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# Chapter 8

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## Inspection and Evaluation of Timber Superstructures

### Topic 8.1 Solid Sawn Timber Bridges

#### 8.1.1

##### Introduction

Timber bridges are gaining resurgence in popularity in some parts the United States. There are two basic classifications in timber construction: solid sawn and glued-laminated (glulam). A solid sawn beam is a section of tree cut to the desired size at a saw mill. Solid sawn multi-beam bridges are the simplest type of timber bridge (see Figure 8.1.1).



**Figure 8.1.1** Elevation View of a Solid Sawn Multi-Beam Bridge

## 8.1.2

### Design Characteristics

#### Multi-beam Bridges

Solid sawn multi-beam bridges consist of multiple solid sawn beams spanning between substructure units (see Figure 8.1.2). The deck is supported by the beams and is typically comprised of transversely laid timber planks, and longitudinally laid planks called runners. Sometimes a bituminous wearing surface is placed on the deck planks to provide a skid resistant riding surface for vehicles, as well as a protective surface for the planks. Beam sizes typically range from approximately 6 inches by 12 inches to 8 inches by 16 inches, and the beams are usually spaced about 24 inches on center.



**Figure 8.1.2** Underside View of a Solid Sawn Multi-Beam Bridge

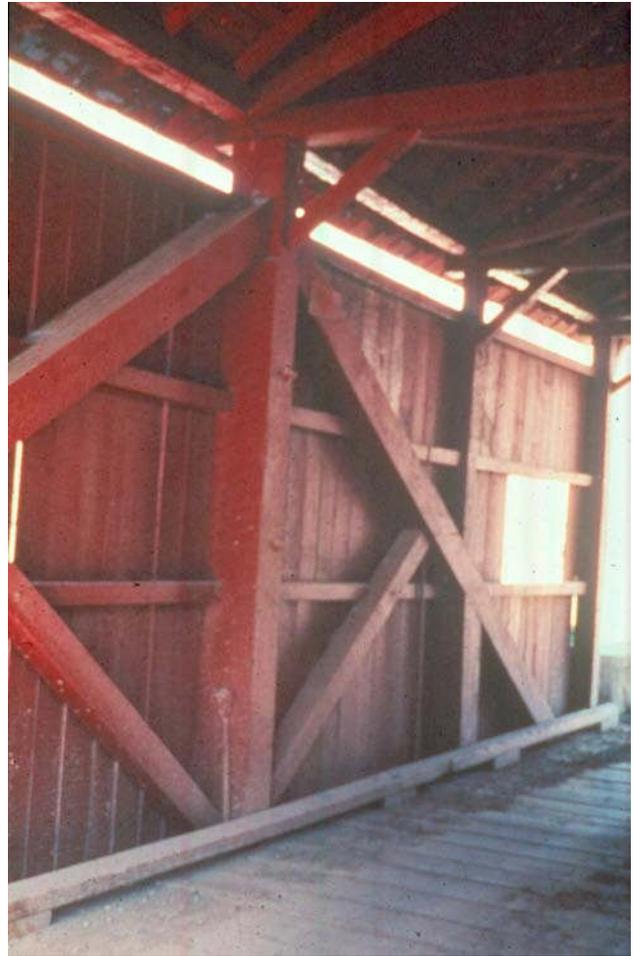
This bridge type is generally used in older, shorter span bridges, spanning up to 25 feet. Shorter spans are sometimes combined to form longer multiple span bridges and trestles. Many older timber trestles were built for railroads and trolley lines. Solid sawn timbers have become obsolete for most modern bridge members due to the development of high quality glulam members (see Topic 8.2).

### Covered Bridges

Covered bridges are generally found along rural roads and get their name from the walls and roof which protect the bridge superstructure (see Figures 8.1.3 and 8.1.4). Covered bridges are usually owned by local municipalities, although some are owned by states or private individuals. Some still carry highway traffic, but many are only open to pedestrians or light weight vehicles. While most covered bridges were built during the 1800's and early 1900's, there are a number of covered bridges being built today as historic reconstruction projects.



**Figure 8.1.3** Elevation View of Covered Bridge



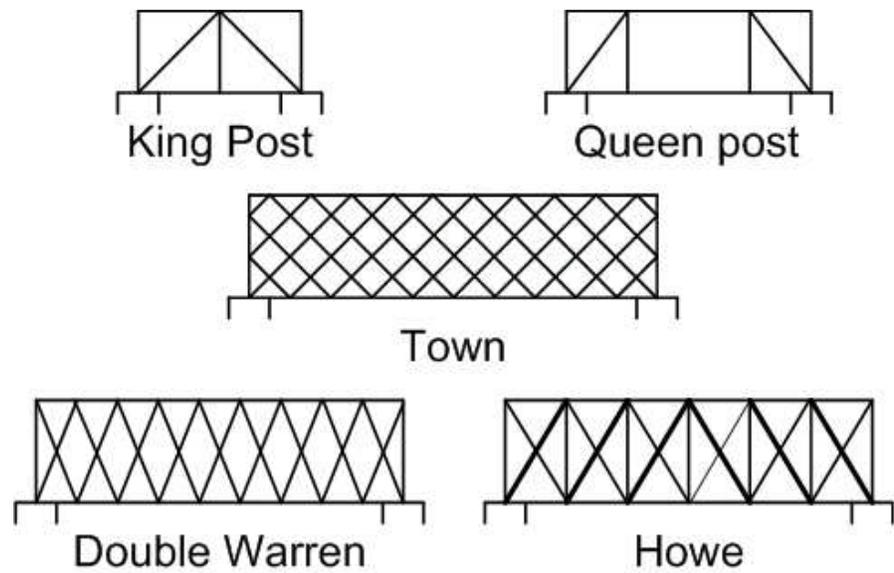
**Figure 8.1.4** Inside View of Covered Bridge Showing King Post Truss Design

### **Trusses**

The majority of covered bridges are essentially truss bridges (see Figure 8.1.5). Solid sawn timber members make up the trusses of these historic structures. The covers on the bridges prevent decay of the truss and are responsible for their longevity. Typical truss types for covered bridges include the king post, queen post, Town, Warren, and Howe (see Figure 8.1.6). The floor system consists of timber deck planks, stringers, and floorbeams. The span lengths of covered bridges generally range from 50 to 100 feet, although many are well over 100 feet and some span over 200 feet.



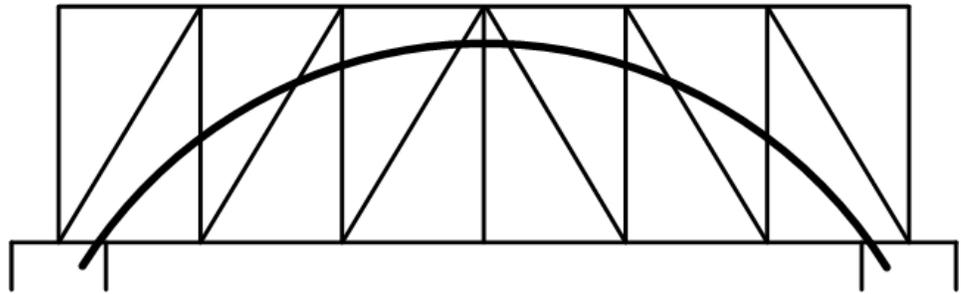
**Figure 8.1.5** Town Truss Covered Bridge



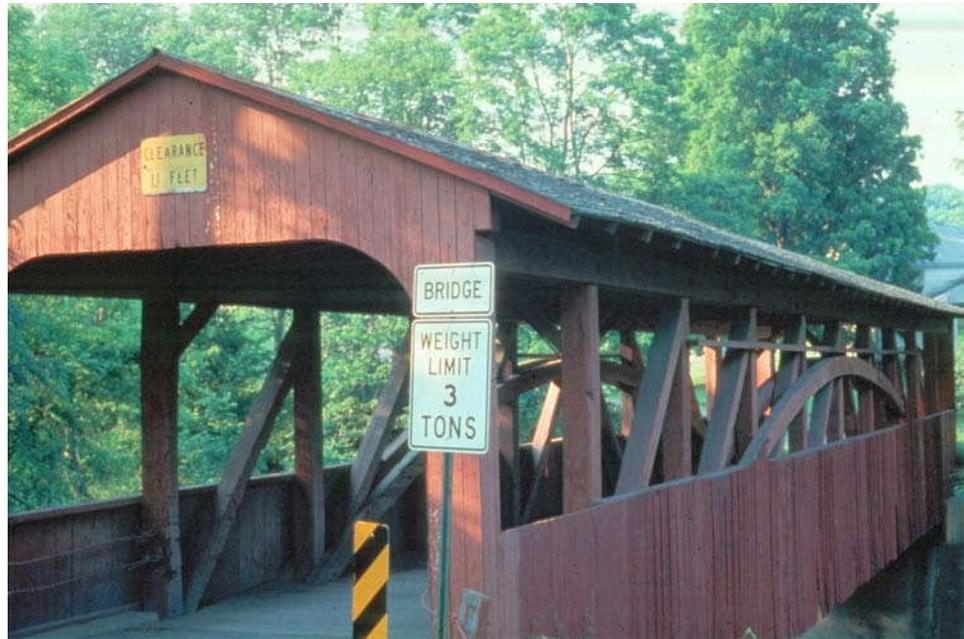
**Figure 8.1.6** Common Covered Bridge Trusses

### Arches

Timber arches were first used in covered bridges by Theodore Burr to strengthen the series of truss configurations normally used in covered bridges. These became known as Burr arch-trusses (see Figures 8.1.7, 8.1.8 and 8.1.9). The arch served as the main supporting element, and the king posts simply strengthened the arch. The span lengths for Burr-arch truss bridges generally range from 50 to 175 feet. Because of their greater strength, many of these structures still exist today.



**Figure 8.1.7** Schematic of Burr Arch-truss Covered Bridge



**Figure 8.1.8** Burr Arch-truss Covered Bridge



**Figure 8.1.9** Inside View of Covered Bridge with Burr Arch-truss Design

**Primary and Secondary Members**

The primary members of solid sawn multi-beam bridges are the beams, and the secondary members are the diaphragms or cross bracing if present (see Figure 8.1.2). These bridges usually have timber diaphragms or cross bracing between beams at several locations along the span.

The primary members in truss and arch structures are the truss members (chords, diagonals, and verticals), arch ribs, stringers, and floorbeams (see Figures 8.1.9 and 8.1.10). The secondary members are the diaphragms and cross bracing between stringers, the upper and lower lateral bracing, sway bracing, and the covers on the roof and sides when present.



**Figure 8.1.10** Town Truss Design

### 8.1.3

#### **Overview of Common Deficiencies**

Common deficiencies that occur on solid sawn timber beams include:

- Inherent defects - Checks, splits, shakes, and knots
- Decay by fungi
- Damage by insects and borers
- Loose connections
- Surface depressions
- Damage from fire
- Damage from impact/collisions
- Damage from wear, abrasion, and mechanical wear
- Damage from overstress
- Damage from weathering/warping
- Failure of protective system

A less common deficiency that may be encountered by the inspector includes damage from chemical attack. Refer to Topic 6.1 for a more detailed presentation of the properties of timber, types and causes of timber deterioration, and the examination of timber.

### 8.1.4

#### **Inspection Methods and Locations**

Inspection methods to determine other causes of timber deterioration are discussed in detail in Topic 6.1.7.

#### **Methods**

##### **Visual**

The inspection of timber for checks, splits, cracks, shakes, fungus decay, deflections, crushing, delaminations, and loose connections is primarily a visual activity.

##### **Physical**

The physical examination of a timber member can be conducted with a hammer or pick. The hammer is used to sound the members to detect hollow areas or internal decay. Picks are used to determine the condition of the surface.

##### **Advanced Inspection Methods**

Several advanced methods are available for timber inspection. Nondestructive methods, described in Topic 15.1.2, include:

- Sonic testing
- Spectral analysis
- Ultrasonic testing
- Vibration

Other methods, described in Topic 15.1.3, include:

- Boring or drilling
- Moisture content
- Probing
- Field ohmmeter

## Locations

### Bearing Areas

Check the bearing areas for crushing of the beams near the bearing seat (see Figure 8.1.11). Investigate for decay and insect damage by visual inspection and sounding and/or probing at the ends of the beams where dirt, debris, and moisture tend to accumulate. Also verify the condition and operation of the bearing devices, if they are present (see Topic 11.1).



**Figure 8.1.11** Bearing Area of Typical Solid Sawn Beam

### Shear Zones

As discussed in Topic 5.1, maximum shear occurs near supports. A horizontal shear force of equal magnitude accompanies the vertical shear component of this force. Because of timber's orthotropic cell structure, it has excellent resistance against vertical shear but low resistance against horizontal shear. The failure of a solid sawn timber member due to load is generally preceded by horizontal shear cracking along the grain. A horizontal shear "crack" is effectively a longitudinal split.

Investigate the area near the supports for the presence of horizontal shear cracking. The presence of transverse cracks on the underside of the girders or horizontal

cracks on the sides of the girders indicate the onset of shear failure. These cracks can propagate quickly toward midspan and represent lost moment capacity of up to 75% (see Figure 8.1.12). Measure these cracks carefully for length, width, and if possible, the depth.



**Figure 8.1.12** Horizontal Shear Crack in a Timber Beam

### **Tension Zones**

Examine the zones of maximum tension for signs of structural distress. The maximum tension generally occurs at the bottom half of the middle third of the beam span. Investigate for section loss due to decay or fire, especially near midspan. Examine beams for excessive deflection or sagging. Tension cracks in timber break the cell structure perpendicular to the grain and are typically preceded by the appearance of horizontal shear cracks.

Solid sawn beams with sloping grain that intersects the surface in the tension zone are particularly susceptible to flexure cracking because the tensile stress and horizontal shear stress combine to split the grain apart.

### **Areas Exposed to Drainage**

Timber bridges with plank decks are exposed to drainage throughout the length of the span. Plank decks with asphalt overlays in good condition offer some protection. In these cases, deck joint areas at span ends are candidates for drainage exposure.

Investigate for signs of decay along the full length of the beam but especially where the beam is subjected to continual wetness and areas that trap moisture. These include member interfaces between deck planks and stringers, deck planks and beams, beams and bearing seats, stringers and floorbeams, floorbeams and trusses, truss member connections, arch connections, and any fastener location.

(see Figure 8.1.13).

Decay and chemical attack may be evidenced by discolored wood, brown and white rot, the formation of fruiting bodies (the result of fungal attacks, which produce disc-shaped bodies that distribute reproductive spores), “sunken” faces in the wood, or soft “punky” texture of the wood. When surface probing for expected decay is inconclusive, the next step is to drill the suspect area. If this has been done in a previous inspection, examine the drill hole area carefully for proper preservation treatment and dowel plug installations.



**Figure 8.1.13** Decay in a Timber Beam

#### **Areas of Insect Infestation**

Insect infestation can be detected in various ways. Carpenter ants generally leave piles of sawdust; powder-post beetles leave small holes in the surface of the wood; and termites can often be readily seen. Another indication of insect infestation is hollow sounding wood. Perform further probing or drilling in suspect areas.

#### **Areas Exposed to Traffic**

For overhead and through structures, check for collision damage from vehicles passing below or adjacent to structural members.

#### **Areas Previously Repaired**

Thoroughly examine any repairs that have been previously made. Determine if repaired areas are sound and functioning properly.

### Secondary Members

Inspect bracing members for decay and fire damage. Examine connections of bracing to beams for tightness, cracked or split members, and corroded, loose, or missing fasteners (see Figure 8.1.14). Deteriorated secondary members may indicate problems in the primary members.



**Figure 8.1.14** Typical Timber End Diaphragm

### Fasteners and Connectors

Check the fasteners (e.g., nails, screws, bolts, and deck clips) for corrosion. Also inspect for loose or missing fasteners. Check for moisture and decay around the holes.

### 8.1.5

#### **Evaluation**

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

#### **NBI Component Condition Rating Guidelines**

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

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

#### **Element Level Condition State Assessment**

In an element level condition state assessment of a solid sawn timber bridge, possible AASHTO National Bridge Elements (NBEs) are:

<u>NBE No.</u>	<u>Description</u>
<u>Superstructure</u>	
111	Timber Girder/Beam
117	Timber Stringer
135	Timber Truss
146	Timber Arch
156	Timber Floorbeam

The unit quantity for the timber superstructures is feet. The total length is distributed among the four available condition states depending on the extent and severity of the deficiency. The sum of all condition states equals the total quantity of the National Bridge Element. Condition State 1 is the best possible rating. See the *AASHTO Guide Manual for Bridge Element Inspection* for condition state descriptions.

The following Defect Flag is applicable in the evaluation of solid sawn timber superstructures:

<u>Defect Flag No.</u>	<u>Description</u>
362	Superstructure Traffic Impact (load capacity)

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

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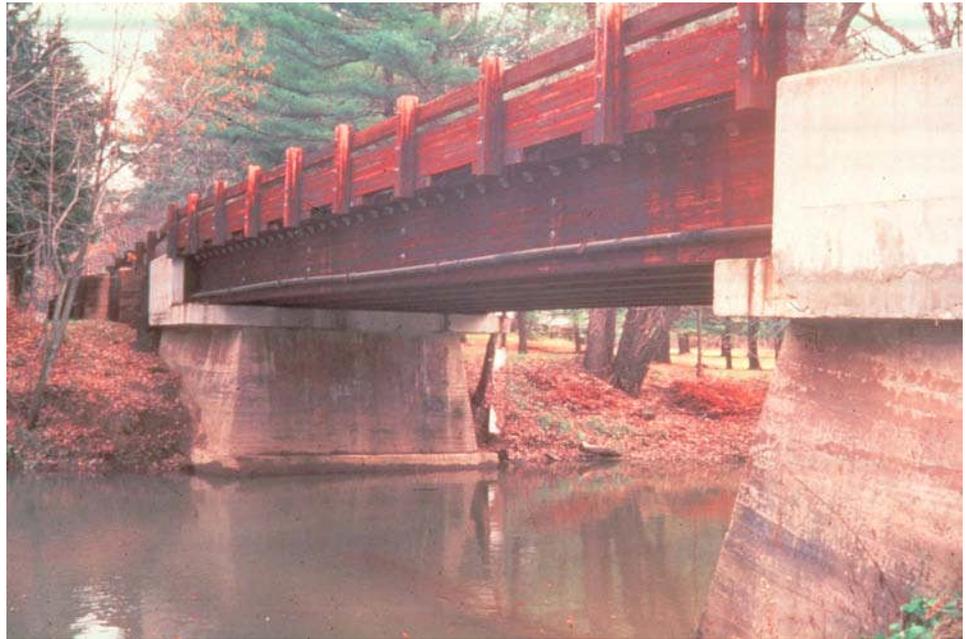
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# Topic 8.2 Glulam Timber Bridges

## 8.2.1

### **Introduction**

A glued-laminated (glulam) member is made by gluing strips of wood together to form a structural member of the desired size. An advantage of glulam members is that they allow for a higher utilization of the wood, since a lower grade of material can be used to fabricate these members. Many strength reducing characteristics of wood, such as knots and checks, are minimized due to relatively small laminate dimensions. Also, the size and length of a glulam member is not limited by the size or length of a tree. Strips of wood used in glulam members are generally 3/4 to 1-1/2 inches thick (see Figures 8.2.1 and 8.2.2).



**Figure 8.2.1** Elevation View of a Glulam Multi-beam Bridge



**Figure 8.2.2** Underside View of a Glulam Multi-beam Bridge

## **8.2.2**

### **Design Characteristics**

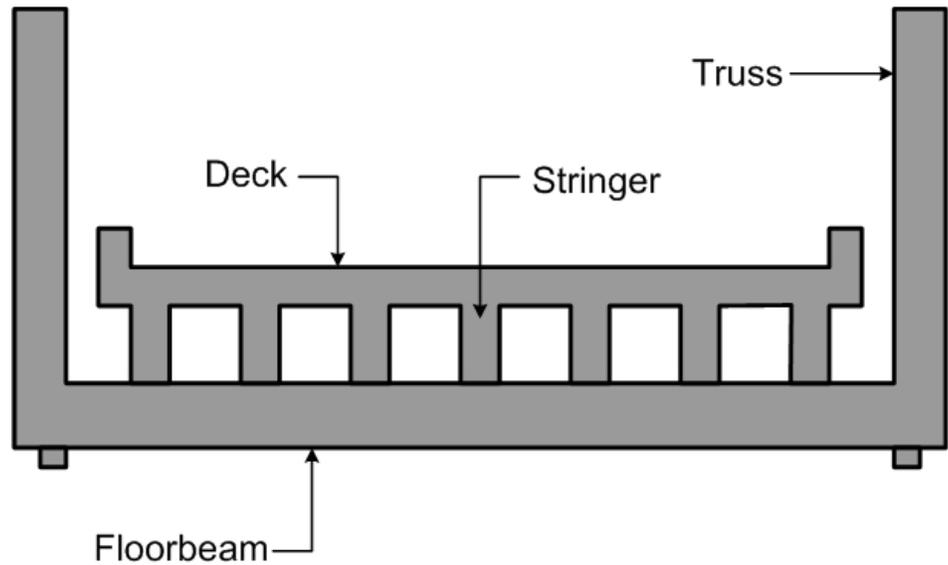
#### **Multi-beam Bridges**

Glulam multi-beam bridges are very similar to solid sawn multi-beam bridges, but they generally use larger members to span greater distances. Glulam multi-beam bridges are typically simple span designs (see Figure 8.2.1). They usually support a deck consisting of glulam panels with a bituminous wearing surface. Beam sizes typically range from 6 inches by 24 inches to 12-1/4 inches by 60 inches, and the beams are usually spaced 5'-6" to 6'-6" on center (see Figure 8.2.2).

These more modern multi-beam bridges can typically be used in spans of up to 80 feet, although some span as long as 150 feet have been constructed. This beam type can be used to form longer multiple span structures. They are generally found on local and secondary roads, as well as in park settings.

### Truss Bridges

Trusses may be of the through-type or of the deck-type. Usually the floor system consists of a timber deck supported by timber stringers and floorbeams, which are supported by the trusses (see Figures 8.2.3 and 8.2.4). Timber trusses are generally used for spans that are not economically feasible for timber multi-beam bridges. Timber trusses are practical for spans that range from 150 to 250 feet (see Figure 8.2.5).

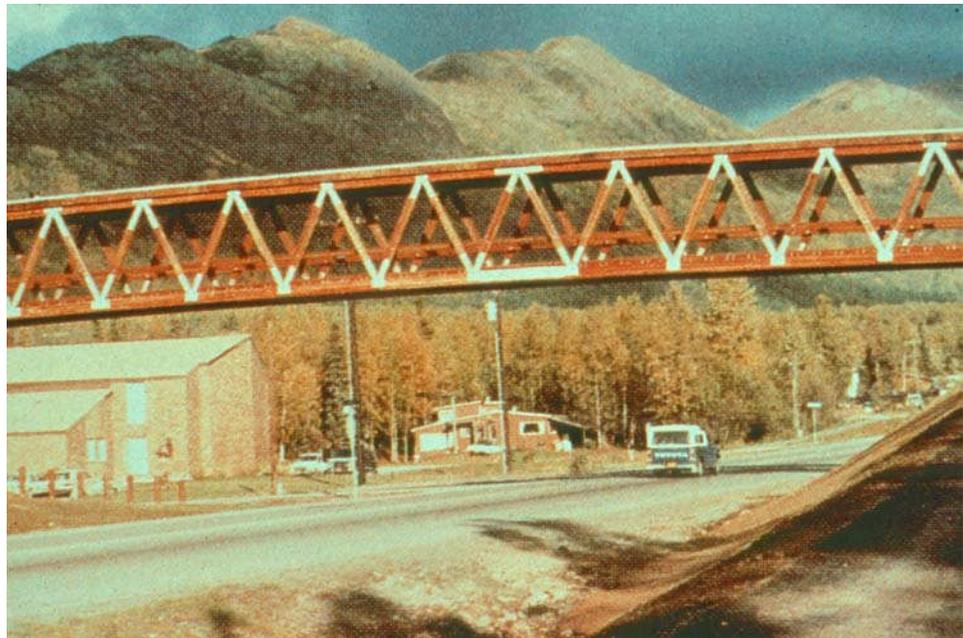


Timber Through Truss  
Typical Section

**Figure 8.2.3** Timber Through Truss Typical Section



**Figure 8.2.4** Bowstring Truss Pedestrian Bridge



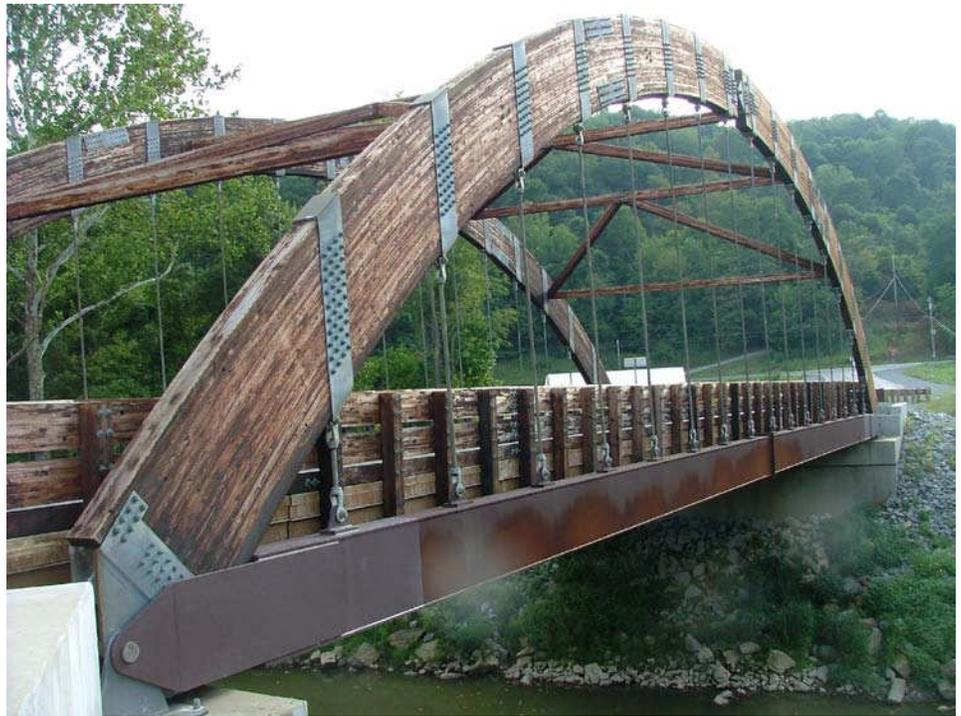
**Figure 8.2.5** Parallel Chord Truss Pedestrian Bridge (Eagle River, Alaska)

### **Arch Bridges**

Glulam arch bridges usually consist of two- or three-hinged deck arches, which support a glulam deck and floor system (see Figures 8.2.6 and 8.2.7). Glulam arches are practical for spans of up to about 300 feet. Arches are used in locations such as parks where aesthetics is important.



**Figure 8.2.6** Glulam Arch Bridge over Glulam Multi-beam Bridge (Keystone Wye interchange, South Dakota)

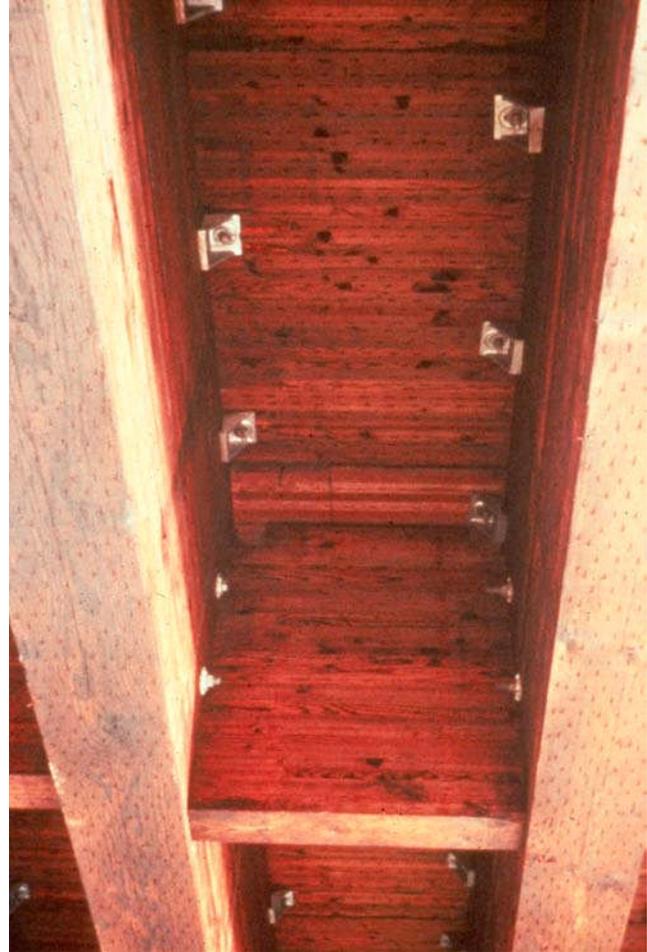


**Figure 8.2.7** Glulam Arch Bridge (West Virginia)

**Primary and Secondary Members**

The primary members of glulam multi-beam bridges are the beams, and the secondary members are the diaphragms or cross bracing (see Figure 8.2.8). Due to the larger depth of the glulam beams, diaphragms or cross bracing are normally present. Diaphragms are usually constructed of short glulam members, and cross bracing is usually constructed of steel angles.

The primary members of glulam arch and truss structures are the arch, truss, stringers, and floorbeams, spandrel bents and hangers. The secondary members include the diaphragms and cross bracing between the stringers and the lateral bracing between the arch or truss.



**Figure 8.2.8** Typical Glulam Diaphragm

Recent technology has also produced glulam timber materials which are reinforced with fibers such as aramids, carbon, and fiberglass. These fiber reinforced glulam beams help increase the strength and improve the mechanical properties of timber bridges.

### 8.2.3

#### **Overview of Common Deficiencies**

Common deficiencies that occur on glulam timber beams include:

- Inherent deficiency - Checks, splits, shakes
- Decay by fungi
- Damage by insects and borers
- Delaminations
- Loose connections
- Surface depressions
- Damage from fire

- Damage from impact/collisions
- Damage from wear, abrasion, and mechanical wear
- Damage from overstress
- Damage from weathering/warping
- Failure of protective system

A less common deficiency that may be encountered by the inspector includes damage from chemical attack. Refer to Topic 6.1 for a more detailed presentation of the properties of timber, types and causes of timber deterioration, and the examination of timber.

## 8.2.4

### **Inspection Methods and Locations**

Inspection methods to determine other causes of timber deterioration are discussed in detail in Topic 6.1.7. The inspection locations and procedures for glulam bridges are similar to those for solid sawn bridges.

#### **Methods**

##### **Visual**

The inspection of timber for checks, splits, cracks, shakes, fungus decay, deflections, crushing, delaminations, and loose connections is primarily a visual activity.

##### **Physical**

The physical examination of a timber member can be conducted with a hammer or pick. The hammer is used to sound the members to detect hollow areas or internal decay. Picks are used to determine the condition of the surface.

##### **Advanced Inspection Methods**

Several advanced methods are available for timber inspection. Nondestructive methods, described in Topic 15.1.2, include:

- Sonic testing
- Spectral analysis
- Ultrasonic testing
- Vibration

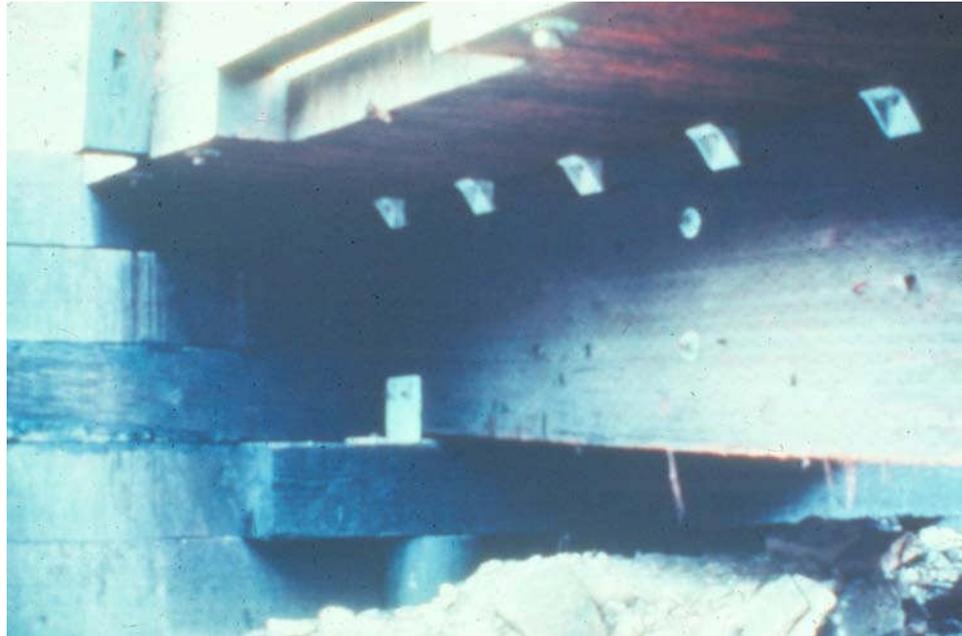
Other methods, described in Topic 15.1.3, include:

- Boring or drilling
- Moisture content
- Probing
- Field ohmmeter

## Locations

### Bearing Areas

Inspect the bearing areas for crushing of the beams (see Figure 8.2.9). Investigate for decay and insect damage by visual inspection, sounding, and/or probing at the ends of the beams. Also check the condition and operation of the bearing devices if they are present (see Topic 11.1).



**Figure 8.2.9** Bearing Area of Typical Glulam Beam

### Shear Zones

Examine for horizontal shear cracks and delaminations near the ends of the beam. Delaminations (i.e., separations in the laminations) can occur due to either failure of the glue or failure at the bond between the glue and the lamination (see Figure 8.2.10). Delaminations that extend completely through the cross section of the member are considered severe since this makes the member act as two smaller members. Delaminations that are located near the center of the cross section are more serious than those near the top or bottom of the beam. Delaminations directly through a connector are also undesirable.



**Figure 8.2.10** Close-up View of Glulam Bridge Showing Laminations

### **Tension Zones**

Examine the zone of maximum tension for signs of structural distress (see Figure 8.2.11). The maximum tension generally occurs at the bottom half of the middle third of the beam span. Investigate for section loss due to decay or fire, especially near mid-span. Inspect for excessive deflection or sagging in the beams.



**Figure 8.2.11** Elevation View of Beam of Glulam Multi-beam Bridge

### **Areas Exposed to Drainage**

Investigate for signs of decay along the full length of the member but especially where the beam is subjected to continual wetness or prolonged exposure to moisture (see Figure 8.2.12). Decay and chemical attack may be evidenced by discolored wood, brown and white rot, the formation of fruiting bodies (the result of fungal attacks, which produce disc-shaped bodies that distribute reproductive spores), "sunken" faces in the wood, or the soft "punky" texture of the wood.



**Figure 8.2.12** Decay on Glulam Beam

### **Areas of Insect Infestation**

Insect infestation can be detected in various ways. Carpenter ants generally leave piles of sawdust; powder-post beetles leave small holes in the surface of the wood; and termites can often be readily seen. Another indication of insect infestation is hollow sounding wood. Perform further probing or drilling in suspect areas.

### **Areas Exposed to Traffic**

For overhead and through structures, check for collision damage from vehicles passing below or adjacent to structural members.

### **Areas Previously Repaired**

Thoroughly examine any repairs that have been previously made. Determine if repaired areas are sound and functioning properly.

### **Secondary Members**

Examine diaphragms for decay, fire damage, and insect damage (see Figure 8.2.13). Check steel cross bracing for corrosion, bowing, or buckling (see Figure 8.2.14). Examine connections for tightness, cracks and splits, and corroded, loose,

or missing fasteners. Deteriorated secondary members may indicate problems in the primary members.



**Figure 8.2.13** Typical Diaphragm for a Glulam Multi-beam Bridge

#### **Fasteners and Connectors**

Inspect any fastener for corrosion, tightness, and missing parts (see Figure 8.2.13).



**Figure 8.2.14** Glulam Beams with Numerous Fastener Locations

## 8.2.5

### **Evaluation**

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

### **NBI Component Condition Rating Guidelines**

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

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

### **Element Level Condition State Assessment**

In an element level condition state assessment of a glulam timber bridge, possible AASHTO National Bridge Elements (NBEs) are:

<u>NBE No.</u>	<u>Description</u>
<u>Superstructure</u>	
111	Timber Girder/Beam
117	Timber Stringer
135	Timber Truss
146	Timber Arch
156	Timber Floorbeam

The unit quantity for the timber superstructures is feet. The total length is distributed among the four available condition states depending on the extent and severity of the deficiency. The sum of all condition states equals the total quantity of the National Bridge Element. Condition State 1 is the best possible rating. See the *AASHTO Guide Manual for Bridge Element Inspection* for condition state descriptions.

The following Defect Flag is applicable in the evaluation of glulam timber superstructures:

<u>Defect Flag No.</u>	<u>Description</u>
362	Superstructure Traffic Impact (load capacity)

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

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# Topic 8.3 Stress-Laminated Timber Bridges

## 8.3.1

### Introduction

Stress-laminated timber bridges were first developed in Canada, in 1976, by the Ontario Ministry of Transportation and Communications. These bridges consist of multiple planks mechanically clamped together using metal rods to perform as one unit (see Figure 8.3.1). The compression induced frictional resistance within the timber laminations is the mechanism that makes this structural system effective.



**Figure 8.3.1** Stress-Laminated Timber Slab Bridge Carrying a 90,000-Pound Logging Truck (Source: Barry Dickson, West Virginia University)

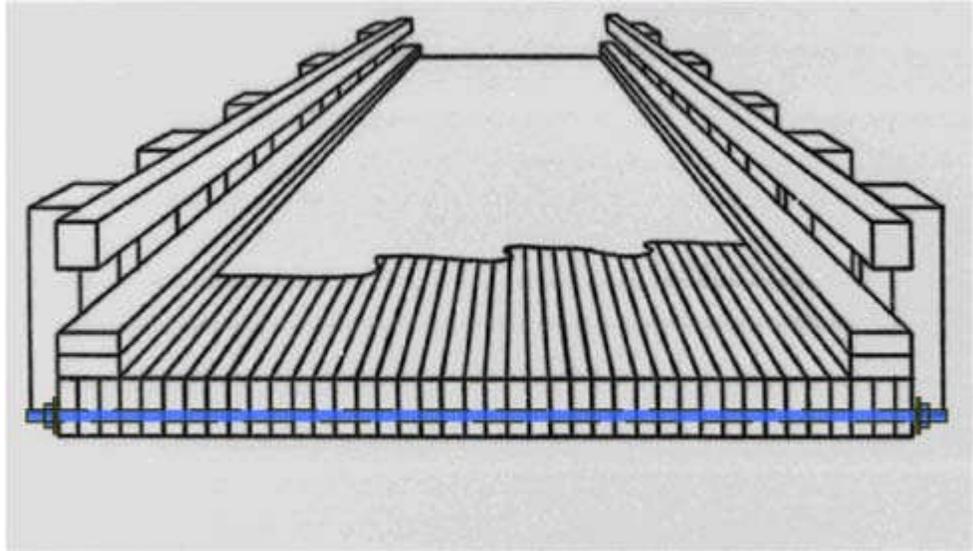
## 8.3.2

### Design Characteristics

Loss of the compressive stress reduces the frictional resistance between members and reduces the load capacity of this structural system.

### Stress-Laminated Timber Slab Bridges

Stress-laminated timber slab bridges can be used for simple spans of up to 50 feet and are capable of carrying modern highway loadings (see Figures 8.3.1 and 8.3.3). Stressed deck bridges have also been constructed using glulam members. Combining glulam technology with stress-lamination increases practical span lengths to 65 feet (see Figure 8.3.4).



**Figure 8.3.2** Typical Section of a Stress-Laminated Timber Slab Bridge



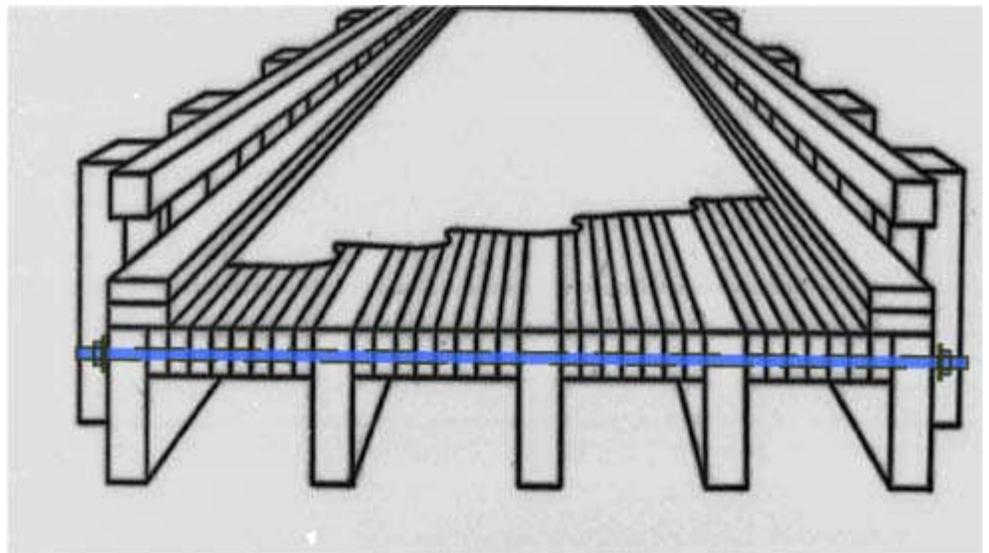
**Figure 8.3.3** Stress-Laminated Timber Slab Bridge



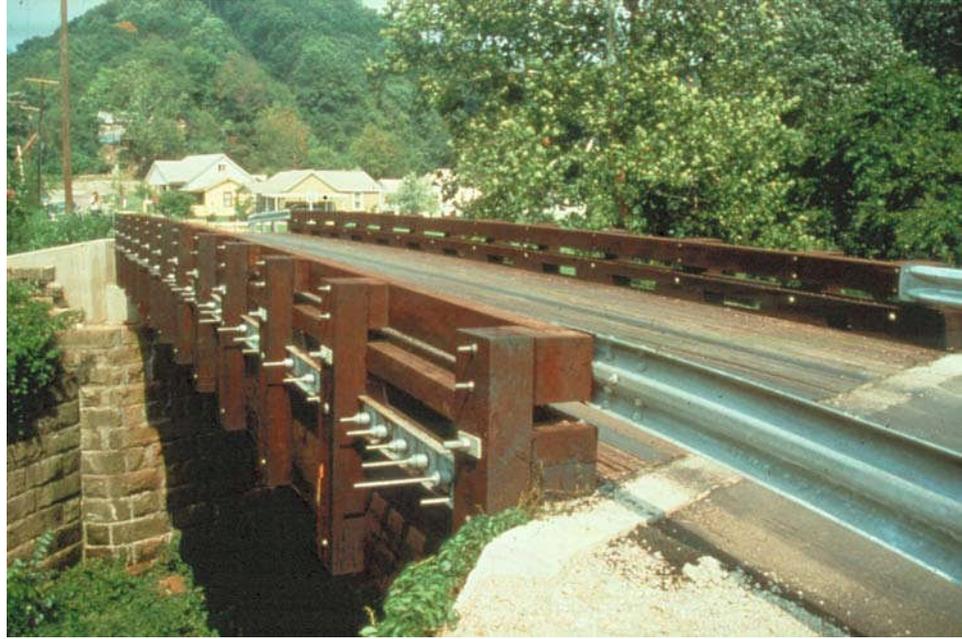
**Figure 8.3.4** Glulam Stress-Laminated Timber Slab Bridge

### **Stress-Laminated Timber Tee Beam Bridges**

The idea for stress-laminated timber tee beam bridges was developed at West Virginia University. These bridges consist of a stress-laminated deck and glulam beams (see Figure 8.3.5). High strength steel rods are used to join the stress-laminated deck and glulam beams together to form stress-laminated timber tee beams. The first structure of this type was built in 1988, near Charleston, West Virginia. It is 75 feet long and has stressing rods spaced at two feet. This bridge has performed well, which encouraged longer span lengths to be constructed. The average span length for stress-laminated tee beam bridges ranges between 25 and 85 feet (see Figure 8.3.6).



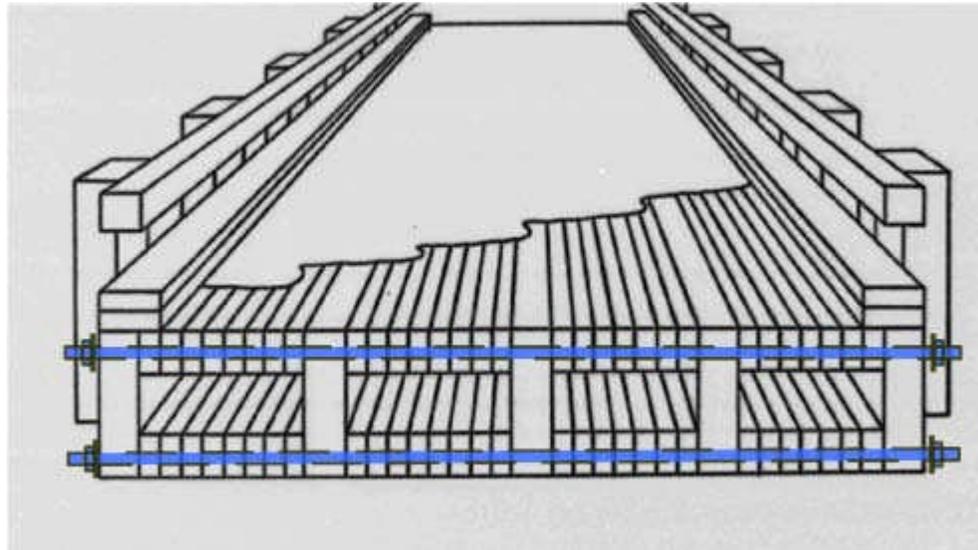
**Figure 8.3.5** Typical Section of a Stress-Laminated Timber Tee Beam Bridge  
(Source: Barry Dickson, West Virginia University)



**Figure 8.3.6** Elevation View of Stress-Laminated Timber Tee Beam Bridge (West Virginia)

### **Stress-Laminated Timber Box Beam Bridges**

Stress-laminated timber box beam bridges represent further development of timber bridges by West Virginia University. These bridges consist of adjacent box beam panels individually comprised of stress-laminated flanges and glulam beam webs (see Figure 8.3.7). This bridge type is also known as a cellular stressed deck. Average span lengths range between 35 and 65 feet, with longer maximum spans (see Figure 8.3.8).



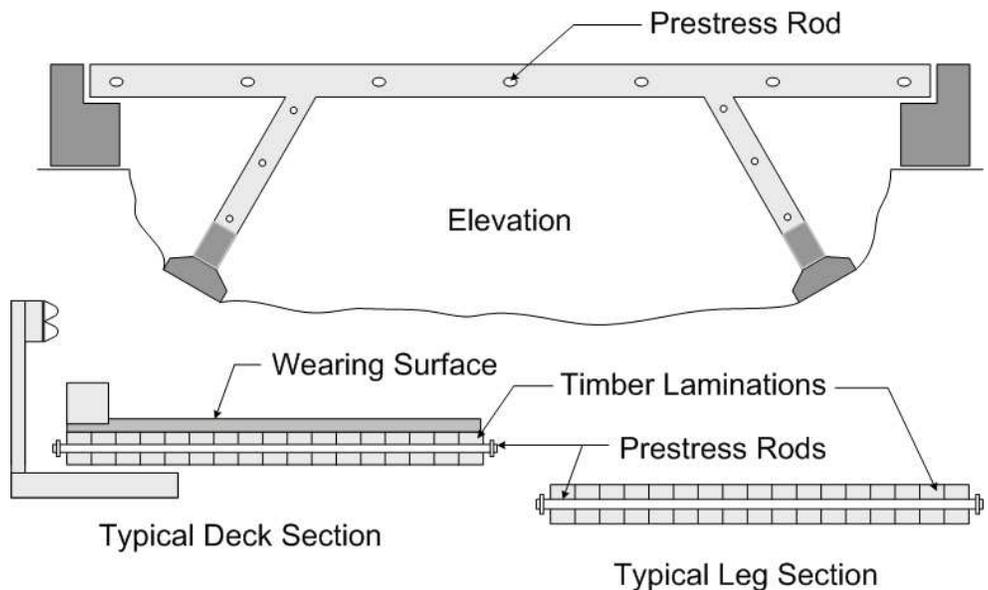
**Figure 8.3.7** Typical Section of a Stress-Laminated Timber Box Beam (Source: Barry Dickson, West Virginia University)



**Figure 8.3.8** Stress-Laminated Timber Box Beam Bridge Being Erected

### Stress-Laminated Timber K-frame Bridges

Stressed K-frame bridges represent further development of the stressed deck bridge by the Ontario Ministry of Transportation and Communications. These bridges consist of three spans in which the stressed deck is supported at two intermediate points by stressed laminated timber struts (see Figure 8.3.9). This bridge type has been used for a bridge with a total length of excess of 100 feet, and it has a potential for center span lengths over 50 feet.



**Figure 8.3.9** Stress-Laminated Timber K-frame Bridge

### Primary and Secondary Members

The primary members are the decks, slabs, tee beams, box beams, and frame legs. The secondary members are the external diaphragms and cross bracing between beams.

### 8.3.3

#### **Overview of Common Deficiencies**

Common deficiencies that occur on stressed timber bridges include:

- Inherent defects - Checks, splits, shakes
- Decay by fungi
- Damage by insects and borers
- Loose connections
- Loose or deteriorated stressing rods or connectors
- Surface depressions
- Damage from fire
- Damage from impact/collisions
- Damage from wear, abrasion, and mechanical wear
- Damage from overstress
- Damage from weathering/warping
- Failure of protective system

A less common deficiency that may be encountered by the inspector includes damage from chemical attack. Refer to Topic 6.1 for a more detailed presentation of the properties of timber, types and causes of timber deterioration, and the examination of timber.

### 8.3.4

#### **Inspection Methods and Locations**

Inspection methods to determine other causes of timber deterioration are discussed in detail in Topic 6.1.7. The inspection of stress-laminated timber bridges is similar to those for glulam bridges.

#### **Methods**

##### **Visual**

The inspection of timber for checks, splits, cracks, shakes, fungus decay, deflections, crushing, delaminations, and loose connections is primarily a visual activity.

##### **Physical**

The physical examination of a timber member can be conducted with a hammer or pick. The hammer is used to sound the members to detect hollow areas or internal decay. Picks are used to determine the condition of the surface.

##### **Advanced Inspection Methods**

Several advanced methods are available for timber inspection. Nondestructive methods, described in Topic 15.1.2, include:

- Sonic testing
- Spectral analysis
- Ultrasonic testing
- Vibration

Other methods, described in Topic 15.1.3, include:

- Boring or drilling
- Moisture content
- Probing
- Field ohmmeter

## Locations

### Stressing Rods

Examine the condition of the steel stressing rods, and inspect for crush and splits in the fascia members. Check for loss of prestress in the rods, which would be indicated by shifted planks in the stress-laminated timber element and excessive deflection or loose rods. This may be observed when the bridge is subject to a moving live load.



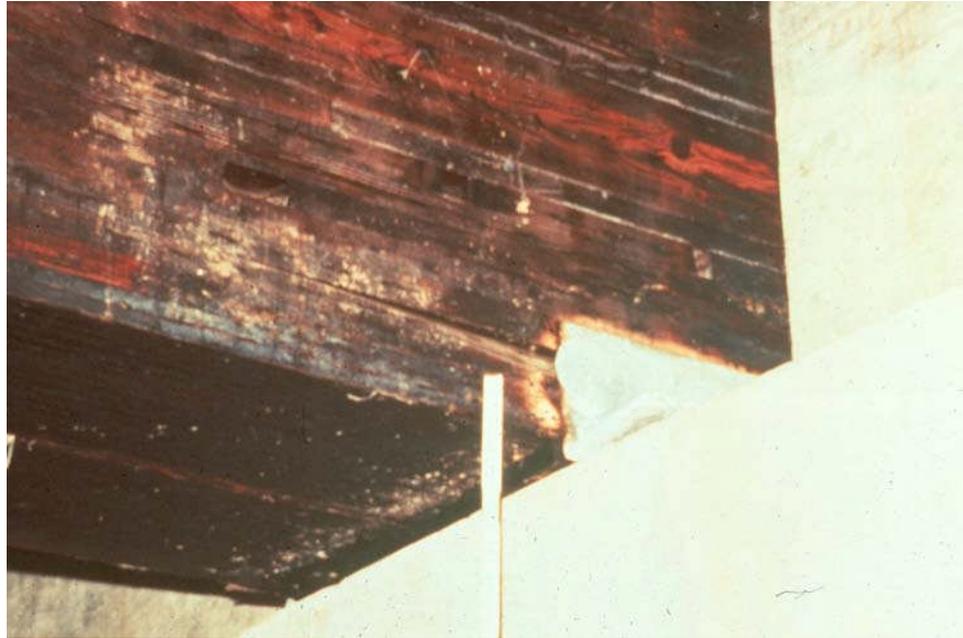
**Figure 8.3.10** Broken Stressing Rods

### Bearing Areas

Inspect the bearing areas for crushing of the beams. Investigate for decay and insect damage by visual inspection, sounding, and/or probing at the ends of the beams. Also check the condition and operation of the bearing devices if they are present (see Topic 11.1, Bearings).

### Shear Zones

Examine for horizontal shear cracks and delaminations near the ends of the beam. Delaminations (i.e., separations in the laminations) can occur due to either failure of the glue or failure at the bond between the glue and the lamination (see Figure 8.3.11). Delaminations that extend completely through the cross section of the member are the most severe since this makes the member act as two smaller members.



**Figure 8.3.11** Close-up View of End of a Stress-Laminated Timber Bridge Showing Laminations

### Tension Zones

Examine the zone of maximum tension for signs of structural distress. The maximum tension generally occurs at the bottom half of the middle third of the beam span. Investigate for section loss due to decay or fire, especially near mid-span. Inspect for excessive deflection or sagging in the beams.

### Areas Exposed to Drainage

Investigate for signs of decay along the full length of the member but especially where the beam is subjected to continual wetness or prolonged exposure to moisture. Decay and chemical attack may be evidenced by discolored wood, brown and white rot, the formation of fruiting bodies (the result of fungal attacks, which produce disc-shaped bodies that distribute reproductive spores), "sunken" faces in the wood, or the soft "punky" texture of the wood. Examine the curb line areas. Standing water soaks into the beam and corrodes the stressing rods.

### **Areas of Insect Infestation**

Insect infestation can be detected in various ways. Carpenter ants generally leave piles of sawdust; powder-post beetles leave small holes in the surface of the wood; and termites can often be readily seen. Another indication of insect infestation is hollow sounding wood. Perform further probing or drilling in suspect areas.

### **Areas Exposed to Traffic**

Check stress-laminated timber members for collision damage from vehicles passing below.

### **Areas Previously Repaired**

Thoroughly examine any repairs that have been previously made. Determine if repaired areas are sound and functioning properly.

### **Secondary Members**

Examine solid sawn or glulam diaphragms for decay, fire damage, and insect damage. Check steel cross bracing for corrosion, bowing, or buckling. Examine connections for tightness, cracks and splits, and corroded, loose, or missing fasteners. Deteriorated secondary members may indicate problems in the primary members.

### **Fasteners and Connectors**

Inspect any fastener for corrosion, tightness, and missing parts. Stressing rod hardware is the most important fastener system on a stress-laminated timber bridge.

## **8.3.5**

### **Evaluation**

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

### **NBI Component Condition Rating Guidelines**

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

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

**Element Level Condition State Assessment** In an element level condition state assessment of timber bridges, possible AASHTO National Bridge Elements (NBEs) and Bridge Management Elements (BMEs) are:

<u>NBE No.</u>	<u>Description</u>
<b>Deck/Slabs</b>	
31	Timber Deck
54	Timber Slab
<b>Superstructure</b>	
111	Timber Girder/Beam

**BME No.**

**Wearing Surfaces and Protection Systems**

520	Deck/Slab Protection System
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The unit quantity for decks, slabs and protection systems is square feet. The total area is distributed among the four available condition states depending on the extent and severity of the deficiency. The unit quantity for the timber superstructures is feet, and the total length is distributed among the four available condition states depending on the extent and severity of the deficiency. The sum of all condition states equals the total quantity of the National Bridge Element or Bridge Management Element. Condition State 1 is the best possible rating. See the *AASHTO Guide Manual for Bridge Element Inspection* for condition state descriptions.

The following Deflect Flag is applicable in the evaluation of stress-laminated timber superstructures:

<u>Deflect Flag No.</u>	<u>Description</u>
362	Superstructure Traffic Impact (load capacity)

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

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# Chapter 9

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## Inspection and Evaluation of Concrete Superstructures

### Topic 9.1 Cast-in-Place Slabs

#### 9.1.1

##### 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 9.1.1 and 9.1.2). 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 and distributes loads to the superstructure. 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 methods and locations and, evaluation, are similar. See Topic 7.2 for further details.



**Figure 9.1.1** Typical Simple Span Cast-in-Place Slab Bridge



**Figure 9.1.2** Typical Multi-Span Cast-in-Place Slab Bridge

## 9.1.2

### 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 or more simply supported spans and spans are typically less than 30 feet long. Continuous multi-span slab bridges are also in service, but not as common as simply supported slabs.

#### Primary and Secondary Members

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

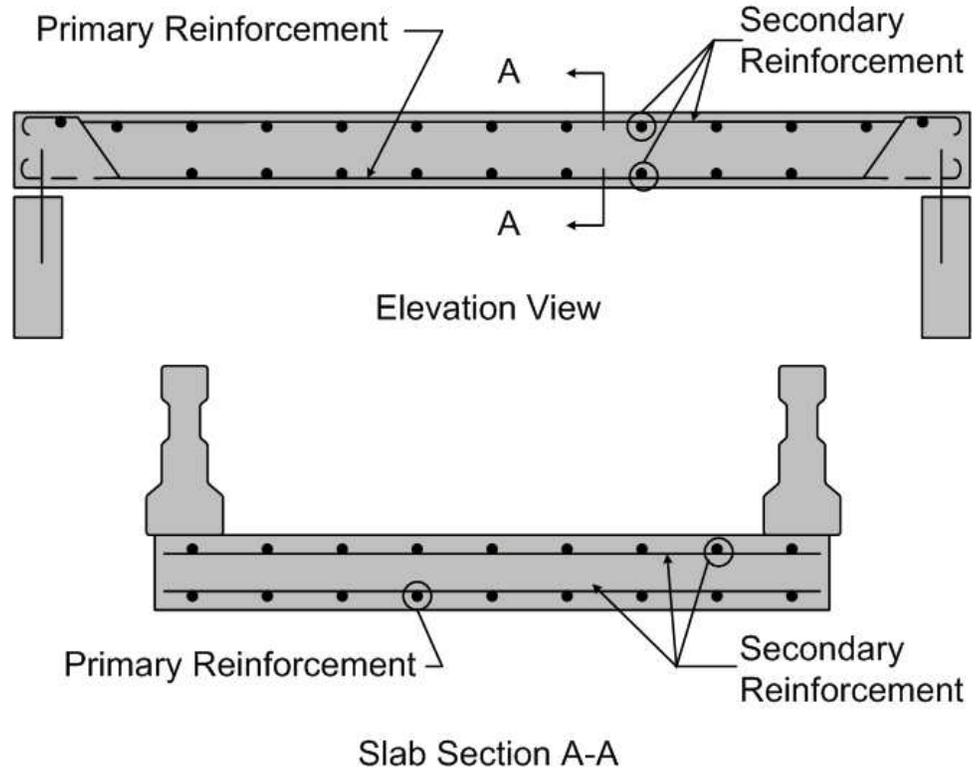
#### Steel Reinforcement

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 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 tension caused by negative bending moments.

Shear reinforcement is also considered to be primary reinforcement. Shear reinforcement, if required, is normally obtained by bending the tension bars at a 45 degree angle close to the slab supports. The shear reinforcement is perpendicular to diagonal tension/shear forces and therefore resists those forces.

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 9.1.3).



**Figure 9.1.3** Steel Reinforcement in a Simply Supported Concrete Slab

### 9.1.3

#### Overview of Common Deficiencies

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

- Cracking (structural, flexure, shear, crack size, nonstructural, crack orientation)
- Scaling
- Delamination
- Spalling
- Chloride contamination
- Freeze-thaw
- Efflorescence
- Alkali silica reactivity (ASR)
- Ettringite formation
- Honeycombs
- Pop-outs
- Wear

- Collision damage
- Abrasion
- Overload damage
- Internal steel corrosion
- Carbonation

Refer to Topic 6.2.6 for a detailed explanation of the properties of concrete, types and causes of concrete deficiencies, and the examination of concrete.

## 9.1.4

### **Inspection Methods and Locations**

Inspection methods to determine causes of concrete deficiencies are presented in detail in Topic 6.2.8.

#### **Methods**

##### **Visual**

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

##### **Physical**

The most common physical method for inspecting concrete is to use a hammer to "sound" the concrete. However, the physical examination of the top surface of the slab with a hammer can be a tedious operation. Instead, a chain drag is used to determine delaminated areas for most cases. A chain drag is typically 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. It is not possible to use a chain drag on the bottom surface, so hammer sounding is the primary physical procedure.

##### **Advanced Inspection Methods**

Several advanced methods are available for concrete inspection.

Nondestructive methods, described in Topic 15.2.2, include:

- Acoustic wave sonic/ultrasonic velocity measurements
- Electrical methods
- Delamination detection machinery
- Ground-penetrating radar
- Electromagnetic methods
- Pulse velocity
- Flat jack testing
- 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
- Smart concrete
- Carbonation

Other inspection methods or tests for material properties, described in Topic 15.2.3, include:

- 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 9.1.4). Check the condition and operation of any bearing devices.

As detailed in Topic 7.2.6, bearing areas are located where one element "sits" on top of another element. For slabs, the bearing areas are located above the substructure supports.



**Figure 9.1.4** 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 an overstress for shear (see Figures 9.1.5 and 9.1.6). Carefully measure cracks as they may represent lost shear capacity.



**Figure 9.1.5** Diagonal Shear Cracks Close to the Ends of a Slab Bridge



**Figure 9.1.6** Shear Zone on the Underside of a Continuous Slab Bridge Near a Pier

### **Tension Zones**

Examine tension zones for flexure cracks, which would be perpendicular to the tensile forces and 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 than 1/16 inch wide indicate overstress due to tensile forces caused by bending stresses. Check for efflorescence from cracks and, more significant, the 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 Figure 9.1.7).

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 9.1.8). Slab bridges which use hooks to develop the primary tension reinforcement are not as susceptible to debonding due to deterioration of the concrete.

### **Secondary Members**

The slab bridge has no secondary members.



**Figure 9.1.7** Inspector examining and documenting deficiencies in concrete slab



**Figure 9.1.8** 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 curblines and fascias (see Figure 9.1.9).

### **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. Also examine the top surface for signs of wear caused by vehicular traffic.

### **Areas Previously Repaired**

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

### **Other Areas Exposed to External Damage**

- Waterborne debris or ice
- Fire
- Equipment hits
- Displacement of superstructure due to floods, storm surges, etc.

### **Acute Angles on Skewed Bridges**

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



**Figure 9.1.9** Deteriorated Slab Fascia due to Roadway Deicing Agents

### **Camber**

Using a string line, check for vertical alignment (camber) changes from the as-built condition of the slab. Downward deflection usually indicates reduced capacity. Upward deflection usually indicates shrinkage.

**Thermal Effects**

These cracks are caused by non-uniform temperatures between two surfaces of the slab. Cracking will typically be transverse in the thinner regions of the slab and longitudinal near changes in cross section thickness.

**9.1.5**

**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 condition rating method and the AASHTO *Guide Manual for Bridge Element Inspection* for element level condition state assessment.

**NBI Component Condition Rating Guidelines**

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

Use previous inspection data along with current inspection findings to determine the correct component condition rating. For this type of structure, the deck and superstructure components may have the same rating.

**Element Level Condition State Assessment**

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

**NBE No.**

**Description**

**Decks/Slabs**

38

Reinforced Concrete Slab\*

\* Note that this element designation is used regardless of the type of riding surface

**BME No.**

**Description**

**Wearing Surfaces and Protection Systems**

510

Wearing Surfaces

520

Deck/Slab Protection Systems

521

Concrete Protective Coating

The unit quantity for decks, slabs, wearing surfaces, protection systems and protective coatings is square feet. The total area is distributed among the four available condition states depending on the extent and severity of the deficiency. The sum of all condition states equals the total quantity of the National Bridge

Element or Bridge Management Element. Condition State 1 is the best possible rating. See the *AASHTO Guide Manual for Bridge Element Inspection* for condition state descriptions.

The following Defect Flags are applicable in the evaluation of cast-in-place slab superstructures:

<b><u>Defect Flag No.</u></b>	<b><u>Description</u></b>
358	Concrete Cracking
359	Concrete Efflorescence
362	Superstructure Traffic Impact (load capacity)

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

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