mat of steel reinforcement in both the top and bottom of the slab that is formed by some combination of primary and secondary reinforcement (see Figure 7.1.3).

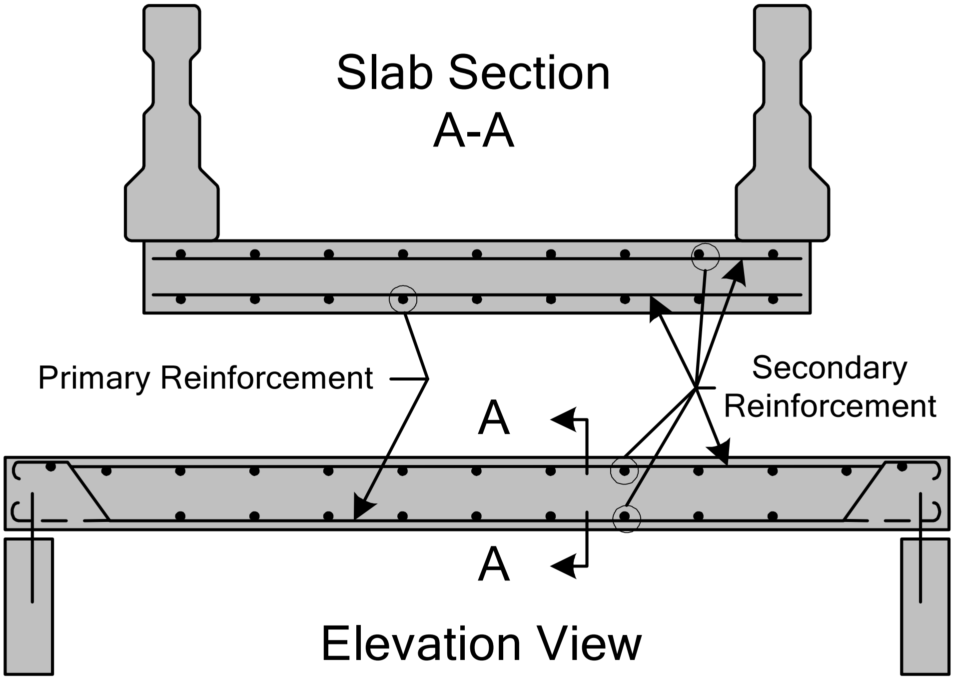

Figure 7.1.3 Steel Reinforcement in a Simply Supported Concrete Slab

7.1.3

Overview of Common Defects

Common defects that occur on cast-in-place slab bridges include:

- Cracking (flexure, shear, temperature, shrinkage, mass concrete)
- Scaling
- Delamination
- Spalling
- Chloride contamination
- Efflorescence
- Ettringite formation
- Honeycombs
- Pop-outs
- Wear
- Collision damage
- Abrasion
- Overload damage
- Reinforcing steel corrosion

Refer to Topic 2.2 for a detailed explanation of the properties of concrete, types and causes of concrete deterioration, and the examination of concrete.

7.1.4

Inspection Procedures and Locations

Inspection procedures to determine other causes of concrete deterioration are discussed in detail in Topic 2.2.8.

Procedures

Visual

The inspection of concrete slabs for cracks, spalls, wear, and other defects is primarily a visual activity.

Physical

The physical examination of the top surface of the slab with a hammer can be a tedious operation. In most cases, a chain drag is used to determine delaminated areas. A chain drag is made of several sections of chain attached to a pipe that has a handle attached to it. The inspector drags this across a slab and makes note of the resonating sounds. A delaminated area will have a distinctive hollow “clacking” sound when tapped with a hammer or revealed with a chain drag. A hammer hitting sound concrete will result in a solid “pinging” type sound.

Advanced Inspection Techniques

Several advanced techniques are available for concrete inspection. Nondestructive methods, described in Topic 13.2.2, include:

- Acoustic wave sonic/ultrasonic velocity measurements
- Delamination detection machinery
- Electrical methods
- Electromagnetic methods
- Pulse velocity
- Flat jack testing
- Ground-penetrating radar
- Impact-echo testing
- Infrared thermography
- Laser ultrasonic testing
- Magnetic field disturbance
- Neutron probe for detection of chlorides
- Nuclear methods
- Pachometer
- Rebound and penetration methods
- Ultrasonic testing

Other methods, described in Topic 13.2.3, include:

- Core sampling
- Carbonation
- Concrete permeability
- Concrete strength
- Endoscopes and videoscopes

- Moisture content
- Petrographic examination
- Reinforcing steel strength
- Chloride test
- Matrix analysis
- ASR evaluation

Locations

Bearing Areas

Examine bearing areas for cracking, delamination, and spalling where friction from thermal movement and high edge or bearing pressure could overstress the concrete (see Figure 7.1.4). Check the condition and operation of any bearing devices.

Figure 7.1.4 Bearing Area: Cast-in-Place Slab

Shear Zones

Investigate areas near the supports for shear cracking. The presence of transverse cracks on the underside near supports or diagonal cracks on the sides of the slab indicate the onset of shear failure (see Figures 7.1.5 and 7.1.6). These cracks represent lost shear capacity and should be carefully measured.

Figure 7.1.5 Shear Cracks in the Ends of a Slab Bridge

Figure 7.1.6 Shear Zone on the Underside of a Continuous Slab Bridge Near a Pier

Tension Zones

Tension zones should be examined for flexure cracks, which would be vertical on the sides and transverse across the slab. The tension zones are at midspan along the bottom of the slab for both simple and continuous span bridges. Additional tension zones are located on top of the slab over the piers for continuous spans. Cracks greater that 2 mm (1/16 inch) wide are considered wide cracks and indicate extreme bending stresses. Check for efflorescence from cracks and discoloration of the concrete caused by rust stains from the reinforcing steel. In severe cases, the reinforcing steel may become exposed due to spalling. Document the remaining cross section of reinforcing steel since section loss will decrease live load capacity.

Check for deteriorated concrete near the tension zones, which could result in the debonding of the tension reinforcement. This would include delamination, spalls, and contaminated concrete (see Figure 7.1.7). Slab bridges which use hooks to develop the primary reinforcement are not as susceptible to debonding due to deterioration of the concrete.

Secondary Members

The slab bridge has no secondary members.

Figure 7.1.7 Concrete Slab Tension Zone: Delamination, Efflorescence, Rust, and Stains

Areas Exposed to Drainage

Inspect areas exposed to roadway drainage for deteriorated concrete. This includes the entire riding surface of the slab, particularly around scuppers or drains. Spalling or scaling may also be found along the curbline and fascias (see Figure 7.1.8).

Areas Exposed to Traffic

For grade crossing structures, check areas exposed to traffic for damage caused by collision. Such damage will generally consist of corner spalls and may include exposed rebars.

Areas Previously Repaired

Examine areas that have been previously repaired. Determine if the repairs are in place, and they are functioning properly.

Skewed Bridges

Examine skewed bridges for lateral displacement and cracking of acute corners due to point loading and insufficient reinforcement.

Figure 7.1.8 Deteriorated Slab Fascia due to Roadway Deicing Agents

7.1.5

Evaluation

State and federal rating guideline systems have been developed to aid in the inspection of concrete 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 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. For a slab bridge, these guidelines must be applied for both the deck component and the superstructure component.

The previous inspection data should be used along with current inspection findings to determine the correct rating. Typically, for this type of structure, the deck and superstructure components will have the same rating.

Element Level Condition State Assessment

In an element level condition state assessment of a slab bridge, the AASHTO CoRe element is one of the following, depending on the riding surface:

Element No.	Description
38	Concrete Slab – Bare
39	Concrete Slab – Unprotected with AC Overlay
40	Concrete Slab – Protected with AC Overlay
44	Concrete Slab – Protected with Thin Overlay
48	Concrete Slab – Protected with Rigid Overlay
52	Concrete Slab – Protected with Coated Bars
53	Concrete Slab – Protected with Cathodic System

The unit quantity for these elements is “each”, and the entire element must be placed in one of the five available condition states based solely on the top surface condition. Some states have elected to use the total area (m^2 or ft^2). When a total area is used, the total area must be distributed among the five available condition states depending on the extent and severity of deterioration. The sum of all condition states must equal the total quantity of the CoRe element. The inspector must know the total slab surface area in order to calculate a percent deterioration and fit into a given condition state description. 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 structural cracks in the top surface of bare slabs, the “Deck Cracking” Smart Flag, Element No. 358, can be used and one of four condition states assigned. Do not use Smart Flag, Element No. 358, if the bridge slab has any overlay because the top surface of the structural slab is not visible. For concrete defects on the underside of a slab element, the “Soffit” Smart Flag, Element No. 359, can be used and one of five condition states assigned. This Smart Flag is particularly useful if the wearing surface inhibits inspection of the top surface of the slab.

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Section 7 Inspection and Evaluation of Common Concrete Superstructures

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Topic 7.2 Tee Beams

7.2.1

Introduction

The concrete tee beam, a predominant bridge type during the 1930's and 1940's, is generally a cast-in-place monolithic deck and stem system formed in the shape of the letter "T" (see Figure 7.2.1).

The cast-in-place tee beam is the most common type of tee beam. However, precast tee beam shapes are used by some highway agencies. Types of precast tee beams include bulb tee, double tee, quad tee, and rib tee (see Topic 7.8, Prestressed Double Tee Beams).

Recent technology has also produced the inverted tee beam, a new type of precast tee beam, for short to medium span bridges. Developed in Nebraska, this prestressed concrete beam reduces the weight up to 20% compared to conventional I-beams and eliminates the need for falsework construction.

Figure 7.2.1 Simple Span Tee Beam Bridge

7.2.2

Design Characteristics

General

Care must be taken not to describe tee beam bridges as composite. They do not meet the definition of composite, because the deck and stem are constructed of the same material. The deck portion of the beam is constructed to act integrally with the stem, providing greater stiffness and allowing increased span lengths (see Figure 7.2.2). The tee beam bridge is used for spans between 9 and 15 m (30 and 50 feet). Simple spans are most common; however, there are some multi-span continuous tee beam bridges in use.

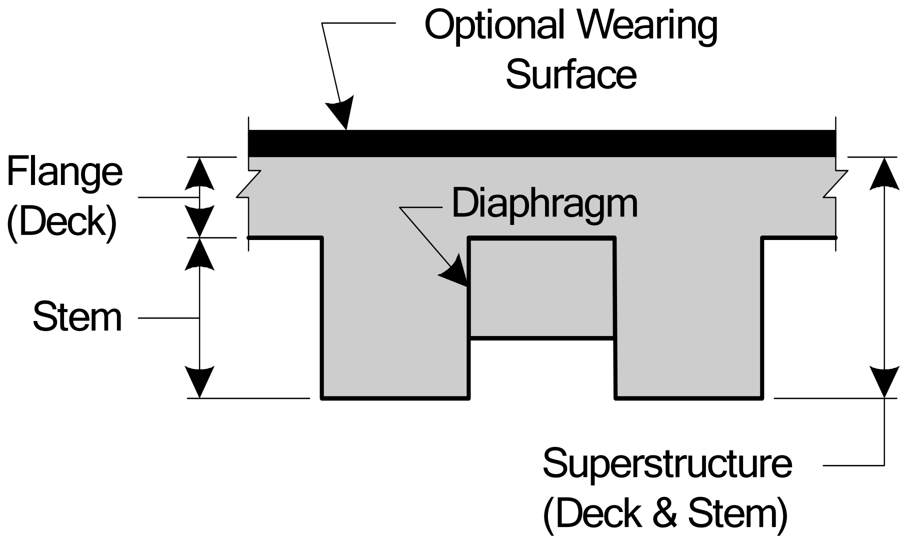

Figure 7.2.2 Tee Beam Cross Section

Spacing of the tee beams is generally 900 to 2400 mm (3 to 8 feet), center-to-center of beam stems. The depth of the stems is generally 450 to 600 mm (18 to 24 inches). Simple span design was most common but continuous span designs were popular in some regions (see Figure 7.2.2). A 75 or 100 mm (3 or 4 inch) fillet at the deck-stem intersection identifies this older form of construction.

Figure 7.2.3 Typical Tee Beam Layout

The inspector should be careful not to mistake a concrete encased steel I-beam bridge for a tee beam bridge. A review of the structure file should eliminate this problem. If necessary, a dimensional evaluation will show the encased steel beams to be smaller in size (see Figure 7.2.4).

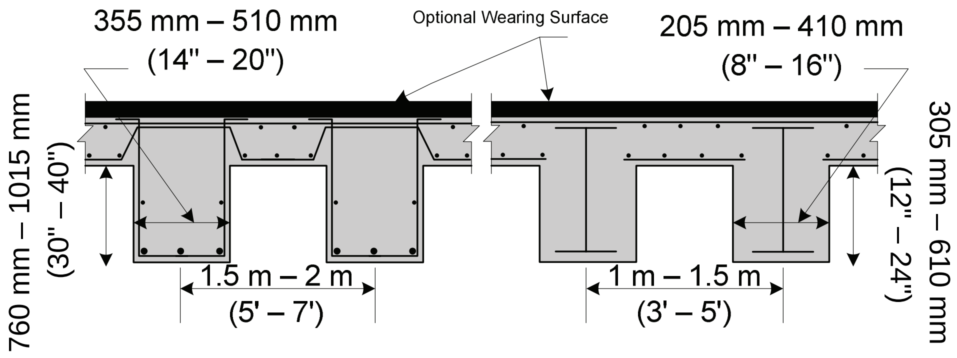

Figure 7.2.4 Comparison Between Tee Beam and Concrete Encased Steel I-beam

Figure 7.2.5 Concrete Encased Steel I-beam

Primary Members and Secondary Members

The primary members of a tee beam bridge are the tee beam stem (web) and deck (flange) (see Figure 7.2.6).

Diaphragms are the only secondary members on a cast-in-place tee beam bridge. End diaphragms support the free edge of the beam flanges. Intermediate diaphragms may also be present in longer span bridges and are usually located at the half or third points along the span.

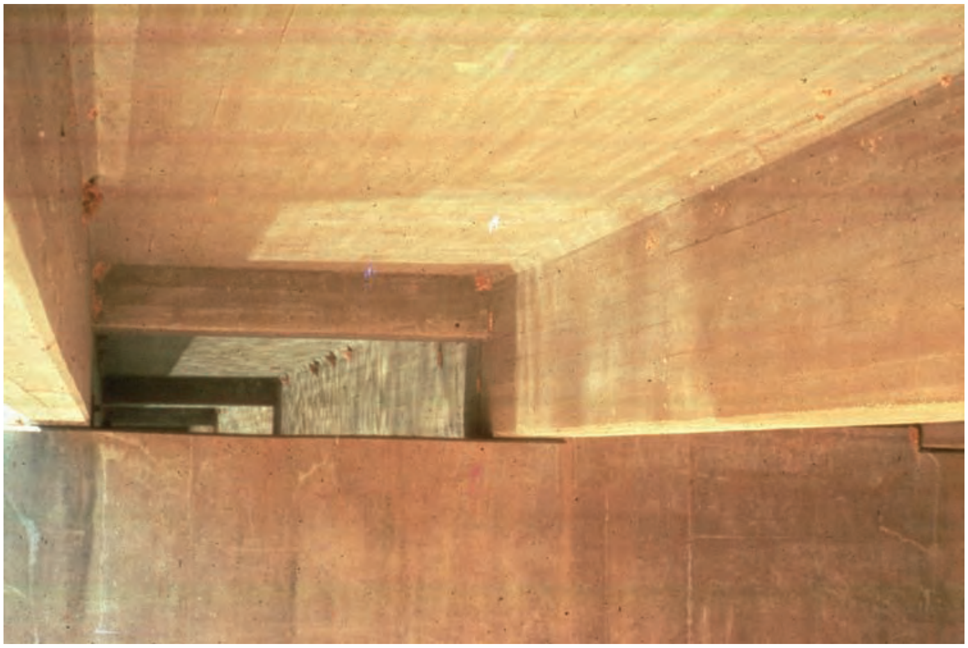

Figure 7.2.6 Tee Beam Primary and Secondary Members

Steel Reinforcement

The primary reinforcing steel consists of main tension reinforcement and shear reinforcement or stirrups. The main tension reinforcement is located in the bottom of the beam stem and oriented longitudinally (see Figure 7.2.7). If the concrete tee beams are continuous, there will be longitudinal reinforcement close to the top surface of the deck over the piers. The sides of the stem contain primary vertical shear reinforcement, called stirrups, and are located throughout the length of the stem at various spacings required by design. Stirrups are generally U-shaped bars and run transversely across the bottom of the stem (see Figure 7.2.7). The need for stirrups is greatest near the beam supports where shear stresses are the highest.

The secondary (temperature and shrinkage) reinforcing steel for the stem is oriented longitudinally in the sides (see Figure 7.2.7). The primary and secondary reinforcing steel for the deck portion of the beam is the same as for a standard concrete deck (see Figure 7.2.7).

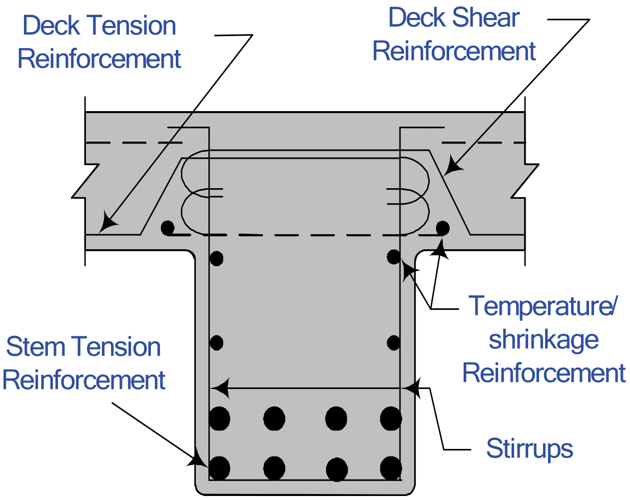

Figure 7.2.7 Steel Reinforcement in a Concrete Tee Beam

7.2.3

Overview of Common Defects

Common defects that occur on concrete tee beam bridges include:

- Cracking (flexure, shear, temperature, shrinkage, mass concrete)
- Scaling
- Delamination
- Spalling
- Chloride contamination
- Efflorescence
- Ettringite formation
- Honeycombs
- Pop-outs
- Wear
- Collision damage
- Abrasion
- Overload damage
- Reinforcing steel corrosion

Refer to Topic 2.2 for a detailed explanation of the properties of concrete, types and causes of concrete deterioration, and the examination of concrete.

7.2.4

Inspection Procedures and Locations

Inspection procedures to determine other causes of concrete deterioration are discussed in detail in Topic 2.2.8.

Procedures

Visual

The inspection of concrete tee beams for cracks, spalls, and other defects is primarily a visual activity.

Physical

The physical examination of a tee beam with a hammer can be a tedious operation. In most cases, a chain drag is used to determine delaminated areas on the top surface. The inspector drags this across a deck and makes note of the resonating sounds. A delaminated area will have a distinctive hollow “clacking” sound when tapped with a hammer or revealed with a chain drag. A hammer hitting sound concrete will result in a solid “pinging” type sound.

Advanced Inspection Techniques

Several advanced techniques are available for concrete inspection. Nondestructive methods, described in Topic 13.2.2, include:

- Acoustic wave sonic/ultrasonic velocity measurements
- Delamination detection machinery
- Electrical methods
- Electromagnetic methods
- Pulse velocity
- Flat jack testing
- Ground-penetrating radar
- Impact-echo testing
- Infrared thermography
- Laser ultrasonic testing
- Magnetic field disturbance
- Neutron probe for detection of chlorides
- Nuclear methods
- Pachometer
- Rebound and penetration methods
- Ultrasonic testing

Other methods, described in Topic 13.2.3, include:

- Core sampling
- Carbonation
- Concrete permeability
- Concrete strength
- Endoscopes and videoscopes
- Moisture content
- Petrographic examination
- Reinforcing steel strength
- Chloride test
- Matrix analysis
- ASR evaluation

Locations

Bearing Areas

Examine bearing areas for cracking, delamination and spalling where friction from thermal movement and high bearing pressure could overstress the concrete. Check for crushing of the stem near the bearing seat. Check the condition and operation of any bearing devices (see Figures 7.2.8 through 7.2.11).

Figure 7.2.8 Bearing Area of Typical Cast-in-Place Concrete Tee Beam Bridge

Figure 7.2.9 Spalled Tee Beam End

Figure 7.2.10 Deteriorated Tee Beam Bearing Area

Figure 7.2.11 Steel Bearing Supporting a Cast-in-Place Concrete Tee Beam

Shear Zones

Investigate the area near the supports for the presence of shear cracking. The presence of transverse cracks on the underside of the stems or diagonal cracks on the sides of the stem indicate the onset of shear failure. These cracks represent lost shear capacity and should be carefully measured.

Figure 7.2.12 Shear Zone of Cast-in-Place Concrete Tee Beam Bridge

Tension Zones

Tension zones should be examined for flexure cracks, which would be vertical on the sides and transverse across the bottom of the stem (see Figure 7.2.13). The tension zones are at the midspan along the bottom of the stem for both simple and continuous span bridges. Additional tension zones are located on the deck over the piers for continuous spans (see Figure 7.2.14). Cracks greater that 2 mm (1/16 inch) wide are considered wide cracks and indicate extreme bending stresses. Check for efflorescence from cracks and discoloration of the concrete caused by rust stains from the reinforcing steel (see Figure 7.2.15). In severe cases, the reinforcing steel may become exposed due to spalling. Document the remaining cross section of reinforcing steel since section loss will decrease live load capacity (see Figure 7.2.16).

Check for deteriorated concrete near the tension zones, which could result in the debonding of the tension reinforcement. This would include delamination, spalls, and contaminated concrete (see Figures 7.2.15 and 7.2.16).

Check for efflorescence from cracks and discoloration of the concrete caused by rust stains from the reinforcing steel. In severe cases, the reinforcing steel and any lap splices may become exposed due to spalling. Document the remaining cross section of reinforcing steel since section loss will decrease live load capacity.

Figure 7.2.13 Flexure Cracks on a Tee Beam

Figure 7.2.14 Flexure Cracks in Tee Beam Deck

Figure 7.2.15 Stem of a Cast-in-Place Concrete Tee Beam with Contaminated Concrete

Figure 7.2.16 Spall on the Bottom of the Stem of a Cast-in-Place Tee Beam with Corroded Main Steel Exposed

Secondary Members

The diaphragms should be inspected for flexure and shear cracks, as well as for typical concrete defects. Defects in the diaphragms may be an indication of differential settlement of the substructure or differential deflection of stems of the tee beams.

Areas Exposed to Drainage

If the roadway surface is bare concrete, check for delamination, scaling, and spalls. The curb lines are most suspect. If the deck has an asphalt wearing surface, check for indications of deteriorated concrete such as reflective cracking and depressions (see Figure 7.2.17).

Check around scuppers or drain holes and deck or stem fascias for deteriorated concrete (see Figure 7.2.18).

Check areas exposed to drainage for concrete spalling or cracking. This may occur at the ends of the stems where drainage has seeped through the deck joints (see Figure 7.2.19).

Figure 7.2.17 Asphalt Covered Tee Beam Deck

Figure 7.2.18 Deteriorated Tee Beam Stem Adjacent to Drain Hole

Figure 7.2.19 Deteriorated Tee Beam End Due to Drainage

Areas Exposed to Traffic

Check areas damaged by collision. Document the number of exposed and severed reinforcing bars with section loss as well as the spalled and delaminated concrete. The loss of concrete due to such an accident is not always serious, unless the bond between the concrete and steel reinforcement is affected (see Figure 7.2.20).

Figure 7.2.20 Collision Damage to Tee Beam Bridge Over a Highway

Areas Previously Repaired

Examine areas that have been previously repaired. Determine if the repairs are in place, and if they are functioning properly.

7.2.5

Evaluation

State and federal rating guideline systems have been developed to aid in the inspection of concrete 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 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 used along with current inspection findings to determine the correct rating. For concrete tee beams, the deck condition influences the superstructure component rating. When the deck component rating is 4 or less, the superstructure component rating may be reduced if the recorded deck defects reduce its ability to carry applied stresses associated with superstructure moments.

Element Level Condition State Assessment

In an element level condition state assessment of a tee beam bridge, the AASHTO CoRe element is one of the following, depending on the riding surface:

Element No.	Description
	Concrete Deck
12	Concrete Deck – Bare
13	Concrete Deck– Unprotected with AC Overlay
14	Concrete Deck – Protected with AC Overlay
18	Concrete Deck – Protected with Thin Overlay
22	Concrete Deck – Protected with Rigid Overlay
26	Concrete Deck – Protected with Coated Bars
27	Concrete Deck – Protected with Cathodic System
	Concrete Open Girder/Beam
110	Concrete Open Girder/Beam

The unit quantity for the deck elements is “each”, and for the tee beam it is linear meters or feet. The entire element must be placed in one of the five available condition states based solely on the top surface condition. Some states have elected to use the total deck area (m^2 or ft^2). When a total area is used, the total area must be distributed among the five available condition states depending on the extent and severity of deterioration. The sum of all condition states must equal the total quantity of the CoRe element. The inspector must know the total deck surface area in order to calculate a percent deterioration and fit into a given condition state description. The unit quantity for the girder is meters or feet, and the total length must be distributed among the four available condition states depending on the extent and severity of deterioration. 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 structural cracks in the surface of bare decks, the “Deck Cracking” Smart Flag, Element No. 358, can be used and one of four condition states assigned. Do not use Smart Flag, Element No. 358, if the bridge deck/slab has any overlay because the top surface of the structural deck is not visible. For concrete defects on the underside of a deck element, the “Soffit” Smart Flag, Element No. 359, can be used and one of five condition states assigned. This Smart Flag is particularly useful if the wearing surface inhibits inspection of the top surface of the deck. 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.

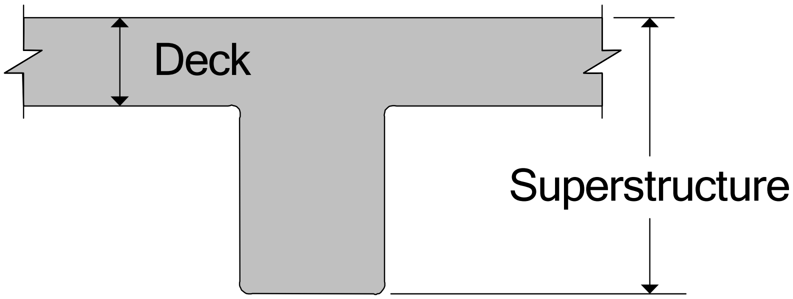

Figure 7.2.21 Components/Elements for Evaluation

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Section 7

Inspection and Evaluation of Common Concrete Superstructures

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Topic 7.3 Concrete Girders

7.3.1 Introduction

Concrete girder bridges generally consist of cast-in-place monolithic decks supported by a two girder system. Concrete girders can be used as deck girders, where the deck is cast on top of the girders (Figure 7.3.1), or as through girders, where the deck is cast between the girders (see Figure 7.3.2). Through girders are very large in appearance and actually serve as the bridge's parapets, as well as the main supporting members. Many of the concrete deck and through girder bridges in service today were built in the 1940's.

Figure 7.3.1 Concrete Deck Girder Bridge

Figure 7.3.2 Concrete Through Girder Bridge

7.3.2

Design Characteristics

General

For the purpose of inspection, the deck does not contribute to the strength of the girders and serves only to distribute traffic loads to the girders. As such, the superstructure condition rating is not affected by the condition of the deck. If floorbeams or stringers are present, they are considered part of the superstructure (see Figure 7.3.3).

Figure 7.3.3 Concrete Deck Girder, Underside View

Concrete through girders are used for spans ranging from 9 to 18 m (30 to 60 feet) at locations with a limited under-clearance (see Figure 7.3.4). They are, however, not economical for wide roadways and are usually limited to about 7 m (24-foot) width. Girders are usually 450 to 760 mm (18 to 30 inches) wide and 1220 to 1830 mm (4 to 6 feet) deep.

Figure 7.3.4 Concrete Through Girder Elevation View

Care must be taken not to describe concrete girder bridges as composite. They do not meet the definition of composite because the concrete girders and deck consist of the same material, even though they are rigidly connected with rebars.

In a deck girder as well as a through girder structure, the live loads from the roadway surface are carried to the girders through the deck. The girders in turn carry the loads to the substructure.

Primary Members and Secondary Members

The primary members of a girder bridge are the girders, floorbeams and stringers (if present) and the deck. The secondary members consist of diaphragms or struts.

Steel Reinforcement

The primary reinforcing steel consists of main longitudinal reinforcement and shear reinforcement or stirrups. The main tension reinforcement is located in the bottom of the girder (positve moment) and on the top (negative moment). The beam also contains shear reinforcement, called stirrups that are located throughout the girder length. A single stirrup is generally two U-shaped bars that run transversely across the top, bottom and sides of the girder (see Figure 7.3.5). The need for stirrups is greatest near the beam supports where shear stresses are the highest.

The secondary (temperature and shrinkage) reinforcing steel is oriented longitudinally in the sides of the girders (see Figure 7.3.5). The primary and secondary reinforcing steel for the deck portion of the beam is the same as for a standard concrete deck.

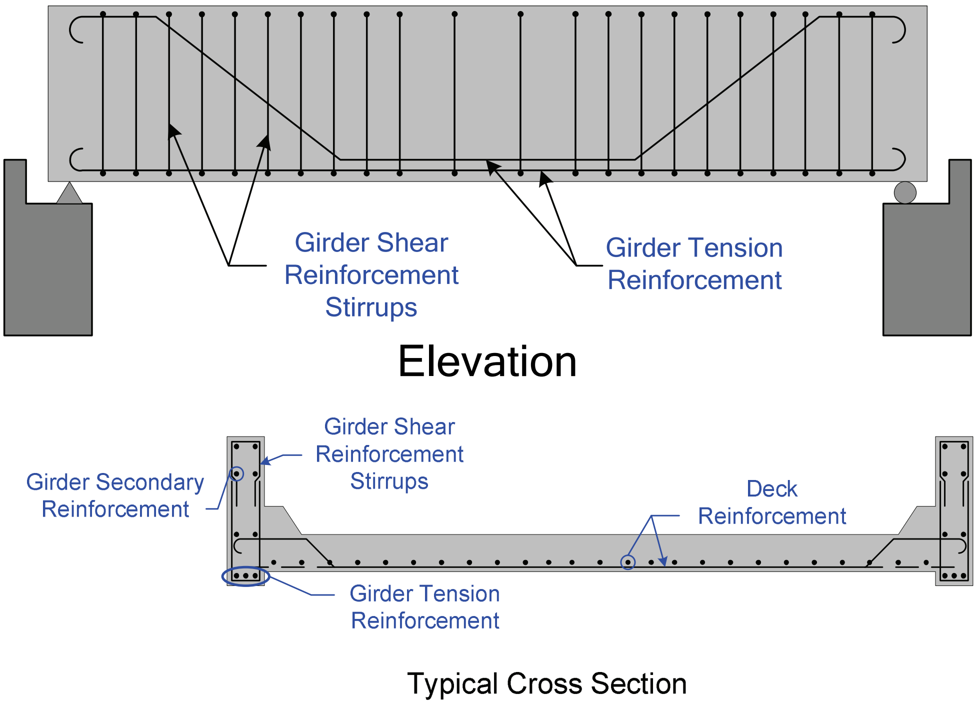

Figure 7.3.5 Steel Reinforcement in a Concrete Through Girder

7.3.3

Overview of Common Defects

Common defects that occur on concrete girder bridges include:

- Cracking (flexure, shear, temperature, shrinkage, mass concrete)
- Scaling
- Delamination
- Spalling
- Chloride contamination
- Efflorescence
- Ettringite formation
- Honeycombs
- Pop-outs
- Wear
- Collision damage
- Abrasion
- Overload damage
- Reinforcing steel corrosion

Refer to Topic 2.2 for a detailed explanation of the properties of concrete, types and causes of concrete deterioration, and the examination of concrete.

7.3.4

Inspection Procedures and Locations

Inspection procedures to determine other causes of concrete deterioration are discussed in detail in Topic 2.2.8.

Procedures

Visual

The inspection of concrete girders for cracks, spalls, and other defects is primarily a visual activity.

Physical

Sounding by a hammer can be used to detect delaminated areas. A delaminated area will have a distinctive hollow “clacking” sound when tapped with a hammer. A hammer hitting sound concrete will result in a solid "pinging" type sound.

Advanced Inspection Techniques

Several advanced techniques are available for concrete inspection. Nondestructive methods, described in Topic 13.2.2, include:

- Acoustic wave sonic/ultrasonic velocity measurements
- Delamination detection machinery
- Electrical methods
- Electromagnetic methods
- Pulse velocity
- Flat jack testing
- Ground-penetrating radar
- Impact-echo testing
- Infrared thermography
- Laser ultrasonic testing
- Magnetic field disturbance
- Neutron probe for detection of chlorides
- Nuclear methods
- Pachometer
- Rebound and penetration methods
- Ultrasonic testing

Other methods, described in Topic 13.2.3, include:

- Core sampling
- Carbonation
- Concrete permeability
- Concrete strength
- Endoscopes and videoscopes
- Moisture content
- Petrographic examination

- Reinforcing steel strength
- Chloride test
- Matrix analysis
- ASR evaluation

Locations

Bearing Areas

Examine bearing areas for cracking, delamination or spalling where friction from thermal movement and high bearing pressure could overstress the concrete. Check for crushing of the girder near the bearing seat. Check the condition and operation of any bearing devices (see Figure 7.3.6).

Figure 7.3.6 Bearing Area of a Through Girder Bridge

Shear Zones

Investigate the area near the supports for the presence of shear cracking. The presence of transverse cracks on the underside of the girders or diagonal cracks on the sides of the girders indicate the onset of shear failure. These cracks indicate extreme shear stresses and should be carefully measured and documented.

Tension Zones

Tension zones should be examined for flexure cracks, which would be vertical on the sides and transverse across the girder and possibly the deck. The tension zones are at the midspan along the bottom of the through girders and possibly the deck for both simple and continuous span bridges (see Figure 7.3.7). Additional tension zones are located along the top of the girders and possibly the deck over the piers for continuous spans. Cracks greater that 2 mm (1/16 inch) wide are considered wide cracks and indicate extreme bending stresses.

Check for deteriorated concrete near the tension zones, which could result in the debonding of the tension reinforcement. This would include delamination, spalls, and contaminated concrete.

Check for efflorescence from cracks and discoloration of the concrete caused by rust stains from the reinforcing steel. In severe cases, the reinforcing steel and any lap splices may become exposed and debonded from the surrounding concrete due to spalling (see Figure 7.3.8). Document loss of bonding between reinforcement and concrete, section loss of concrete and remaining cross section of reinforcing steel since section loss and any debonding will decrease live load capacity.

Figure 7.3.7 Typical Elevation View of a Through Girder Bridge with Tension Zones Indicated

Secondary Members

The diaphragms should be inspected for flexural and shear cracks, as well as for typical concrete defects. Defects in the diaphragms may be an indication of differential settlement of the substructure or differential deflection of the concrete girders.

Figure 7.3.8 Exposed Reinforcement in a Through Girder (under hammer)

Areas Exposed to Drainage

Inspect areas exposed to drainage. These areas will usually be at any joints or around the scuppers. Look for contamination due to deicing agents on the interior face of through girders (see Figure 7.3.9). Check around drain holes for deterioration of girder concrete.

Figure 7.3.9 Close-up of an Interior Face of a Through Girder with Heavy Scaling due to Deicing Agents

Areas Exposed to Traffic

Check areas damaged by collision. Document the number of exposed and severed reinforcing bars with section loss as well as the spalled and delaminated concrete. The loss of concrete due to such an accident is not always serious, unless the bond between the concrete and steel reinforcement is affected.

Areas Previously Repaired

Examine areas that have been previously repaired. Determine if the repairs are in place and if they are functioning properly.

7.3.5

Evaluation

State and federal rating guideline systems have been developed to aid in the inspection of concrete 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 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 concrete girder bridge, the AASHTO CoRe element is:

Element No.	Description
110	Concrete Open Girder/beam
116	Concrete Stringer
155	Concrete Flooream

The unit quantity for the girder/beam, floorbeam or stringer is meters or feet, and the total length must be distributed among the four available condition states depending on the extent and severity of deterioration. 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 traffic impact, the “Traffic Impact” Smart Flag, Element No. 362, can be used and one of the three condition states assigned.

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Section 7

Inspection and Evaluation of Common Concrete Superstructures

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Topic 7.4 Concrete Channel Beams

7.4.1
Introduction

In appearance, the channel beam bridge resembles the tee beam bridge because the stems of the adjacent channel beams extend down to form a single stem (see Figures 7.4.1 and 7.4.2). The channel beam can either be pre-cast or cast-in-place.

Figure 7.4.1 Underside View of Precast Channel Beam Bridge

Figure 7.4.2 Underside View of a Cast-in-Place Channel Beam Bridge

7.4.2

Design Characteristics

General

Channel beams are usually found on spans up to 15 m (50 ft).

Channel beams are generally precast and consist of a mildly reinforced deck cast monolithically with two stems 900 to 1200 mm (3 to 4 feet) apart (see Figure 7.4.1). Precast channel beams may be conventionally reinforced or may be prestressed. Stem tie bolts (see Figure 7.4.1) and shear keys (see Figure 7.4.4) are used to achieve monolithic action between precast channel beams.

Channel beams can also be cast-in-place with a curved underbeam soffit constructed over U-shaped beam forms (see Figure 7.4.2).

Figure 7.4.3 General View of a Precast Channel Beam Bridge

Primary and Secondary Members

The primary members of channel beam bridges are the channel beams. The secondary members of channel beam bridges are the diaphragms.

Steel Reinforcement

Reinforcement cover for older channel beam bridges is often less than today's cover requirements. Air entrained concrete was not specified in cast-in-place channel beams fabricated in the 1940's and early 1950's, and concrete was often poorly consolidated.

The primary reinforcing steel consists of stem tension reinforcement and shear reinforcement or stirrups. The tension reinforcement is located in the bottom of the channel stem and oriented longitudinally. The tension steel reinforcement in current channel beams consists of either mild reinforcing bars or prestressing strands. The sides of the stems are reinforced with stirrups. The stirrups are located vertically in the sides of the channel stems at various spacings throughout the length and closer near the beam supports. The need for stirrups is greatest near the beam supports where the shear stresses are the highest.

The primary reinforcing steel for the deck portion of the beam is located in the bottom of the deck and is placed transversely, or perpendicular to the channel stems (see Figure 7.4.4).

The secondary (temperature and shrinkage) reinforcing steel is oriented longitudinally in the sides of deep channel stems and longitudinally in the deck. The primary and secondary reinforcing steel for the deck portion of the beam is the same as for a standard concrete deck (see Figure 7.4.4).

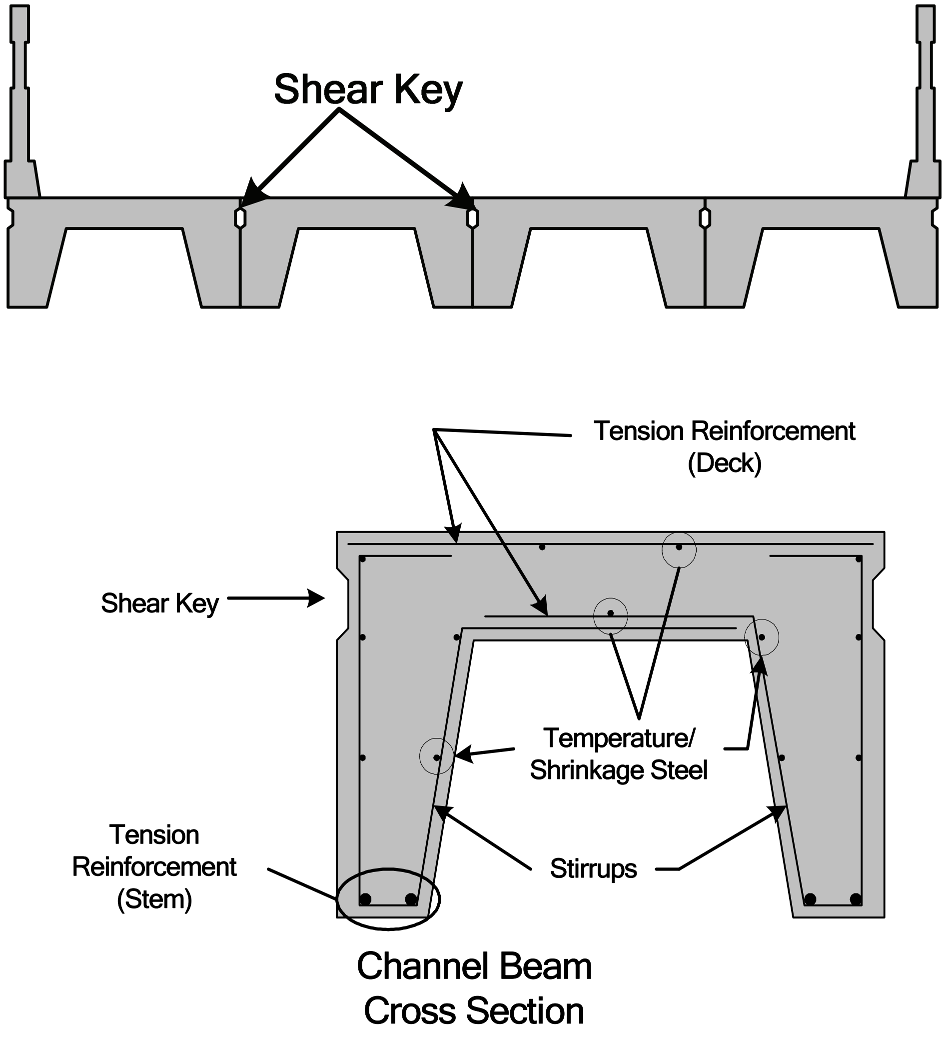

Figure 7.4.4 Cross Section of a Typical Channel Beam

7.4.3

Overview of Common Defects

Common defects that occur on concrete channel beam bridges include:

- Cracking (flexure, shear, temperature, shrinkage, mass concrete)
- Scaling
- Delamination
- Spalling
- Chloride contamination
- Efflorescence
- Ettringite formation
- Honeycombs
- Pop-outs
- Wear
- Collision damage
- Abrasion
- Overload damage
- Reinforcing steel corrosion
- Prestressed concrete deterioration

Refer to Topic 2.2 for a detailed explanation of the properties of concrete, types and causes of concrete deterioration, and the examination of concrete.

7.4.4

Inspection Procedures and Locations

Inspection procedures to determine other causes of concrete deterioration are discussed in detail in Topic 2.2.8.

Procedures

Visual

The inspection of concrete channel beams for cracks, spalls, and other defects is primarily a visual activity.

Physical

Sounding by hammer can be used to detect delaminated areas. A delaminated area will have a distinctive hollow “clacking” sound when tapped with a hammer or revealed with a chain drag. A hammer hitting sound concrete will result in a solid "pinging" type sound. In most cases, a chain drag is used to check the top surface of a concrete deck.

Since prestressed beams are designed to maintain all concrete in compression, cracks are indications of serious problems. For this reason, any crack should be carefully measured with an optical crack gauge or crack comparator card and documented.

Advanced Inspection Techniques

Several advanced techniques are available for concrete inspection. Nondestructive methods, described in Topic 13.2.2, include:

- Acoustic wave sonic/ultrasonic velocity measurements
- Delamination detection machinery
- Electrical methods
- Electromagnetic methods
- Pulse velocity
- Flat jack testing
- Ground-penetrating radar
- Impact-echo testing
- Infrared thermography
- Laser ultrasonic testing
- Magnetic field disturbance
- Neutron probe for detection of chlorides
- Nuclear methods
- Pachometer
- Rebound and penetration methods
- Ultrasonic testing

Other methods, described in Topic 13.2.3, include:

- Core sampling
- Carbonation
- Concrete permeability
- Concrete strength
- Endoscopes and videoscopes
- Moisture content
- Petrographic examination
- Reinforcing steel strength
- Chloride test
- Matrix analysis
- ASR evaluation

Locations

Bearing Areas

Inspect bearing areas for cracking, delamination or spalling where friction from thermal movement and high bearing pressure could overstress the concrete. Check for crushing of the stem near the bearing seat. Check the condition and operation of any bearing devices.

Shear Zones

Inspect the area near the supports for the presence of shear cracking. The presence of transverse cracks on the underside of the stem or diagonal cracks on the sides of the stems indicate the onset of shear failure. These cracks indicate extreme shear stresses and should be carefully measured and documented.

Tension Zones

Superstructure tension zones should be examined for flexure cracks, which would be vertical on the sides and transverse across the bottom of the stem. The tension zones are at the midspan along the bottom of the stem for both simple and continuous span bridges. Additional tension zones are located on the deck over the piers for continuous spans.

Flexure cracks caused by tension in the deck will be found on the underside in a longitudinal direction.

Check for deteriorated concrete near the tension zones, which could result in the debonding of the tension reinforcement. This would include delamination, spalls, and contaminated concrete. These could occur on both the concrete stems and the deck.

Check for efflorescence from cracks and discoloration of the concrete caused by rust stains from the reinforcing steel. In severe cases, the reinforcing steel may become exposed and debonded from the surrounding concrete due to spalling. Document loss of bonding between reinforcement and concrete, section loss of concrete and remaining cross section of reinforcing steel since section loss and any debonding will decrease live load capacity. Check for evidence of sagging or camber loss (see Figure 7.4.5).

Figure 7.4.5 Excessive Deflection at Midspan

Secondary Members

The diaphragms (See Figure 7.4.10) should be inspected for flexural and shear cracks, as well as for typical concrete defects. Defects in the diaphragms may be an indication of differential settlement of the substructure or differential deflection of the concrete channel beams.

Areas Exposed to Drainage

Inspect the seam or joint between adjacent precast beams for leakage. Leakage generally indicates a broken shear key between the channel beams (see Figure 7.4.6). If signs of leakage are present between beams, the shear keys should be observed closely for differential channel beam deflection under live load (see Figure 7.4.7). Also, check beam ends for concrete deterioration due to leaking joints.

Examine areas exposed to drainage. Look for spalls and contamination at the ends and edges of the channel beams, scuppers, drain holes, and the curb line.

Check the stem tie-bolts for tightness and corrosion (see Figures 7.4.8 and 7.4.9). Do not confuse signs of corrosion with the epoxy used for the bolt.

Figure 7.4.6 Joint Leakage Between Channel Beams

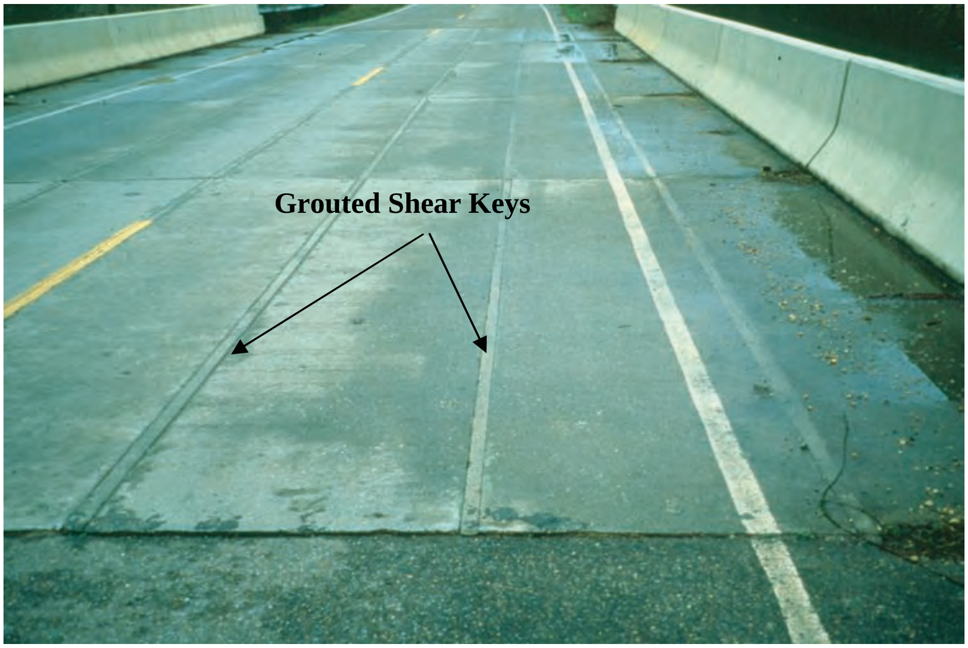

Figure 7.4.7 Top of Deck View of Precast Channel Beam Bridge

Figure 7.4.8 Stem Tie-bolts

Figure 7.4.9 Close-up of Stem Tie-bolt (Epoxy Resin)

Figure 7.4.10 Close-up of Diaphragm

Areas Exposed to Traffic

Check areas damaged by collision. Document the number of exposed and severed reinforcing bars with section loss, as well as the spalled and delaminated concrete. The loss of concrete due to such an accident is not always serious, unless the bond between the concrete and steel reinforcement is affected.

Areas Previously Repaired

Examine areas that have been previously repaired. Determine if the repairs are in place, and if they are functioning properly.

7.4.5 Evaluation

State and federal rating guideline systems have been developed to aid in the inspection of concrete 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 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 (Items 58 and 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. For concrete channel beams, the deck condition influences the superstructure component rating (see figure 7.4.11). When the deck component rating is 4 or less, the superstructure component rating may be reduced if the recorded deck defects reduce its ability to carry applied stresses associated with superstructure moments.

Element Level Condition State Assessment

In an element level condition state assessment of a concrete channel beam bridge, the AASHTO CoRe element is:

Element No.	Description
	Concrete Deck
12	Concrete Deck – Bare
13	Concrete Deck– Unprotected with AC Overlay
14	Concrete Deck – Protected with AC Overlay
18	Concrete Deck – Protected with Thin Overlay
22	Concrete Deck – Protected with Rigid Overlay
26	Concrete Deck – Protected with Coated Bars
27	Concrete Deck – Protected with Cathodic System
	Concrete Open Girder/Beam
110	Concrete Open Girder/beam
109	Prestressed Concrete Open Girder/beam

The unit quantity for the deck elements is “each”, and for the channel beam it is linear meters or feet. The entire element must be placed in one of the five available condition states based solely on the top surface condition. Some states have elected to use the total deck area (m^2 or ft^2). When a total area is used, the total area must be distributed among the five available condition states depending on the extent and severity of deterioration. The sum of all condition states must equal the total quantity of the CoRe element. The inspector must know the total deck surface area in order to calculate a percent deterioration and fit into a given condition state description. The unit quantity for the girder is meters or feet, and the total length must be distributed among the four available condition states depending on the extent and severity of deterioration. 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 structural cracks in the surface of bare decks, the "Deck Cracking" Smart Flag, Element No. 358, can be used and one of four condition states assigned. Do not use Smart Flag, Element No. 358, if the bridge deck/slab has any overlay because the top surface of the structural deck is not visible. For concrete defects on the underside of a deck element, the "Soffit" Smart Flag, Element No. 359, can be used and one of five condition states assigned. This Smart Flag is particularly useful if the wearing surface inhibits inspection of the top surface of the deck. 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.

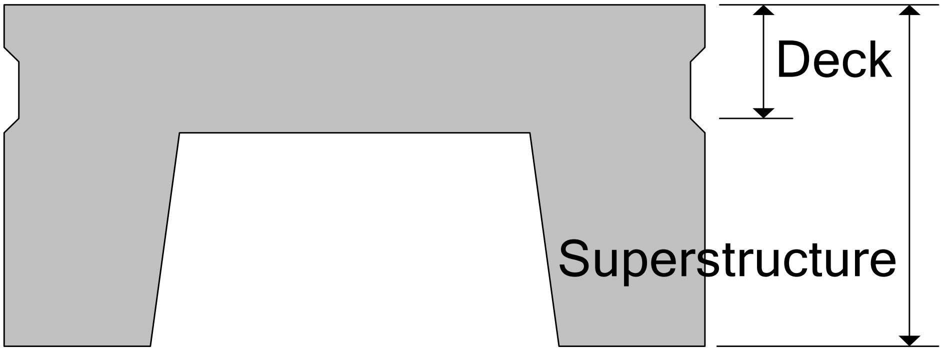

Figure 7.4.11 Components/Elements for Evaluation

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Section 7 Inspection and Evaluation of Common Concrete Superstructures

Topic 7.5 Concrete Arches and Arch Culverts

7.5.1 Introduction

A true arch has an elliptical shape and functions in a state of pure axial compression. It can be thought of as a long curved column. This makes the true arch an ideal form for the use of concrete. Unfortunately, the true arch form is often compromised to adjust for a specific bridge site. Because of this compromise, modern concrete arch bridges resist a load combination of bending moments, and shear in addition to axial compression.

7.5.2 Design Characteristics

The basic design concept in arch construction utilizes a "building block" approach. Arch elements, although connected, are stacked or "bearing" on top of one another. The elements at the bottom of the pile receive the largest compressive loads due to the weight of the elements above. Arch spans are always considered "simple span" designs because of the basic arch function.

General

Open Spandrel Arch

The open spandrel concrete arch is considered a deck arch since the roadway is above the arches. The area between the arches and the roadway is called the spandrel.

Open spandrel concrete arches receive traffic loads through spandrel bents that support a deck or tee beam floor system (see Figure 7.5.1). This type of arch is generally for 61 m (200 feet) and longer spans.

Figure 7.5.1 Open Spandrel Arch Bridge

Closed Spandrel Arch

Closed spandrel arches are deck arches. The spandrel area (i.e., the area between the arch and the roadway) is occupied by fill retained by vertical walls. The arch member is called a ring or barrel and is continuous between spandrel walls.

Closed spandrel arches receive traffic loads through the fill material which is contained by spandrel walls (see Figure 7.5.2). This type of arch is efficient in short span applications.

Figure 7.5.2 Multi-span Closed Spandrel Arch Bridge

A closed spandrel arch with no fill material has a hollow vault between the spandrel walls. This type of arch has a floor system similar to the open spandrel arch and should be inspected accordingly.

Through Arch

A concrete through arch is constructed having the crown of the arch above the deck and the arch foundations below the deck. Hangers or cables suspend the deck from the arch. Concrete through arches are very rare (see Figure 7.5.3). These types of arches are sometimes referred to as “Rainbow Arches”.

Figure 7.5.3 Concrete Through Arch Bridge

Precast Arch

Precast concrete arches are gaining popularity and can be integral or segmental. The integral arches typically have an elliptical barrel with vertical integral sides (see Figure 7.5.4). Segmental arches are oval or elliptical and can have several hinges along the arch (see Figure 7.5.5). The hinges allow for rotation and eliminate the moment at the hinge location. Both integral and segmental precast arch sections are bolted or post-tensioned together perpendicular to the arch.

Figure 7.5.4 Precast Concrete Arch with Integral Vertical Legs

Figure 7.5.5 Precast Segmental Concrete Arch

Large segmental precast arches that are post-tensioned have the ability to span great distances. This type of arch is constructed from the arch foundations to the crown using segmental hollow sections. The segmental sections are post-tensioned together along the arch through post-tensioning ducts placed around the perimeter of the segmental section. For this type of design, the deck and supporting members bear on the top or crown of the arch (see Figure 7.5.6).

High quality control can be obtained for precast arches. Sections are precast in a casting yard which allows manufacturers to properly monitor the concrete placement and curing. Reinforcement clearances and placement is also better controlled in a casting yard. Precast sections are typically tested prior to gaining acceptance for use. This ensures that the product can withstand the required loads that are applied.

Figure 7.5.6 Precast Post-tensioned Concrete Arch without Spandrel Columns

Arch Culvert

Although concrete arch culverts look like and experience most of the same defects as concrete arch bridges, concrete arch culverts are separate from concrete arch bridges due to hydraulic, structural, maintenance, traffic safety, construction, durability, and inspection differences. An arch culvert is a curved shaped culvert that works primarily in compression. A variation of the arch culvert is the tied arch culvert. It is basically the same as the arch culvert, but it has an integral floor serving as a tie between the ends of the arch. Concrete arch culverts can be cast-in-place or precast. Unlike arch bridges, arch culverts are designed to flow full at peak flows. Also, the embankment material surrounding an arch culvert is more important than the embankment material around an arch bridge. These differences plus others require special attention to be given to culverts (see Figures 7.5.7 and 7.5.8).

Figure 7.5.7 Concrete Arch Culvert

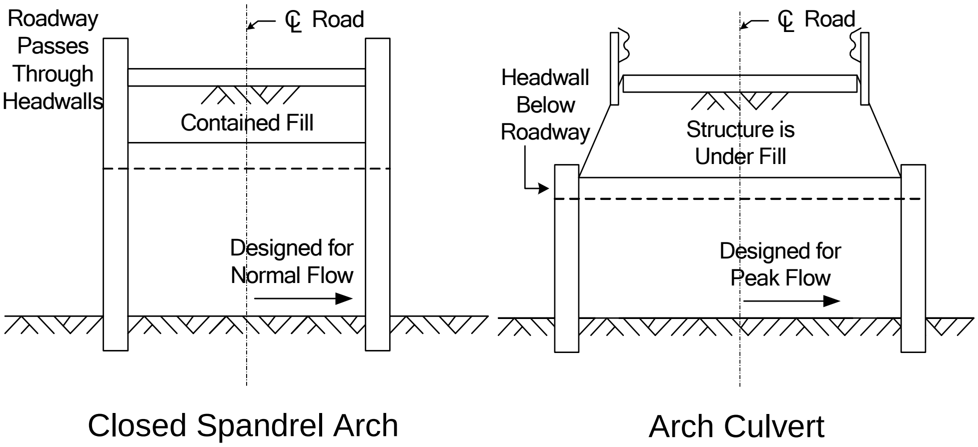

Figure 7.5.8 Closed Spandrel Arch versus Arch Culvert

Primary Members and Secondary Members

Open Spandrel Arch

The reinforced concrete open spandrel arch consists of one or more arch ribs. The arch members are the primary load-carrying elements of the superstructure. The arch and the following members supported by the arch are also considered primary superstructure elements:

- Spandrel bents - support floor system
- Spandrel bent cap - transverse beam member of the spandrel bent
- Spandrel columns - vertical members of the spandrel bent which support the spandrel bent cap

- Spandrel beams - fascia beams of the floor system
- Floor system - a slab or tee beam arrangement supported by the spandrel bent caps and the substructure elements

The secondary members of an open spandrel arch bridge are the arch struts, which are transverse beam elements connecting the arch ribs. Arch struts provide stability against lateral forces and reduce the unsupported compression length between supports (see Figure 7.5.9).

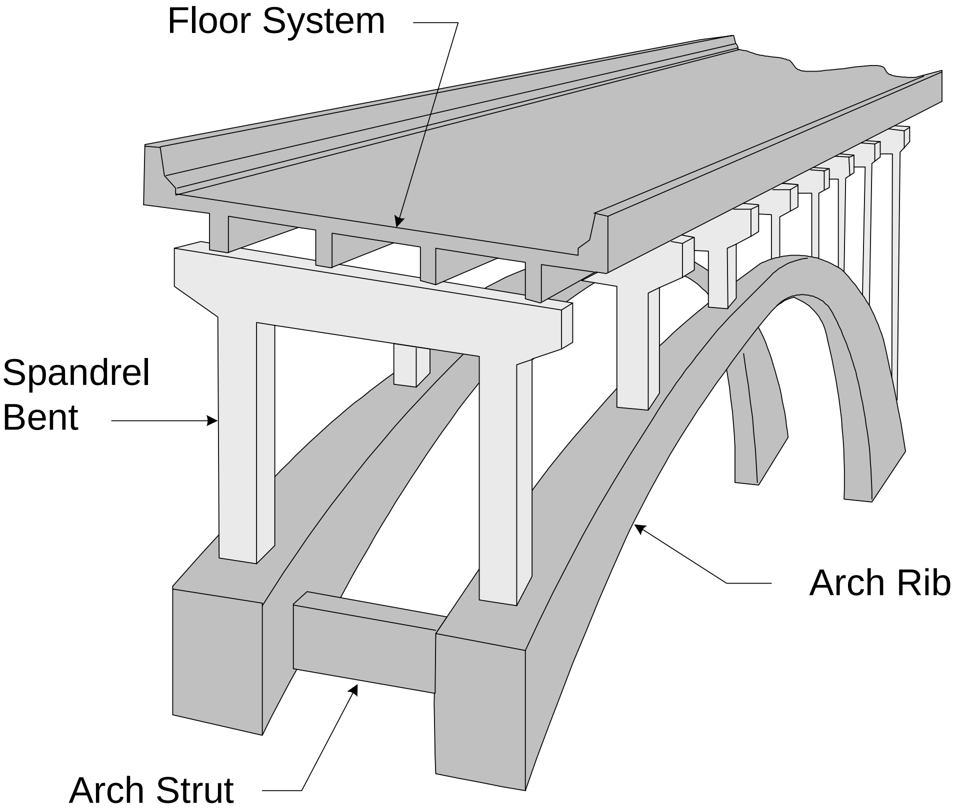

Figure 7.5.9 Primary and Secondary Members of an Open Spandrel Arch

Closed Spandrel Arch

For a closed spandrel arch, the primary members are the arch rings and spandrel walls. The arch rings support fill material, roadway, and traffic, while the spandrel walls retain fill material and support the bridge parapets.

The arch and members supported by the arch are superstructure elements. The arch itself is the primary load-carrying element of the superstructure (see Figure 7.5.10).

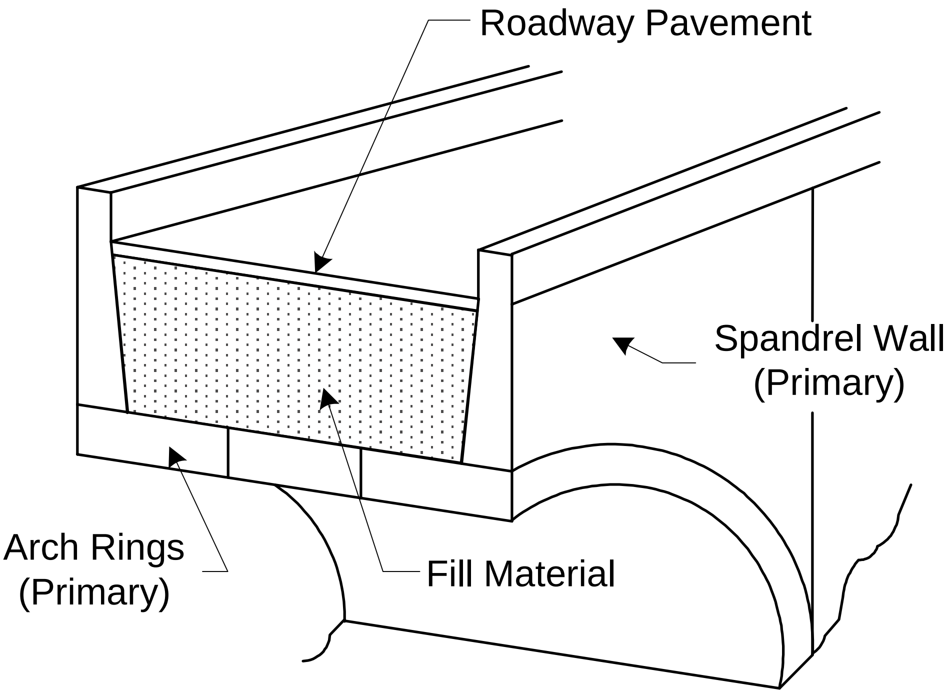

Figure 7.5.10 Primary Members of a Closed Spandrel Arch

Concrete Arch Culverts

The primary member in a concrete arch culvert is the culvert barrel. The barrel supports fill material and any live loads crossing the structure.

Steel Reinforcement

For the proper inspection and evaluation of concrete arch bridges and culverts, the inspector must be familiar with the location and purpose of steel reinforcement.

Open Spandrel Arch

The primary reinforcing steel in an open spandrel arch follows the shape of the arch from support to support. Since the arch is a compression member, reinforcement is similar to column reinforcement. The surfaces of the arch rib are reinforced with equal amounts of longitudinal steel held in place with lateral ties. This longitudinal or column reinforcement can act as compression reinforcement when the arch must resist moment due to axial load eccentricity or lateral loads. Spandrel columns are also compression members and are reinforced similar to the arch rib (see Figure 7.5.11).

In spandrel bent caps, the primary reinforcement is tension and shear steel. This is provided using "Z" shaped bars and stirrups since the cap behaves like a fixed end beam (see Figure 7.5.12).

The floor system is designed and reinforced similar to other concrete beams (e.g. tee beams).

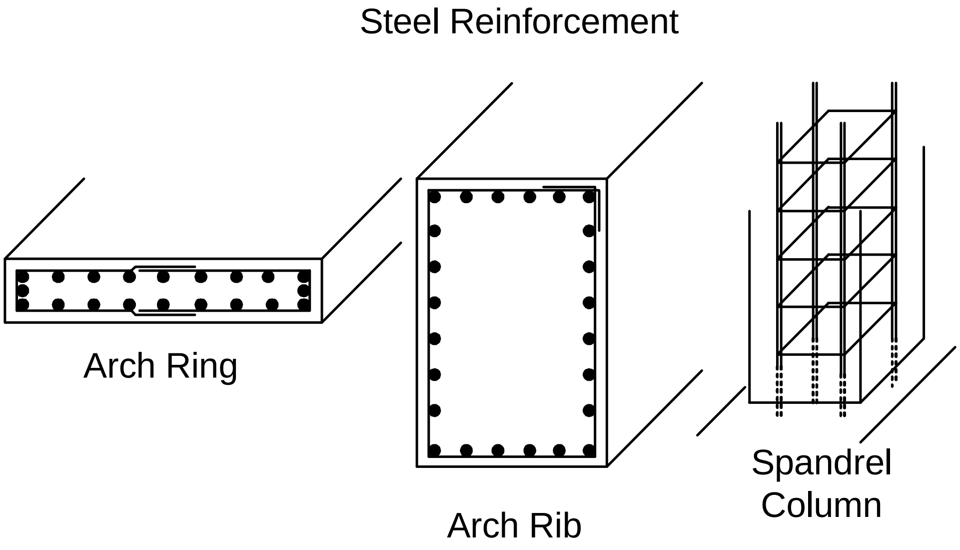

Figure 7.5.11 Open Spandrel Arch Reinforcement

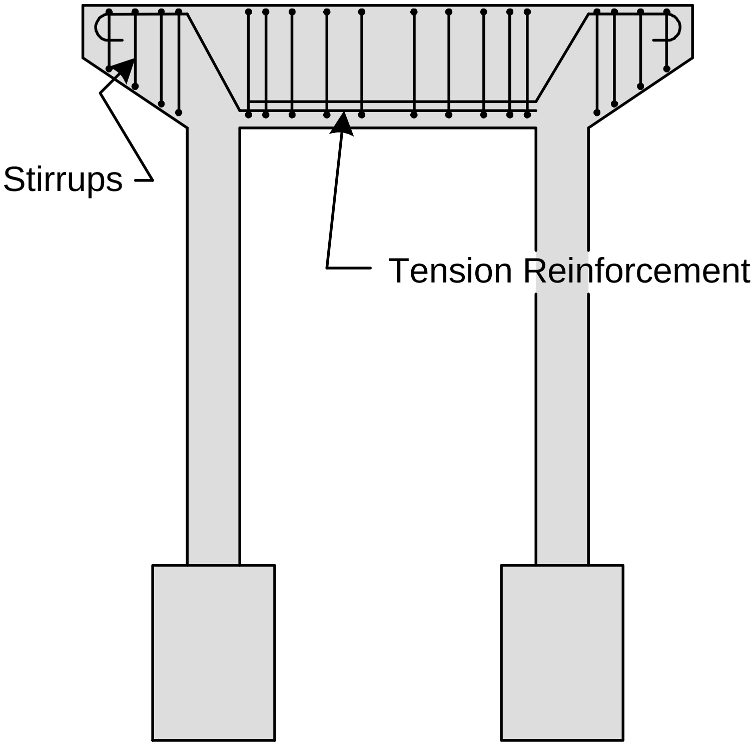

Figure 7.5.12 Spandrel Bent Cap Reinforcement

Closed Spandrel Arch

The primary reinforcing steel in the arch ring follows the shape of the arch from support to support and consists of a mat of reinforcing steel on both the top and bottom surfaces of the arch. The inspector will be unable to inspect the top surface of the arch due to the backfill.

The spandrel walls are designed to retain the backfill material. The primary tension steel for the wall is usually at the back, or unexposed, face of the wall, hidden from view. The front, or outside, face of the wall is reinforced in both directions with temperature and shrinkage steel (see Figure 7.5.13).

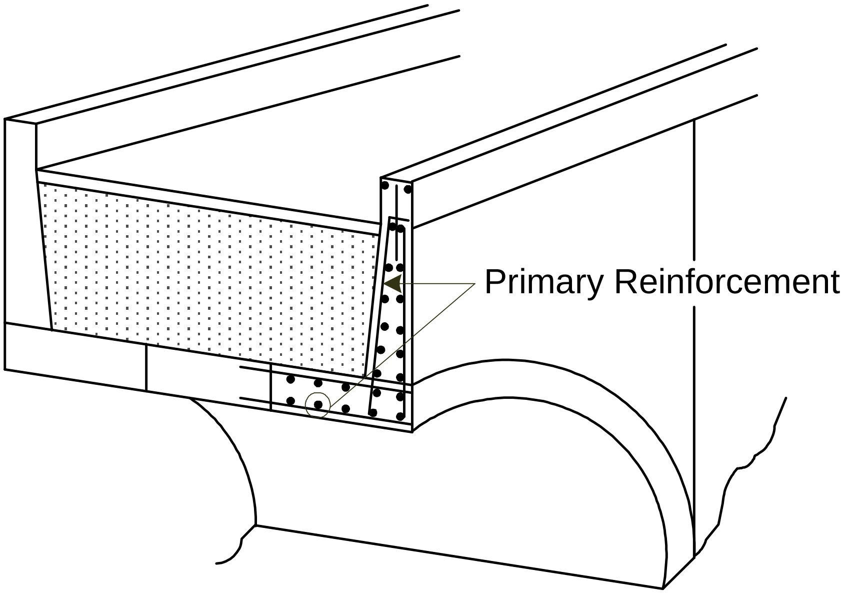

Figure 7.5.13 Reinforcement in a Closed Spandrel Arch

Arch Culvert

Reinforcement for arch culverts follows the shape of the arch from support to support. A mat of reinforcing steel is used on the top and bottom surfaces of the arch.

Other Reinforcement

Temperature and shrinkage reinforcement is used in the floor system for open spandrel arches.

A grid of temperature and shrinkage reinforcement is used in spandrel walls for closed spandrel arches.

7.5.3
Overview of Common Defects

Common defects that occur on concrete arches and culverts include:

- Cracking (flexure, shear, temperature, shrinkage, mass concrete)
- Scaling
- Delamination
- Spalling
- Chloride contamination
- Efflorescence
- Ettringite formation

- Honeycombs
- Pop-outs
- Wear
- Collision damage
- Abrasion
- Overload damage
- Reinforcing steel corrosion
- Prestressed concrete deterioration
- Stress corrosion

Refer to Topic 2.2 for a detailed presentation of the properties of concrete, types and causes of concrete deterioration, and the examination of concrete.

7.5.4

Inspection Procedures and Locations

Inspection procedures to determine other causes of concrete deterioration are discussed in detail in Topic 2.2.8.

Procedures

Visual

The inspection of concrete arches and culverts for cracks, spalls, and other defects is primarily a visual activity.

Physical

Sounding by hammer can be used to detect areas of delamination. A delaminated area will have a distinctive hollow “clacking” sound when tapped with a hammer or revealed with a chain drag. A hammer hitting sound concrete will result in a solid "pinging" type sound.

Advanced Inspection Techniques

Several advanced techniques are available for concrete inspection. Nondestructive methods, described in Topic 13.2.2, include:

- Acoustic wave sonic/ultrasonic velocity measurements
- Delamination detection machinery
- Electrical methods
- Electromagnetic methods
- Pulse velocity
- Flat jack testing
- Ground-penetrating radar
- Impact-echo testing
- Infrared thermography
- Laser ultrasonic testing
- Magnetic field disturbance
- Neutron probe for detection of chlorides
- Nuclear methods

- Pachometer
- Rebound and penetration methods
- Ultrasonic testing

Other methods, described in Topic 13.2.3, include:

- Core sampling
- Carbonation
- Concrete permeability
- Concrete strength
- Endoscopes and videoscopes
- Moisture content
- Petrographic examination
- Reinforcing steel strength
- Chloride test
- Matrix analysis
- ASR evaluation

Locations

Open and Closed Spandrel Arches

Bearing Areas

The arch/skewback interface has the greatest bearing load magnitude. Inspect for loss of cross section of the reinforcement bars at the spalls. Examine the arch for longitudinal cracks. These indicate an overstress condition.

The arch/spandrel column interface has the second greatest bearing load magnitude. Examine for reinforcement cross-section loss at the spalls. Check for horizontal cracks in the columns within several meters from the arch. These indicate excessive bending in the column, which is caused by overloads and differential arch rib deflection.

The spandrel column/cap interface has the third greatest bearing load magnitude. Inspect for loss of section due to spalling. Examine the column for cracks which begin at the inside corner and propagate upward. These indicate differential arch rib deflections (see Figure 7.5.14).

The floor system/bent cap interface has the smallest bearing load magnitude. Examine bearing areas as described in the deck, tee beam and girder sections.

Examine the arch ring for unsound concrete. Look for rust stains, cracks, discoloration, crushing, and deterioration of the concrete. The interface between the spandrel wall and the arch should be carefully inspected for spalls that could reduce the bearing area. Investigate the arch for transverse cracks, which indicate an overstress condition.

Figure 7.5.14 Spandrel Column Cap Interface

Shear Zones

Check for shear cracks at the ends of the spandrel bent caps. When arch ribs are connected with struts, examine the arches near the connection for diagonal cracks due to torsional shear. These cracks indicate excessive differential deflection in the arch ribs. Also investigate the floor system for shear cracks.

Tension Zones

Inspect the tension areas of the spandrel bent caps and columns (i.e., mid-span at the bottom and ends at the top) (see Figure 7.5.15). Also check the tension areas in the floor system.

Check for transverse cracks in the arch which indicate an overstress condition. Transverse cracks are oriented perpendicular to the arch member.

Inspect the spandrel walls for sound concrete. Look for cracks, movement, and general deterioration of the concrete (see Figure 7.5.16).

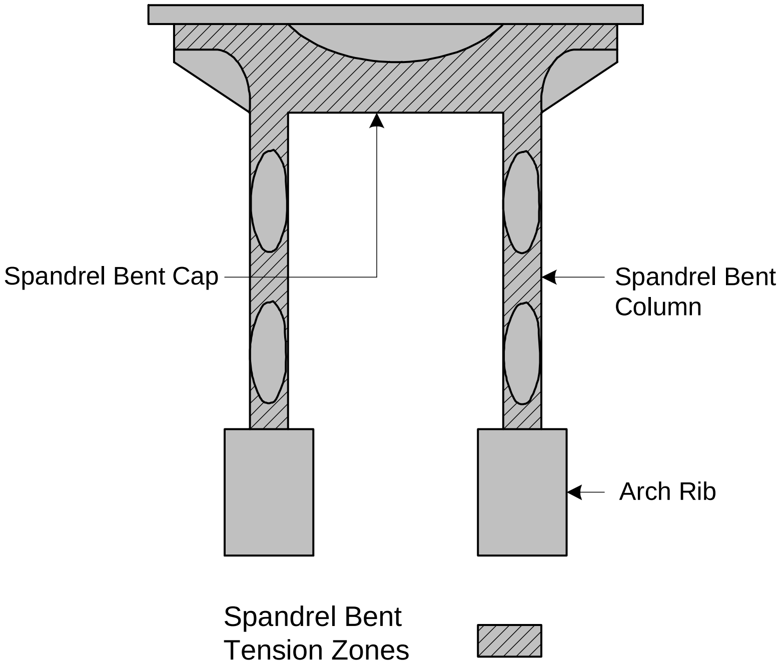

Figure 7.5.15 Spandrel Bent Tension Zone

Figure 7.5.16 Deteriorated Arch/Spandrel Wall Interface

Compression Zones

Investigate the compression areas throughout the arches and spandrel columns (not only at the bearing areas). Transverse or lateral cracks indicate excessive surface stresses caused by buckling forces and bending moment (see Figure 7.5.17).

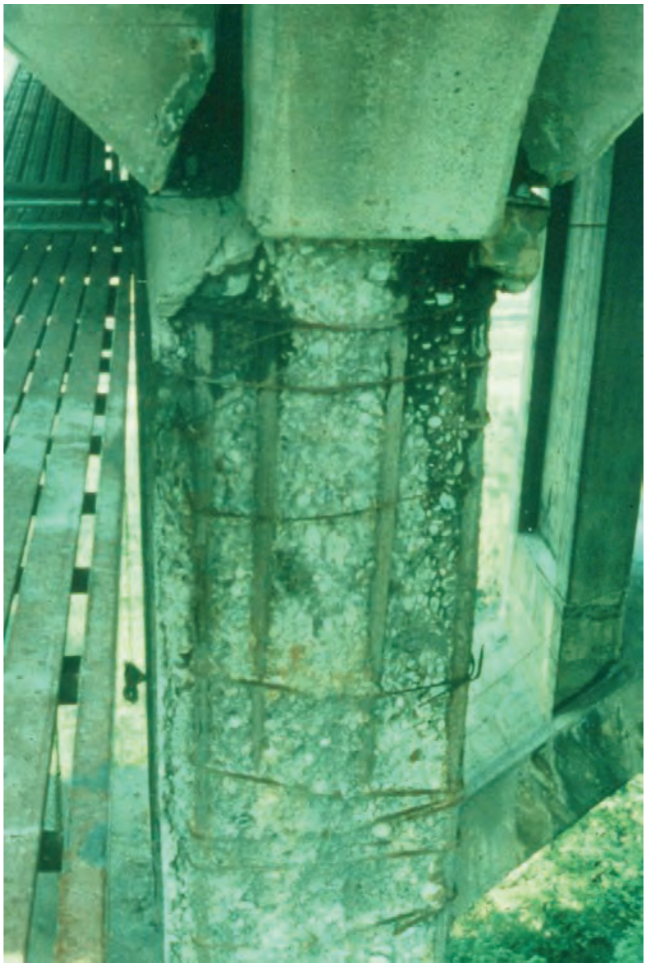

Figure 7.5.17 Severe Scaling and Spalling on a Spandrel Column

Secondary Members

The diaphragms and struts should be inspected for flexural and shear cracks, as well as for typical concrete defects. Defects in the secondary members may be an indication of differential settlement of the substructure or differential deflection of the concrete arches.

Areas Exposed to Drainage

For an open spandrel arch, check the areas exposed to drainage and roadway runoff. Elements beneath the floor system are prone to scaling, spalling, and chloride contamination (see Figure 7.5.18).

For a closed spandrel arch, make sure that weep holes are working properly. Also, check that surface water drains properly and does not penetrate the fill material.

Figure 7.5.18 Scaling and Contamination on an Arch Rib Due to a Failed Drainage System

Areas Exposed to Traffic

Check areas damaged by collision. Document the number of exposed and severed reinforcing bars with section loss as well as the spalled and delaminated concrete. The loss of concrete due to such an accident is not always serious, unless the bond between the concrete and steel reinforcement is affected.

Areas Previously Repaired

Examine thoroughly any repairs that have been previously made. Determine if repaired areas are functioning properly. Effective repairs and patching are usually limited to protection of exposed reinforcement.

Concrete Arch Culverts

For a concrete arch culvert, the following locations should be inspected:

Inspect the culvert barrel for rust stains, cracks, discoloration, crushing, and other deterioration of the concrete. Inspect the culvert barrel for spalls, delaminations, and rebar section loss.

Check weep holes for partial or full blockage.

Check approach conditions for dips, sags, cracks, pavement patches or other settlement indicators.

Examine headwalls and wingwalls for scour, undermining and settlement. Cracking, tipping, or separations of the barrel from the headwall are indications of undermining and settlement.

When dealing with precast concrete culverts, inspect for joint defects, leaking joints, cracked joints, and separated joints.

Refer to Topics 11.1 through 11.3 for waterway inspection procedures and locations.

7.5.5

Evaluation

State and federal rating guideline systems have been developed to aid in the inspection of concrete 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 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 or culvert. Rating codes range from 9 to 0, where 9 is the best rating possible. The previous inspection data should be considered along with current inspection findings to determine the correct rating. See Topic 4.2 (Item 59 and Item 62) for additional details about NBI Rating Guidelines.

For concrete arch culverts, the NBI rating guidelines yield a 1-digit code on the Federal (SI&A) sheet that indicates the overall condition of the culvert. The culvert item not only evaluates the structural condition of the culvert, but also encompasses the alignment, settlement in the approach roadway and embankment, joints, scour, and headwalls and wingwalls. Integral wingwalls are included in the evaluation up to the first construction or expansion joint. Like concrete arches, the 1-digit code that best describes the culvert’s overall condition is chosen, and the rating codes range from 9 to 0, where 9 is the highest possible rating.

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 concrete arch or arch culvert, the AASHTO CoRe element is one or more of the following:

Element No.	Description
	Open Spandrel Arch
109	Open Girder/Beam (P/S Concrete)
110	Open Girder/Beam (Reinforced Concrete)
154	Floorbeam (P/S Concrete)
155	Floorbeam (Reinforced Concrete)
115	Stringer (stringer floorbeam system) (P/S Concrete)
116	Stringer (stringer floorbeam system) (Reinforced Concrete)

143	Arch (P/S Concrete)
144	Arch (Reinforced Concrete)
204	Column or Pile Extension (P/S Concrete)
205	Column or Pile Extension (Reinforced Concrete)
233	Cap (P/S Concrete)
234	Cap (Reinforced Concrete)
	Closed Spandrel Arch
143	Arch (P/S Concrete)
144	Arch (Reinforced Concrete)
	Arch Culvert
241	Arch Culvert (Precast, Prestressed, or Reinforced Concrete)

The quantities, when dealing with concrete arches or culverts, are all in meters or feet except for Elements 204 and 205, which are given in units of each. The above elements for concrete arches and culverts consist of three to five condition state descriptions to choose from for each element. The total length must be distributed among the three to five available condition states depending on the extent and severity of deterioration. Condition state 1 is the best possible rating. See the *AASHTO Guide for Commonly Recognized (CoRe) Structural Elements* for condition state descriptions.

Use Figure 7.5.19 to determine total quantities of concrete closed spandrel arches and arch culverts.

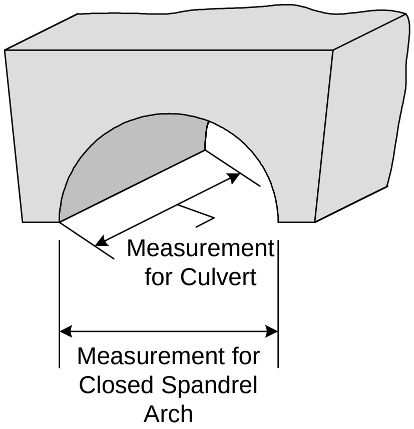

Figure 7.5.19 Measurements for Closed Spandrel Arches and Arch Culverts

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.

Smart Flag element numbers available for use in the case of open and closed spandrel arches are Element 360 “Settlement”, and Element 362 “Traffic Impact”. In addition, concrete arch culverts can use Smart Flag Element 361 “Scour” or Element 362 “Traffic Impact” if needed. One of three condition state descriptions is chosen for each Smart Flag element that is used.

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Section 7
Inspection and Evaluation of Common Concrete Superstructures

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Topic 7.6 Concrete Rigid Frames

7.6.1 Introduction

A concrete rigid frame structure is a bridge type in which the superstructure and substructure components are constructed as a single unit. Rigid frame action is characterized by the ability to transfer moments at the knee, the intersection between the frame legs and the frame beams or slab. Reinforced concrete rigid frame bridges and culverts are cast-in-place monolithic units.

7.6.2 Design Characteristics

General

The rigid frame bridge can either be single span or multi-span (see Figure 7.6.1). Single span frame bridges span up to 15 m (50 feet) and are generally a slab beam design. The basic single span frame shape is most easily described as an inverted "U" (see Figure 7.6.2).

Figure 7.6.1 Three Span Concrete Rigid Frame Bridge

Multi-span frame bridges are used for spans over 15 m (50 feet) with slab or rectangular beam designs (see Figure 7.6.3). Other common multi-span frame shapes include the basic rectangle, the slant leg or K-frame, and Delta frames (see Figure 7.6.4). Due to frame action between the horizontal members and the vertical or inclined members, multi-span frames are not considered continuous.

Figure 7.6.2 Typical Single-span Rectangular Concrete Rigid Frame Bridge

Figure 7.6.3 Typical Concrete Frame Culvert

Rigid frame structures are utilized both at grade and under fill, such as in concrete frame culverts (see Figure 7.6.3).

Figure 7.6.4 Typical Concrete K-frame Bridge

Primary and Secondary Members

For single span frames, the primary member is considered to be the slab portion and the legs of the frame (see Figure 7.6.5). For state and federal rating evaluation, the slab portion is considered the superstructure while the legs are considered the substructure.

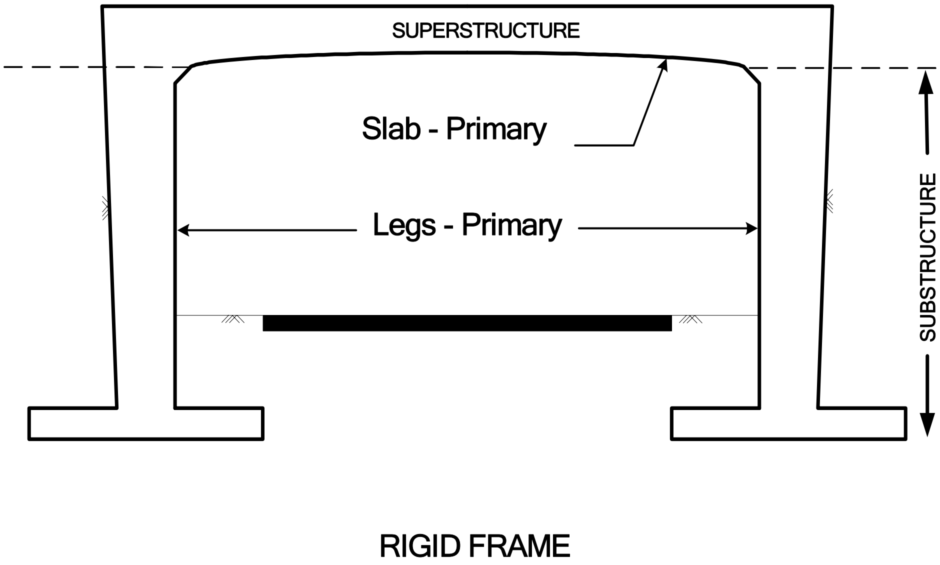

Figure 7.6.5 Elevation of a Single Span Frame

For multi-span frames, the primary members include the frame legs (the slanted beam portions which replace the piers) and the frame beams or slab (the horizontal portion which is supported by the frame legs and abutments) (see Figure 7.6.6). For state and federal rating evaluation, the frame beams or slabs and frame legs are considered the superstructure while the abutments are considered the substructure.

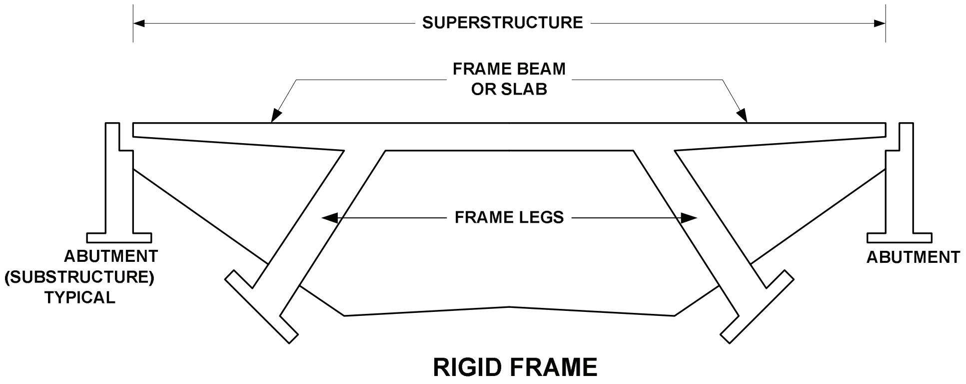

Figure 7.6.6 Elevation of a K-frame

There are no secondary members for concrete rigid frames.

Steel Reinforcement

Rigid frame structures develop positive and negative moment throughout due to the interaction of the frame legs and frame beams (see Figure 7.6.7). In slab beam frames, the primary reinforcement is used to resist tension and possibly shear.

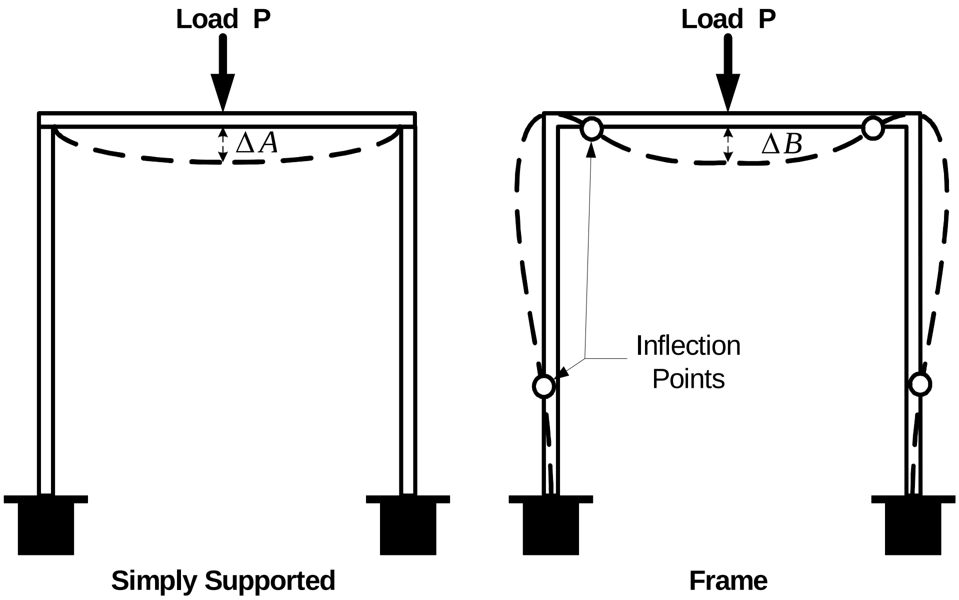

Figure 7.6.7 Deflected Simply Supported Slab versus Deflected Frame Shape

Primary Reinforcement

For gravity and traffic loads on single span slab frames, the tension steel is placed longitudinally in the bottom of the frame slab, vertically in the front face of the frame legs, and longitudinally and vertically in the outside corners of the frame (see Figure 7.6.8).

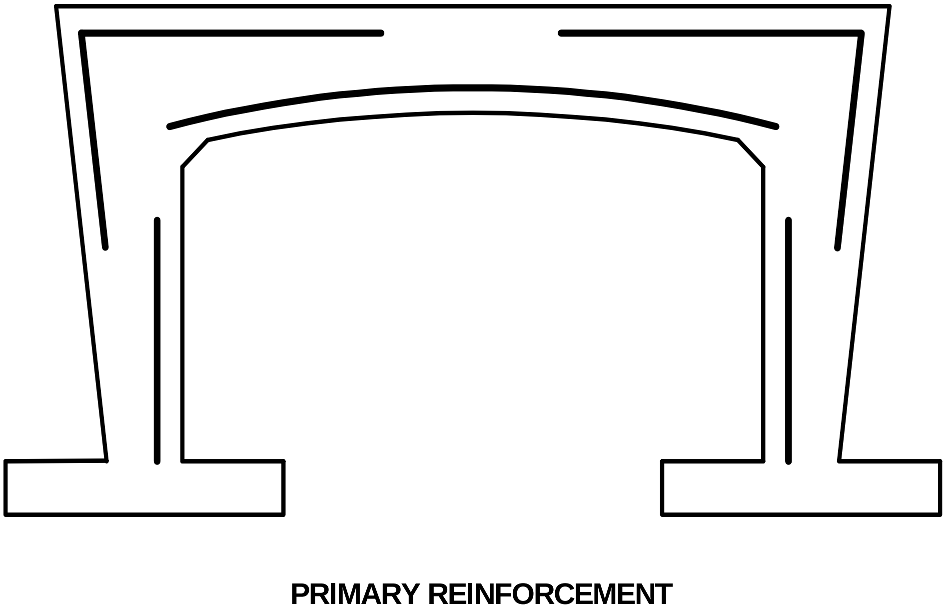

Figure 7.6.8 Tension Reinforcement in a Single Span Slab or Beam Frame

For multi-span slab frames, the tension steel is placed longitudinally in the top and bottom of the frame slab and vertically in both faces of the frame legs (see Figure 7.6.9).

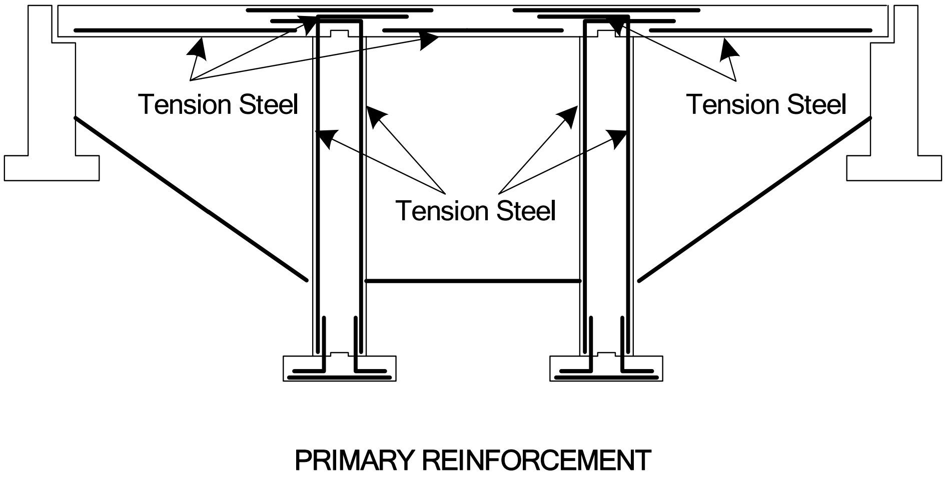

Figure 7.6.9 Tension Reinforcement in a Multi-span Slab or Beam Frame

The primary reinforcement in the frame beam portion is longitudinal tension and shear stirrup steel, similar to continuous beam reinforcement (see Topic 7.2.2).

In the frame legs, the primary reinforcement is tension and shear steel near the top and compression steel with ties for the remaining length (see Figure 7.6.10). See Topic 10.2 for a discussion of compression steel and column ties.

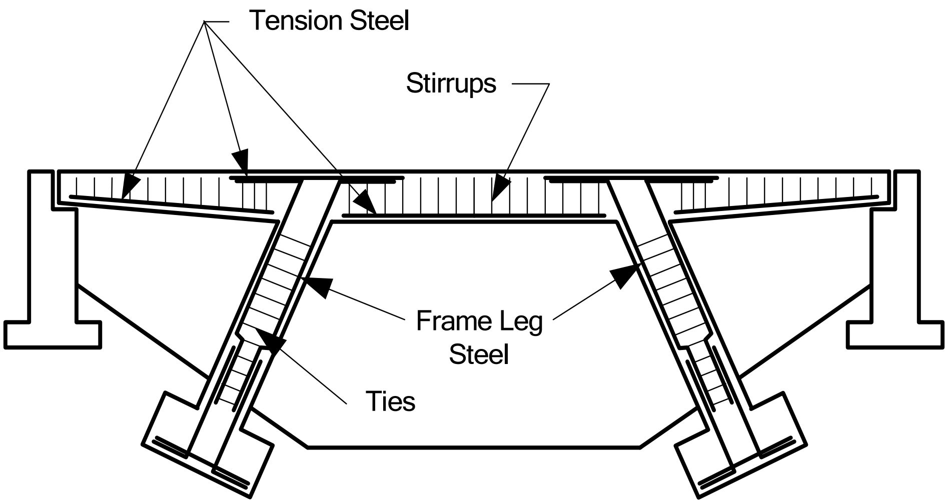

Figure 7.6.10 Tension, Shear, and Column Reinforcement in a Typical K-frame

Secondary Reinforcement

Temperature and shrinkage reinforcement is distributed similar to that of a slab (see Topic 7.1) or tee-beam (see Topic 7.2) or box beams (see Topic 7.10).

7.6.3

Overview of Common Defects

Common defects that occur on concrete rigid frame bridges include:

- Cracking (flexure, shear, temperature, shrinkage, mass concrete)
- Scaling
- Delamination
- Spalling
- Chloride contamination
- Efflorescence
- Ettringite formation
- Honeycombs
- Pop-outs
- Wear
- Collision damage
- Abrasion
- Overload damage
- Reinforcing steel corrosion
- Prestressed concrete deterioration

Refer to Topic 2.2 for a detailed explanation of the properties of concrete, types and causes of concrete deterioration, and the examination of concrete.

7.6.4

Inspection Procedures and Locations

Inspection procedures to determine other causes of concrete deterioration are discussed in detail in Topic 2.2.8.

Procedures

Visual

The inspection of concrete rigid frames for cracks, spalls, and other defects is primarily a visual activity.

Physical

Sounding by hammer or chain drag can be used to detect delaminated areas. A delaminated area will have a distinctive hollow "clacking" sound when tapped with a hammer or revealed with a chain drag. A hammer hitting sound concrete will result in a solid "pinging" type sound.

Advanced Inspection Techniques

Several advanced techniques are available for concrete inspection. Nondestructive methods, described in Topic 13.2.2, include:

- Acoustic wave sonic/ultrasonic velocity measurements
- Delamination detection machinery
- Electrical methods
- Electromagnetic methods
- Pulse velocity
- Flat jack testing
- Ground-penetrating radar
- Impact-echo testing
- Infrared thermography
- Laser ultrasonic testing
- Magnetic field disturbance
- Neutron probe for detection of chlorides
- Nuclear methods
- Pachometer
- Rebound and penetration methods
- Ultrasonic testing

Other methods, described in Topic 13.2.3, include:

- Core sampling
- Carbonation
- Concrete permeability
- Concrete strength
- Endoscopes and videoscopes
- Moisture content

- Petrographic examination
- Reinforcing steel strength
- Chloride test
- Matrix analysis
- ASR evaluation

Locations

Bearing Areas

Examine the bearing areas for cracking, delamination or spalling where friction from thermal movement and high bearing pressure could overstress the concrete. Check for crushing of the slab or frame beams over the frame legs. Check the condition of the bearings, if present.

Shear Zones

Inspect the area near the supports where the frame beams or slab meet the frame legs or abutments. Look for shear cracks in the frame beams or slab (beginning at the frame legs and propagating upward toward mid-span).

Inspect the frame legs for diagonal cracks that initiated at the frame beam/slab or footing (see Figure 7.6.11).

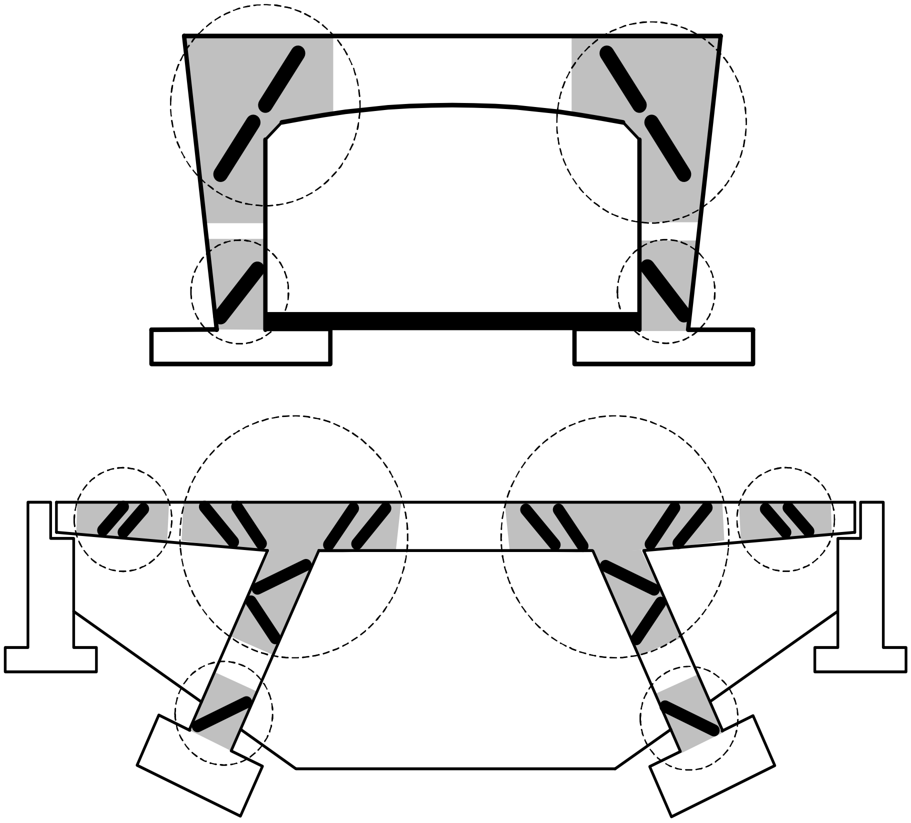

Figure 7.6.11 Shear Zones in Single Span and Multi-span Frames

Tension Zones

Inspect the tension areas for flexure cracks, rust stains, efflorescence, exposed and corroded reinforcement, and deteriorated concrete which would cause debonding of the tension reinforcement. The tension areas are located at the bottom of the frame beam at mid-span, the base of each frame leg (usually buried), and the inside faces of the frame legs at mid-height of single span slab frames (see Figures7.6.12 and 7.6.13).

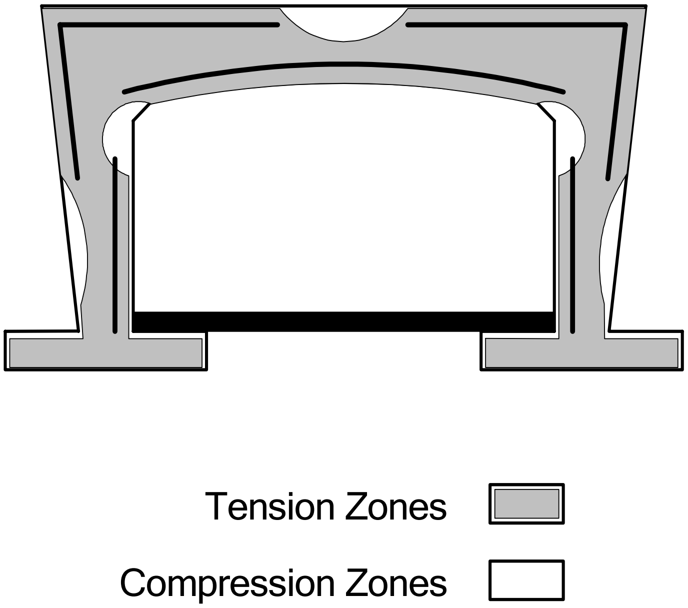

Figure 7.6.12 Tension Zones in a Single Span Beam Frame

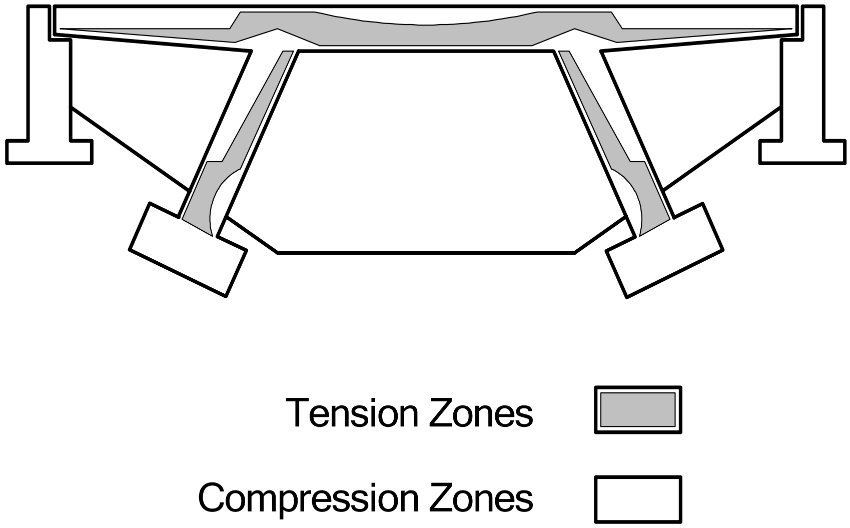

Figure 7.6.13 Tension Zones in a Multi-span Frame

Compression Zones

Investigate the compression areas for delamination, spalling, scaling, crushing, and exposed reinforcement. The legs of a frame act primarily as columns with a moment applied at the top (see Figures 7.6.12 and 7.6.13). Check the entire length of the frame legs for horizontal cracks, which indicate crushing.

Areas Exposed to Drainage

Examine the areas exposed to drainage for deteriorated and contaminated concrete. Check the roadway surface of the slab or frame beams for delamination and spalls (see Figure 7.6.14). Special attention should be given to the tension zones and water tables.

Figure 7.6.14 Roadway of a Rigid Frame Bridge with Asphalt Wearing Surface

Check longitudinal joint areas of adjacent slab or frame beams for leakage and concrete deterioration (see Figure 7.6.15). Check around scuppers and drain holes for deteriorated concrete. Check slab or frame beam ends for deterioration due to leaking deck joints at the abutments. Check to see if weep holes are functioning

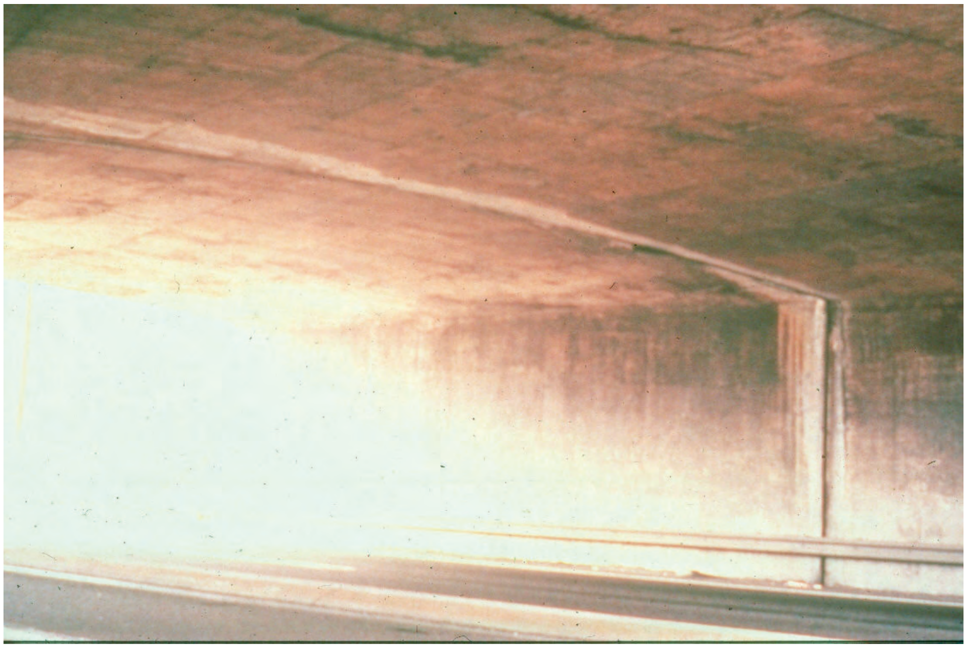

Figure 7.6.15 Longitudinal Joint Between Slab Beam Frames

Areas Exposed to Traffic

Check areas damaged by collision. Document the number of exposed and severed reinforcing bars with section loss as well as the spalled and delaminated concrete. The loss of concrete due to such an accident is not always serious, unless the bond between the concrete and steel reinforcement is affected.

Areas Previously Repaired

Examine thoroughly any repairs that have been previously made. Determine if repaired areas are functioning properly. Effective repairs and patching are usually limited to protection of exposed reinforcement.

Concrete Box Culverts

For additional inspection procedures and locations unique to concrete box culverts and waterways, see Topic 7.12 and Topic 11.2.

7.6.5

Evaluation

State and federal rating guideline systems have been developed to aid in the inspection of concrete 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 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 or 62) 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

There is no specific element level condition state assessment of a concrete rigid frame bridges. The following AASHTO CoRe elements may be used to best describe a concrete rigid frame:

Element No.	Description
038	Concrete Slab - Bare
052	Concrete Slab – Protected with Coated Bars
053	Concrete Slab – Protected with Cathodic System
105	Concrete Closed Web/Box Girder
110	Concrete Open Girder/beam
205	Column or Pile Extension – Reinforced Concrete
210	Pier Wall – Reinforced Concrete
215	Abutment – Reinforced Concrete
241	Reinforced Concrete Culvert (see Topic 7.12)

The unit quantity for slab and columns is each, and the entire element must be placed in one of the five available condition states. Some states have elected to use the total area for the slab top surface (m^2 or ft^2). When a total area is used, the total area must be distributed among the five available condition states depending on the extent and severity of deterioration. The sum of all condition states must equal the total quantity of the CoRe element. The inspector must know the total slab surface area in order to calculate a percent deterioration and fit into a given condition state description. The unit quantity for the girder/beam and pier wall is meters or feet, and the total length must be distributed among the available condition states depending on the extent and severity of deterioration. 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 structural cracks in the surface of bare decks, the “Deck Cracking” Smart Flag, Element No. 358, can be used and one of four condition states assigned. Do not use Smart Flag, Element No. 358, if the bridge deck/slab has any overlay because the top surface of the structural deck is not visible. For concrete defects on the underside of a deck element, the “Soffit” Smart Flag, Element No. 359, can be used and one of five condition states assigned. This Smart Flag is particularly useful if the wearing surface inhibits inspection of the top surface of the deck. For damage to traffic impact, the “Traffic Impact” Smart Flag, Element No. 362, can be used and one of the three condition states assigned.

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Section 7
Inspection and Evaluation of Common Concrete Superstructures

Topic 7.7 Precast and Prestressed Slabs

7.7.1

Introduction

Precast and prestressed slabs have gained popularity since the 1950's. This type of design acts as a deck and superstructure combined (see Figure 7.7.1). Individual members are placed side by side and connected together so they act as one slab. When vertical clearances are lacking, this type of design is effective, due to the slab's shallow depth. Wearing surfaces are generally applied to the top of precast and prestressed slabs and are either concrete or bituminous.

Figure 7.7.1 Typical Prestressed Slab Beam Bridge

Although precast and prestressed slabs are different from concrete decks, the design characteristics, wearing surfaces, protection systems, common defects, inspection procedures and locations, evaluation, and motorist safety concerns are similar to concrete decks. Refer to Topic 5.2 for additional information about concrete decks. For the purpose of this manual, decks are supported by superstructure members while slabs are supported by substructure units.

7.7.2

Design Characteristics

General

The precast voided slab bridge is the modern replacement of the cast-in-place slab. This type of bridge superstructure is similar to the cast-in-place slab in appearance only. It is comprised of individual precast slab beams fabricated with circular voids. The voids afford economy of material and reduce dead load (see Figure 7.7.2). Precast slab bridges with very short spans may not contain voids.

Precast slab units are practical for spans of 6 to 15 m (20 to 50 feet). The slabs can be single or multiple simple spans. The units are typically 915 to 1220 mm (36 or

48 inches) wide and have a depth of up to 530 mm (21 inches). These special precast units are generally comprised of 28 to 56 MPa (4,000 to 8,000 psi) prestressed concrete, and reinforced with 1860 MPa (270 ksi) pre- or post-tensioned steel tendons.

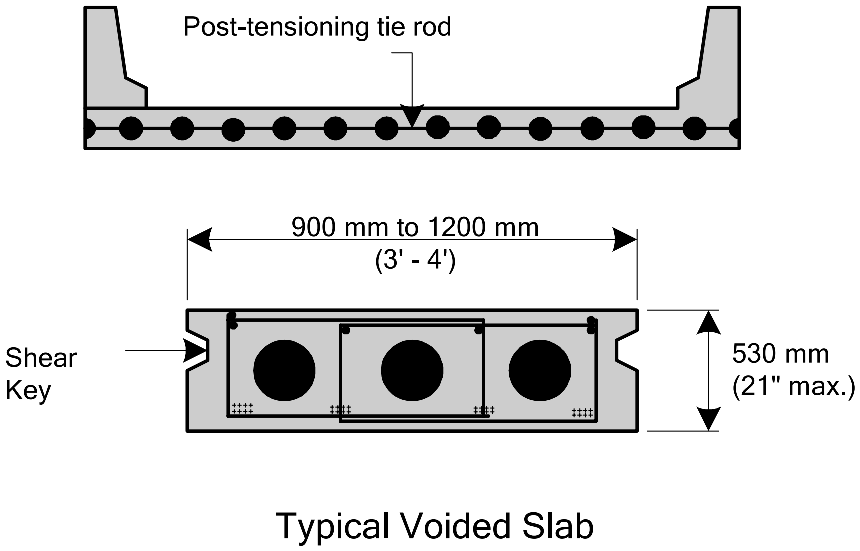

Figure 7.7.2 Cross Section of a Typical Voided Slab

Monolithic Behavior

Adjacent slab units may be post-tensioned together with tie rods having a tensile capacity of 1000 MPa (145 ksi) and grouted at the shear keys. Together these enable the slab units to act monolithically. Drain holes are placed strategically in the bottom of the slab to allow accumulated moisture to escape.

Identifying Voided Slabs

Physical dimensions alone are not enough to distinguish a slab unit from a box beam. Design or construction plans need to be reviewed. A box beam has one rectangular void, bounded by a top slab, bottom slab, and two webs. A typical box beam has a minimum depth of 305 mm (12"). A typical voided slab section has two or three circular voids through it. It is also possible to find precast solid slab units.

Primary and Secondary Members

The primary members of a precast voided slab bridge are the individual slab units. The slab units make up the superstructure and the deck and are commonly protected by an asphalt or concrete overlay. There are no secondary members.

Steel Reinforcement

Primary Reinforcement

The primary reinforcement consists of longitudinal tension steel and shear reinforcement or stirrups.

Prestressing strands placed near the bottom of the slab make up the main tension steel. Depending on the age of the structure, the strand size will be 6, 10, 11, or 13 mm (1/4, 3/8, 7/16, or 1/2 inch) diameter. Strands are normally spaced 50 mm (2 inches) on center (see Figure 7.7.3).

Shear reinforcement consists of U-shaped or closed loop stirrups located throughout the slab at various spacings required by design.

Secondary Reinforcement

Secondary reinforcement is provided to control temperature and shrinkage cracking. This reinforcement is placed longitudinal in the beam.

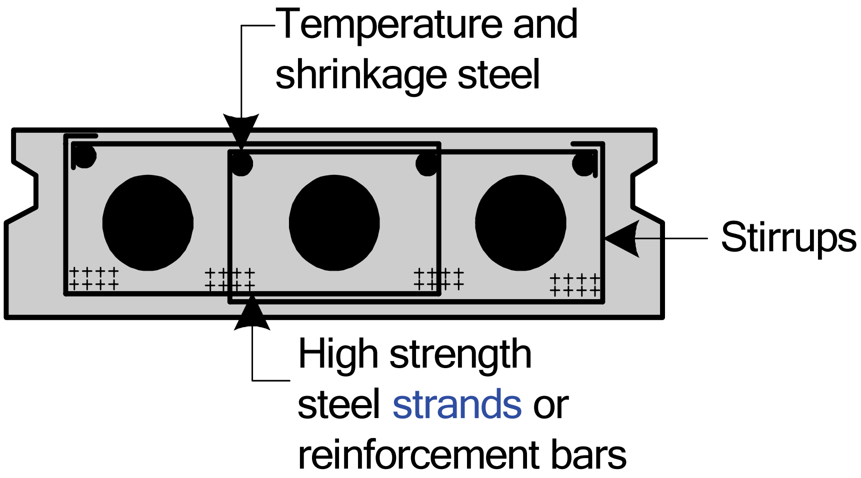

Figure 7.7.3 Prestressed Slab Beam Bridge Reinforcement

7.7.3 Overview of Common Defects

Common defects that occur on precast and prestressed slab bridges include:

- Cracking (flexure, shear, temperature, shrinkage, mass concrete)
- Scaling
- Delamination
- Spalling
- Chloride contamination
- Efflorescence
- Ettringite formation
- Honeycombs
- Pop-outs
- Wear
- Collision damage
- Abrasion
- Overload damage
- Reinforcing steel corrosion
- Prestressed concrete deterioration
- Stress corrosion

Refer to Topic 2.2 for a detailed presentation of the properties of concrete, types and causes of concrete deterioration, and the examination of concrete.

7.7.4

Inspection Procedures and Locations

Inspection procedures to determine other causes of concrete deterioration are discussed in detail in Topic 2.2.8.

Procedures

Visual

The inspection of concrete slabs for cracks, spalls, wear, and other defects is primarily a visual activity.

Physical

The physical examination of the top surface of the slab with a hammer can be a tedious operation. In most cases, a chain drag is used to determine delaminated areas. A chain drag is made of several sections of chain attached to a pipe that has a handle attached to it. The inspector drags this across a slab and makes note of the resonating sounds. A delaminated area will have a distinctive hollow "clacking" sound when tapped with a hammer or revealed with a chain drag. A hammer hitting sound concrete will result in a solid "pinging" type sound.

Since prestressed beams are designed to maintain all concrete in compression, cracks are indications of serious problems. For this reason, any crack should be carefully measured with an optical crack gauge or crack comparator card and documented.

Advanced Inspection Techniques

Several advanced techniques are available for concrete inspection. Nondestructive methods, described in Topic 13.2.2, include:

- Acoustic wave sonic/ultrasonic velocity measurements
- Delamination detection machinery
- Electrical methods
- Electromagnetic methods
- Pulse velocity
- Flat jack testing
- Ground-penetrating radar
- Impact-echo testing
- Infrared thermography
- Laser ultrasonic testing
- Magnetic field disturbance
- Neutron probe for detection of chlorides
- Nuclear methods
- Pachometer
- Rebound and penetration methods
- Ultrasonic testing

Other methods, described in Topic 13.2.3, include:

- Core sampling
- Carbonation
- Concrete permeability
- Concrete strength
- Endoscopes and videoscopes
- Moisture content
- Petrographic examination
- Reinforcing steel strength
- Chloride test
- Matrix analysis
- ASR evaluation

Locations

Bearing Areas

Examine the bearing areas for cracking, delamination or spalling where thermal movement and high bearing pressure could overstress the concrete. End spalling can eventually lead to the loss of bond in the prestressing tendons. Bearing areas should also be checked for defects or deterioration due to leaking joints.

Check bearing areas for spalls or vertical cracks. Spalls and cracks may be caused by corrosion of steel due to water leakage or restriction of thermal movement due to a faulty bearing mechanism.

Shear Zones

Inspect near the supports for diagonal or shear cracks.

Inspect the top surface for longitudinal reflective cracking and between the slab sections for leakage (see Figure 7.7.4). These problems indicate failed shear keys and that the slab units are no longer tied together or acting monolithically. Observe if there is differential slab deflection under live load.

Figure 7.7.4 Leaking Joint between Adjacent Slab Units

Tension Zones

Check the bottom of the slab sections for flexure cracks due to positive moments. Since prestressed concrete is under high compressive forces, no cracks should be present. Cracks can be a serious problem since they indicate overloading or loss of prestress. Cracks that may be present will be difficult to detect with the naked eye. To improve detection, a common practice is to wet the slab surface with water using a spray bottle. Capillary action will draw water into a crack, thus producing a visible line when the surrounding surface water evaporates. All cracks should be measured with an optical crack gauge or crack comparator card.

Examine the top of the slab sections (if exposed) near the ends for tensile cracks due to prestress eccentricity. This indicates excessive prestress force. If the top of the slab has a wearing surface applied, check for cracks in the wearing surface. Cracks in the wearing surface may be an indication that the slab is overstressed or that water is getting to the slab.

Investigate for evidence of sagging, which indicates a loss of prestress. Use a string line or site down the bottom edge of the fascia slab.

Inspect the slabs for exposed strands. Prestressed strands will corrode rapidly and fail abruptly. Therefore, any exposure is significant (see Figure 7.7.5).

Check for longitudinal cracking in slab members. Water freezing in the voids can cause longitudinal cracks. Skewed slab units may exhibit longitudinal cracks due to uneven prestressing force in the strands.

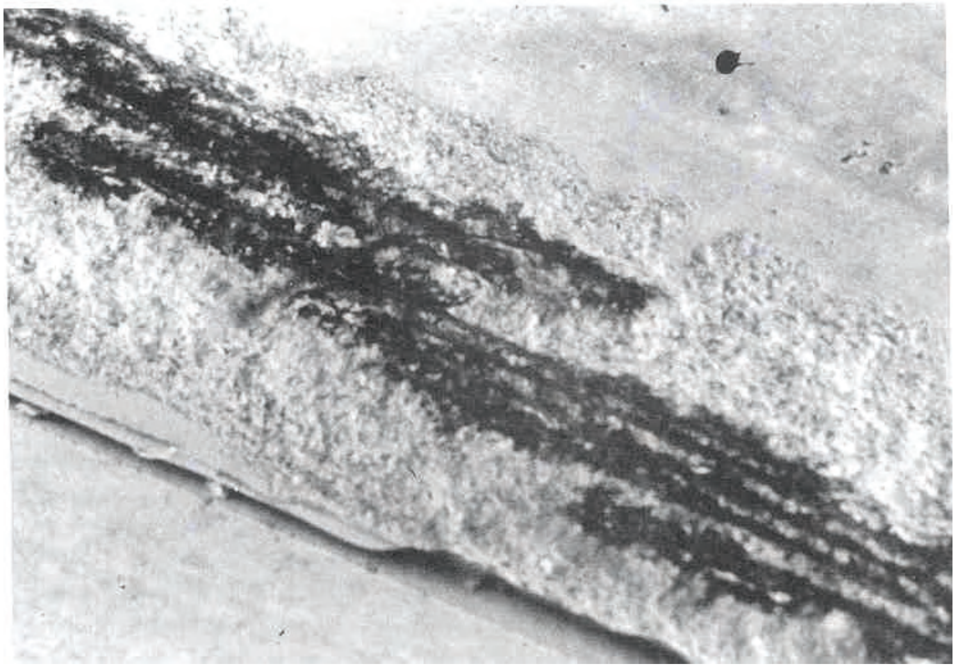

Figure 7.7.5 Exposed Strands in a Precast Slab Beam

Areas Exposed to Drainage

Inspect areas exposed to drainage for deteriorated and contaminated concrete. This includes the entire riding surface of the slab, particularly around scuppers or drains. Spalling or scaling may also be found along the curbline and fascias.

Inspect longitudinal joints between the precast slabs. Drainage through the joints indicates a broken shear key and loss of monolithic action.

Areas Exposed to Traffic

When precast voided slab superstructures are used for a grade crossing, check the areas over the traveling lanes for collision damage. This is generally not a problem due to the good vertical clearance afforded by the relatively shallow slab units.

Check areas exposed to wear on the top surface.

Areas Previously Repaired

Examine thoroughly any repairs that have been previously made. Determine if repaired areas are sound and functioning properly. Effective repairs and patching are usually limited to protection of exposed tendons and reinforcement.

General

Check the camber of the slab units. Loss of positive camber indicates loss of prestress in the tendons.

Check the condition of the lateral post-tensioning grout pockets. Cracked grout or rust stains may indicate a failure of the post-tensioning tendon or loss of monolithic action.

7.7.5
Evaluation

State and federal rating guideline systems have been developed to aid in the inspection of concrete 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 deck and the superstructure. Rating codes range from 9 to 0, where 9 is the best rating possible. See Topic 4.2 (Items 58 and 59) for additional details about NBI Rating Guidelines. For a precast or prestressed slab bridge, these guidelines must be applied for both the deck component and the superstructure component.

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

Typically, for this type of structure, the deck and superstructure components will have the same rating.

Element Level Condition State Assessment

In an element level condition state assessment of a precast or prestressed slab bridge, the AASHTO CoRe element is one of the following depending on the riding surface:

Element No.	Description
	Concrete Slab
38	Concrete Slab – Bare
39	Concrete Slab – Unprotected with AC Overlay
40	Concrete Slab – Protected with AC Overlay
44	Concrete Slab – Protected with Thin Overlay
48	Concrete Slab – Protected with Rigid Overlay
52	Concrete Slab – Protected with Coated Bars
53	Concrete Slab – Protected with Cathodic System
	P/S Box Girder
104	P/S Closed Web/Box Girder

The unit quantity for the slab elements is “each”, and the entire element must be placed in one of the five available condition states based solely on the top surface condition. Some states have elected to use the total slab area (m^2 or ft^2). When a total area is used, the total area must be distributed among the five available condition states depending on the extent and severity of deterioration. The sum of all condition states must equal the total quantity of the CoRe element. The inspector must know the total slab surface area in order to calculate a percent deterioration and fit into a given condition state description. The unit quantity for the girder is meters or feet, and the total length must be distributed among the available condition states depending on the extent and severity of deterioration. Element 104 is the closest choice in the AASHTO element list for precast/prestressed slabs. Condition state 1 is the best possible rating. See the *AASHTO Guide for Commonly Recognized (CoRe) Structural Elements* for condition state descriptions. States may decide to choose their own element number for precast/prestressed slabs because AASHTO does not have a specific element number for prestressed slabs.

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 structural cracks in the top surface of bare slabs, the “Deck Cracking” Smart Flag, Element No. 358, can be used and one of four condition states assigned. Do not use Smart Flag, Element No. 358, if the bridge deck/slab has any overlay because the top surface of the structural deck is not visible. For concrete defects on the underside of a slab element, the “Soffit” Smart Flag, Element No. 359, can be used and one of five condition states assigned.

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Section 7

Inspection and Evaluation of Common Concrete Superstructures

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Topic 7.8 Prestressed Double Tees

7.8.1 Introduction

A prestressed double tee beam, like the name implies, resembles two capital letter T's that are side by side (see Figure 7.8.1). The horizontal section is called the deck or flange, and the two vertical leg sections are called the webs or stems. This type of bridge beam is mostly used in short spans or in situations where short, obsolete bridges are to be replaced.

Figure 7.8.1 Typical Prestressed Double Tee Beam

7.8.2 Design Characteristics

General

Prestressed concrete double tee beams have a monolithic deck and stem design that allows the deck to act integrally with the superstructure. The integral design provides a stiffer member, while the material-saving shape reduces the dead load (see Figure 7.8.2).

This type of construction was originally used for buildings and is quite common in parking garages. They have been adapted for use in highway structures.

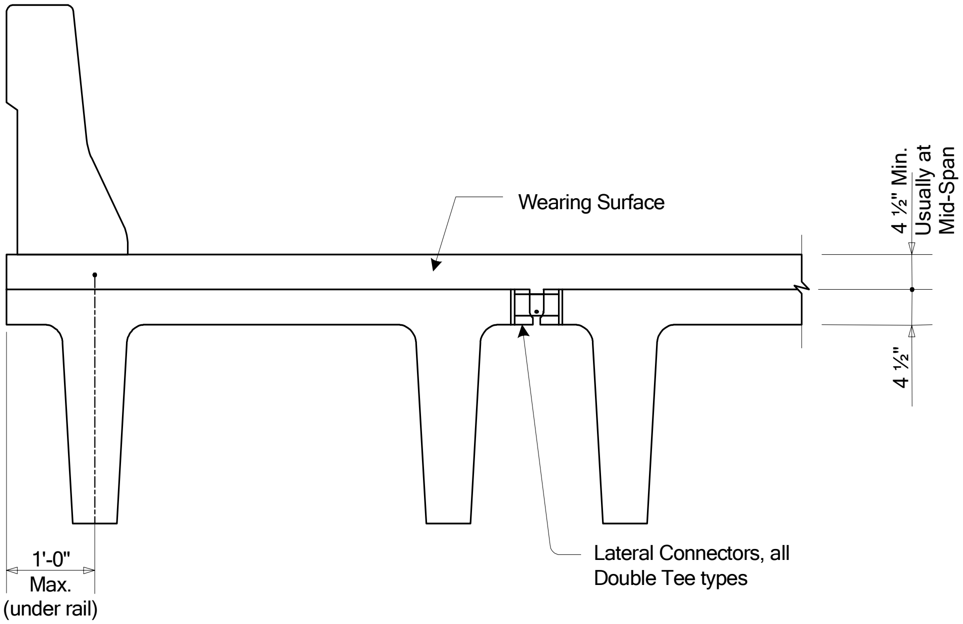

Figure 7.8.2 Prestressed Double Tee Beam Typical Section

Prestressed double tees have a typical stem depth of 305 to 865 mm (12 to 34 inches). The average flange width is 2.4 to 3.1 m (8 to 10 feet), with a typical span length of approximately 7.6 to 16.8 m (25 to 55 ft). Prestressed double tees can be used in spans approximately 24.4 m (80 ft) long with stem depths up to 1.5 m (5 feet) and flange widths up to 3.7 m (12 feet). Prestressed double tee bridges are typically simple spans, but continuous spans have also been constructed. Continuity is achieved from span to span by forming the open section between beam ends, placing the required reinforcement, and casting concrete in the void area. Once the concrete reaches its design strength, the spans are considered to be continuous for live load.

In some prestressed double tee designs, the depth of the stems at the beam end is dapped, or reduced (see Figure 7.8.3). This occurs so that the beam end can sit flush on the bearing seat.

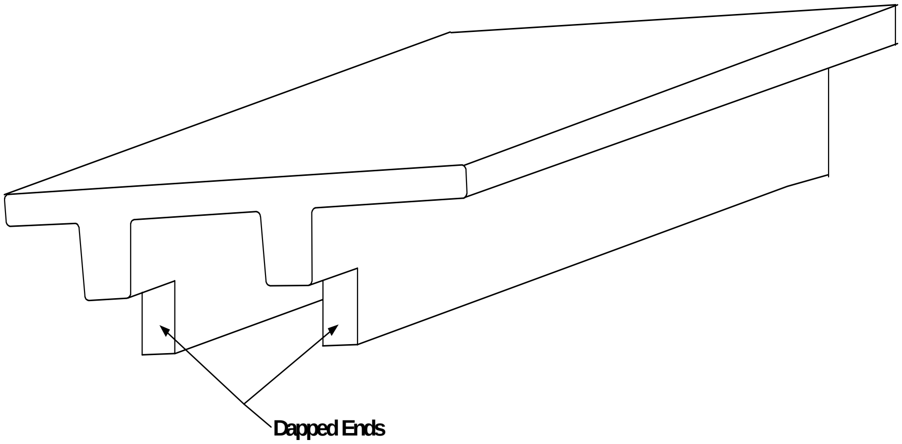

Figure 7.8.3 Dapped End of a Prestressed Double Tee Beam

The top of the flange or deck section of prestressed double tees can act as the integral wearing surface or be overlaid. Bituminous asphalt and concrete are typical examples of wearing surfaces that may be applied. See Topic 5.2.3 for a detailed description of the different types of concrete deck wearing surfaces.

Primary Members and Secondary Members

The primary members of a prestressed double tee beam are the stems and the deck.

The secondary members of a prestressed double tee bridge are the transverse diaphragms. The diaphragms are located at the span ends. They connect adjacent stems and prevent lateral movement. In the case of longer spans, intermediate diaphragms may also be placed to compensate for torsional forces. The diaphragms can be constructed of reinforced concrete or steel.

Steel Reinforcement

The primary tension and shear steel reinforcement consists of prestressing strands and mild reinforcement (see Figure 7.8.4). The prestressing strands are placed longitudinally in each stem at the required spacing and clearance. When the double tees are to be continuous over two or more spans, conduits may be draped through the stems of each span to allow for post-tensioning. The shear reinforcement in a prestressed double tee beam consists of vertical U-shaped stirrups that extend from the stem into the flange. The shear reinforcement or stirrups are spaced along the length of the stem at a spacing required by design. The primary reinforcement for the deck or flange section of a prestressed double tee beam follows the reinforcement pattern of a typical concrete deck (see Topic 5.2.2).

In some wider applications, the deck or flange portions of adjacent prestressed double tee beams may be transversely post-tensioned together through post-tensioning ducts. Transverse post-tensioning decreases the amount of damage that can occur to individual flange sides due to individual deflection and helps the double tee beams deflect as one structure.

The secondary, or temperature and shrinkage, reinforcement is placed longitudinally on each side of each stem and deck. In some newer designs, welded-wire-fabric is used as the secondary and shear reinforcement in the stems. The vertical bars in the welded-wire-fabric act as the shear reinforcement and the longitudinal bars perform as the secondary reinforcement. Tests have shown that temperature and shrinkage cracking can be reduced when welded-wire-fabric is used.

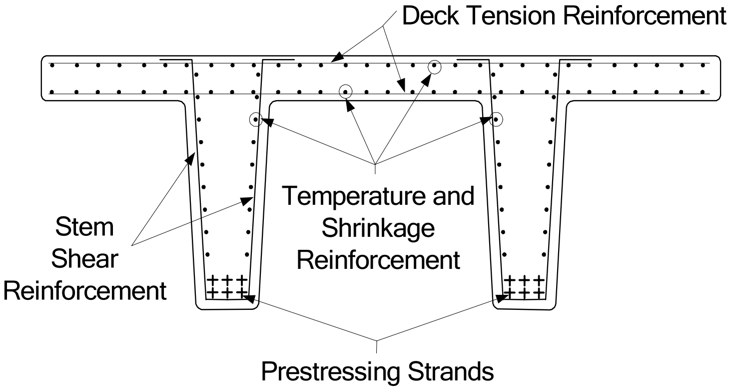

Figure 7.8.4 Steel Reinforcement in a Prestressed Double Tee Beam

7.8.3

Overview of Common Defects

Common defects that occur on prestressed concrete double tee beam bridges include:

- Cracking (flexure, shear, temperature, shrinkage, mass concrete)
- Scaling
- Delamination
- Spalling
- Chloride contamination
- Efflorescence
- Ettringite formation
- Honeycombs
- Pop-outs
- Wear
- Collision damage
- Abrasion
- Overload damage
- Reinforcing steel corrosion
- Prestressed concrete deterioration
- Stress corrosion of prestressing strands

Refer to Topic 2.2 for a detailed explanation of the properties of concrete, types and causes of concrete deterioration, and the examination of concrete.

7.8.4

Inspection Procedures Locations

Inspection procedures to determine other causes of concrete deterioration are discussed in detail in Topic 2.2.8.

Procedures

Visual

The inspection of prestressed double tees for cracks, spalls, and other defects is primarily a visual activity.

Physical

Sounding by hammer can be used to detect delaminated areas. A delaminated area will have a distinctive hollow “clacking” sound when tapped with a hammer or revealed with a chain drag. A hammer hitting sound concrete will result in a solid "pinging" type sound. In most cases, a chain drag is used to check the top surface of a concrete deck.

Since prestressed beams are designed to maintain all concrete in compression, cracks are indications of serious problems. For this reason, any crack should be carefully measured with an optical crack gauge or crack comparator card and documented.

Advanced Inspection Techniques

Several advanced techniques are available for concrete inspection. Nondestructive methods, described in Topic 13.2.2, include:

- Acoustic wave sonic/ultrasonic velocity measurements
- Delamination detection machinery
- Electrical methods
- Electromagnetic methods
- Pulse velocity
- Flat jack testing
- Ground-penetrating radar
- Impact-echo testing
- Infrared thermography
- Laser ultrasonic testing
- Magnetic field disturbance
- Neutron probe for detection of chlorides
- Nuclear methods
- Pachometer
- Rebound and penetration methods
- Ultrasonic testing

Other methods, described in Topic 13.2.3, include:

- Core sampling
- Carbonation
- Concrete permeability
- Concrete strength
- Endoscopes and videoscopes
- Moisture content
- Petrographic examination
- Reinforcing steel strength
- Chloride test
- Matrix analysis
- ASR evaluation

Locations

Bearing Areas

Examine bearing areas for cracking, delamination or spalling where friction from thermal movement and high bearing pressure could overstress the concrete. Check for crushing of the stem near the bearing seat. Check the condition and operation of any bearing devices.

For dapped-end double tee beams, look for vertical flexure cracks and diagonal shear cracks in the reduced depth section that sits on the bearing seat. At the full depth-to-reduced depth vertical interface, check for vertical direct shear cracking. At the bottom corner where the reduced section meets the full depth section, check for diagonal shear corner cracks. At the bottom corner of the full depth section, check for diagonal tension cracks (see Figure 7.8.5).

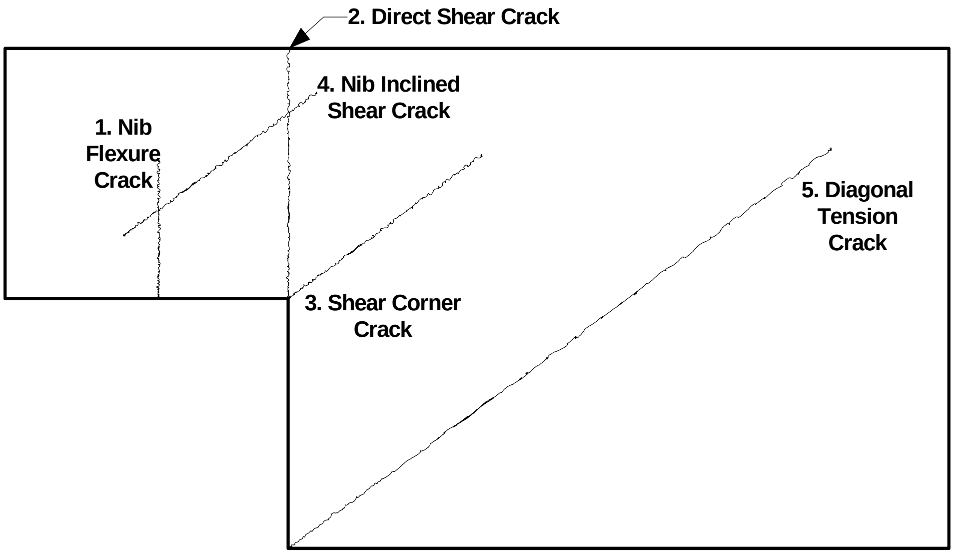

Figure 7.8.5 Crack Locations for Dapped End Double Tee Beams

Shear Zones

Inspect the area near the supports for the presence of shear cracking. The presence of transverse cracks on the underside of the stems or diagonal cracks on the sides of the stem indicate the onset of shear failure. These cracks represent lost shear capacity and should be carefully measured.

Tension Zones

Tension zones should be examined for flexure cracks, which would be transverse across the bottom of the stems and vertical on the sides. The tension zones are at the midspan along the bottom of the stem for both simple and continuous span bridges. Additional tension zones are located on the deck over the piers of continuous spans.

Flexural cracks caused by tension in the deck will be found on the underside in a longitudinal direction between the stems.

Check for deteriorated concrete near the tension zones, which could result in the debonding of the tension reinforcement. This would include delamination, spalls, and contaminated concrete.

Secondary Members

The diaphragms are designed as simple beams and should be inspected for flexure and shear cracks as well as typical concrete defects. Cracks in the diaphragms could be an indication of overstress or excessive differential deflection in the double tee beams or differential settlement of the substructure.

Areas Exposed to Drainage

If the roadway surface is bare concrete, check for delamination, scaling and spalls. The curb lines are most suspect. If the deck has an asphalt wearing surface, check for indications of deteriorated concrete such as reflective cracking and depressions.

Inspect the seam or joint between adjacent beams for leakage.

Check around scuppers or drain holes and deck fascias for deteriorated concrete.

Check areas exposed to drainage for concrete spalling or cracking. This may occur at the ends of the beams where drainage has seeped through the deck joints.

Areas Exposed to Traffic

For grade crossing structures, check areas of damage caused by collision. This will generally be a corner spall with a few exposed rebars or prestressing strands.

Areas Previously Repaired

Examine areas that have been previously repaired. Determine if the repairs are in place and if they are functioning properly.

General

Check for efflorescence from cracks and discoloration of the concrete caused by rust stains from the reinforcing steel. In severe cases, the reinforcing steel may become exposed due to spalling. Document the remaining cross section of reinforcing steel since section loss will decrease live load capacity. See Table 2.2.2 for concrete crack width guidelines.

Using a string line, check for horizontal alignment and camber of the prestressed double tee beams. Signs of downward deflection usually indicate loss of prestress. Signs of excessive upward deflection usually indicate extreme creep and shrinkage.

7.8.5

Evaluation

State and federal rating guideline systems have been developed to aid in the inspection of concrete 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 deck and the superstructure. Rating codes range from 9 to 0, where 9 is the best rating possible. See Topic 4.2 (Items 58 and 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.

For prestressed double tees, the deck condition influences the superstructure component rating. When the deck component rating is 4 or less, the superstructure component rating may be reduced if the recorded deck defects reduce its ability to carry applied stresses associated with superstructure moments.

Element Level Condition State Assessment

In an element level condition state assessment of a prestressed double tee beam bridge, the AASHTO CoRe element is one of the following, depending on the riding surface:

Element No.	**Description**
	Concrete Deck
012	Concrete Deck – Bare
013	Concrete Deck – Unprotected with AC Overlay
014	Concrete Deck – Protected with AC Overlay
018	Concrete Deck – Protected with Thin Overlay
022	Concrete Deck – Protected with Rigid Overlay
026	Concrete Deck – Protected with Coated Bars
027	Concrete Deck – Protected with Cathodic System
	P/S Girder/Beam
109	P/S Concrete Open Girder/beam

The unit quantity for the deck elements is “each”, and the entire element must be placed in one of the five available condition states based solely on the top surface condition. Some states have elected to use the total deck area (m^2 or ft^2). When a total area is used, the total area must be distributed among the five available condition states depending on the extent and severity of deterioration. The sum of all condition states must equal the total quantity of the CoRe element. The inspector must know the total deck surface area in order to calculate a percent deterioration and fit into a given condition state description. The unit quantity for the prestressed double tee beam is meters or feet, and the total length must be distributed among the four available condition states depending on the extent and severity of deterioration. 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 structural cracks in the top surface of bare decks, the “Deck Cracking” Smart Flag, Element No. 358, can be used and one of four condition states assigned. Do not use Smart Flag, Element No. 358, if the bridge deck/slab has any overlay because the top surface of the structural deck is not visible. For concrete defects on the underside of a deck element, the “Soffit” Smart Flag, Element No. 359, can be used and one of five condition states assigned. For damage due to traffic impact, the “Traffic Impact” Smart Flag, Element No. 362, can be used and one of three condition states assigned.

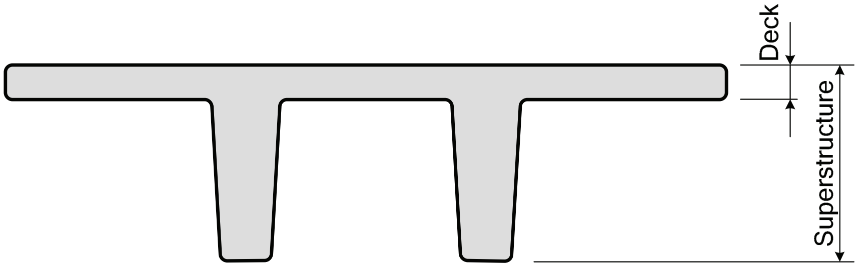

Figure 7.8.6 Components/Elements for Evaluation