FHWA Bridge Inspector's Manual: *Primer on Bridge Terminology and Mechanics*

Course No: S06-007

Credit: 6 PDH

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Topic 3.1 Basic Bridge Terminology

3.1.1
Introduction

It is important to be familiar with the terminology and elementary theory of bridge mechanics and materials. This topic presents the terminology needed by inspectors to properly identify and describe the individual elements that comprise a bridge. First the major components of a bridge are introduced. Then the basic member shapes and connections of the bridge are presented. Finally, the purpose and function of the major bridge components are described in detail.

3.1.2
NBIS Structure Length

According to the *FHWA Recording and Coding Guide for the Structure Inventory and Appraisal of the Nation's Bridges*, the structure length is measured in accordance with Item 49 as shown on Figure 3.1.1. The structure length is the length of the roadway that is supported by the bridge structure. To determine the length, measure back to back of back-walls of abutments or from paving notch to paving notch. If the location of the backs of backwalls cannot be exactly determined, inspectors can then measure the distance between the paving notches to determine structure length.

To measure the length of culverts, measure along the center line of the roadway regardless of their depth below grade. The measurements will be between the inside faces of the exterior walls. Tunnels should be measured along the center of the roadway.

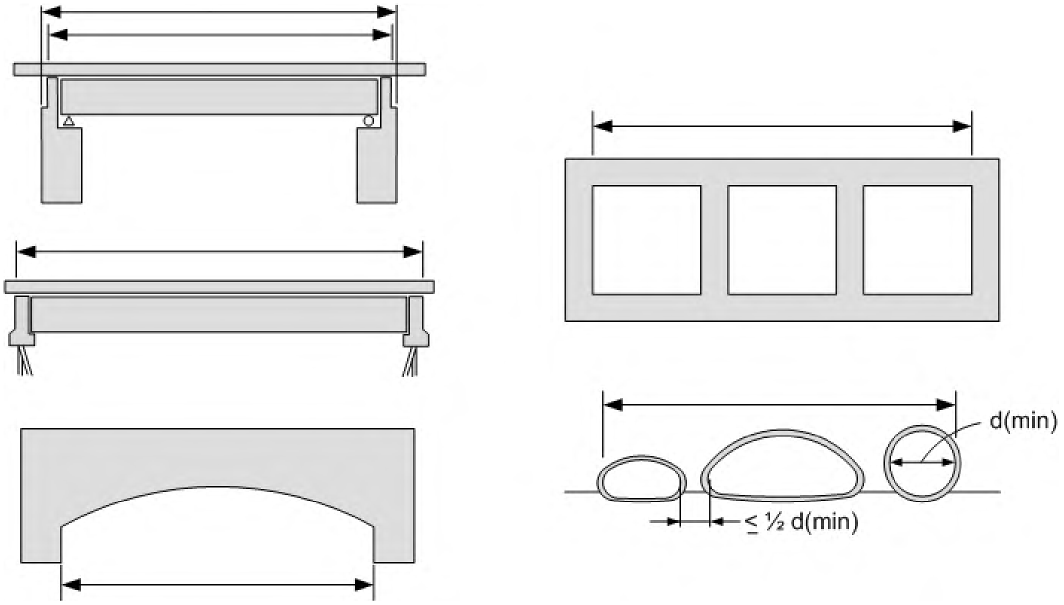


Figure 3.1.1 NBIS Structure Length

3.1.3

NBIS Bridge Length

The *FHWA Recording and Coding Guide for the Structure Inventory and Appraisal of the Nation's Bridges* also states, in accordance with Item 112 – NBIS Bridge Length, that the minimum length for a structure to be considered a bridge for National Bridge Inspection Standards purposes, is to be 20 feet (see Figure 3.1.2).

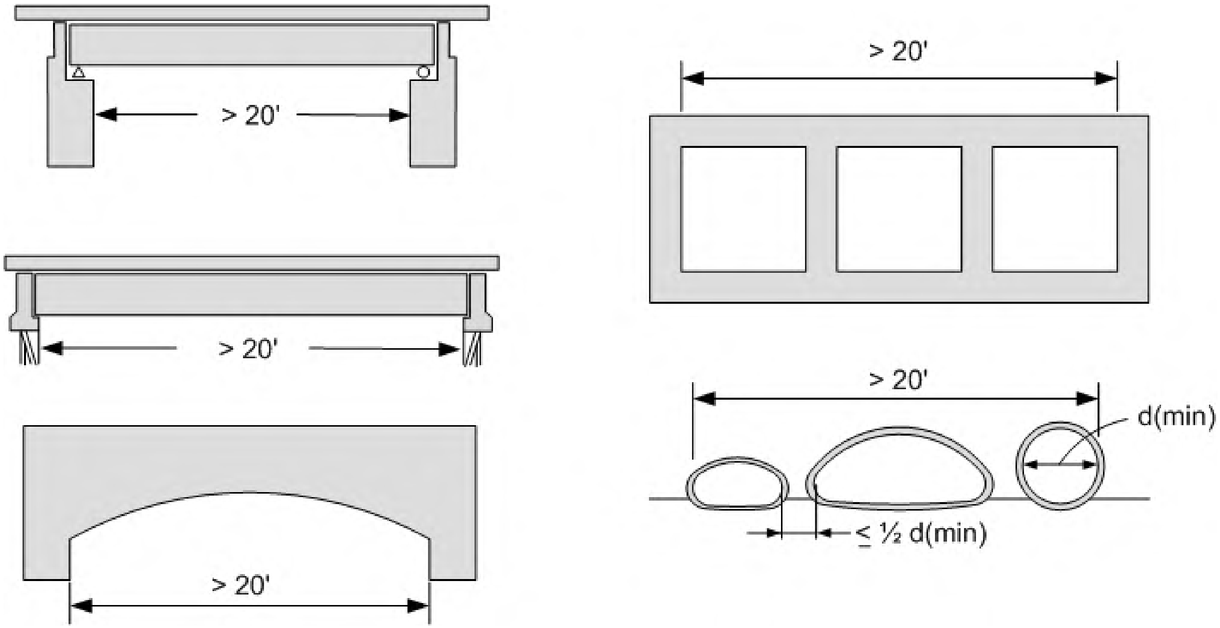


Figure 3.1.2 NBIS Bridge Length (Coding Guide Item 112)

23 CFR Part 650.305 Definitions gives the definition of a bridge as it applies to the NBIS regulations: A bridge is a structure including supports erected over a depression or an obstruction, such as water, highway, or railway, and having a track or passageway for carrying traffic or other moving loads, and having an opening measured along the center of the roadway of more than 20 feet between undercopings of abutments or spring lines of arches, or extreme ends of openings for multiple boxes; it may also include multiple pipes, where the clear distance between openings is less than half of the smaller contiguous opening.

3.1.4

Major Bridge Components

A thorough and complete bridge inspection is dependent upon the bridge inspector's ability to identify and understand the function of the major bridge components and their elements. Most bridges can be divided into three basic parts or components (see Figure 3.1.3):

- Deck
- Superstructure
- Substructure

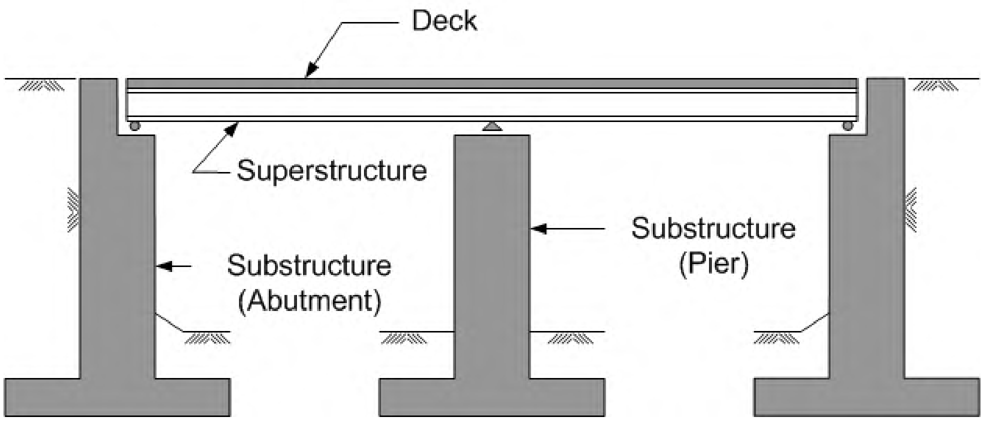


Figure 3.1.3 Major Bridge Components

3.1.5 Basic Member Shapes

The ability to recognize and identify basic member shapes requires an understanding of the timber, concrete, and steel shapes used in the construction of bridges.

Every bridge member is designed to carry a unique combination of tension, compression, and shear. These are considered the three basic kinds of member stresses. Bending loads cause a combination of tension and compression in a member. Shear stresses are caused by transverse forces exerted on a member. As such, certain shapes and materials have distinct characteristics in resisting the applied loads. For a review of bridge loadings and member responses, see Topic 5.1.

Timber Shapes

Basic shapes, properties, gradings, deficiencies, protective systems, and examination of timber are covered in detail in Topic 6.1.

Timber members are found in a variety of shapes (see Figure 3.1.4). The sizes of timber members are generally given in nominal dimensions (such as in Figures 3.1.4 and 3.1.5). However, sawn timber members are generally seasoned and surfaced from the rough sawn condition, making the actual dimension about 1/2 to 3/4 inches less than the nominal dimension.

The physical properties of timber enable it to resist both tensile and compressive stresses. Therefore, it can function as an axially-loaded or bending member. Timber bridge members are made into three basic shapes:

- Round – piles, columns, posts
- Rectangular – planks, beams, columns, piles
- Built-up shapes - beams

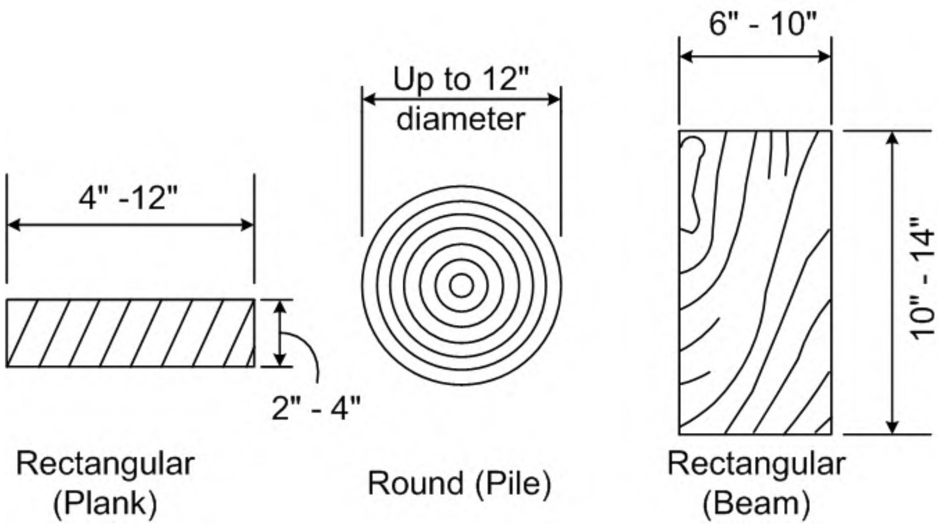


Figure 3.1.4 Timber Members

Planks

Planks are characterized by elongated, rectangular dimensions determined by the intended bridge use. Plank thickness is dependent upon the distance between the supporting points and the magnitude of the vehicle load. Common nominal or rough sawn dimensions for timber planks are 2 to 4 inches thick and 6 to 12 inches wide. Dressed lumber dimensions would be 1 ½ inches x 11 ¼ inches (see Figure 3.1.4).

Planks are most often used for bridge decks on bridges carrying light or infrequent truck traffic. Timber plank decks have been used for centuries. Timber planks are advantageous in that they are economical, lightweight, readily available, and easy to install.

Beams

Timber beams have more equal rectangular dimensions than do planks, and they are sometimes square. Common dimensions include 10 inch by 10 inch square timbers, and 6 inch by 14 inch rectangular timbers. Beams generally are installed with the larger dimension vertical.

As the differences in the common dimensions of planks and timber beams indicate, beams are larger and heavier than planks and can support heavier loads, as well as span greater distances. As such, timber beams are used in bridge superstructures and substructures to carry bending and axial loads.

Timbers can either be solid sawn or built-up glued-laminated (see Figure 3.1.5). Glued-laminated timbers are advantageous in that they can be fabricated from smaller, more readily available pieces. Glued lamination also allows larger rectangular members to be formed without the presence of natural deficiencies such as knots. Glued-laminated timbers are normally manufactured from well-seasoned wood and display very little shrinkage after they are fabricated.

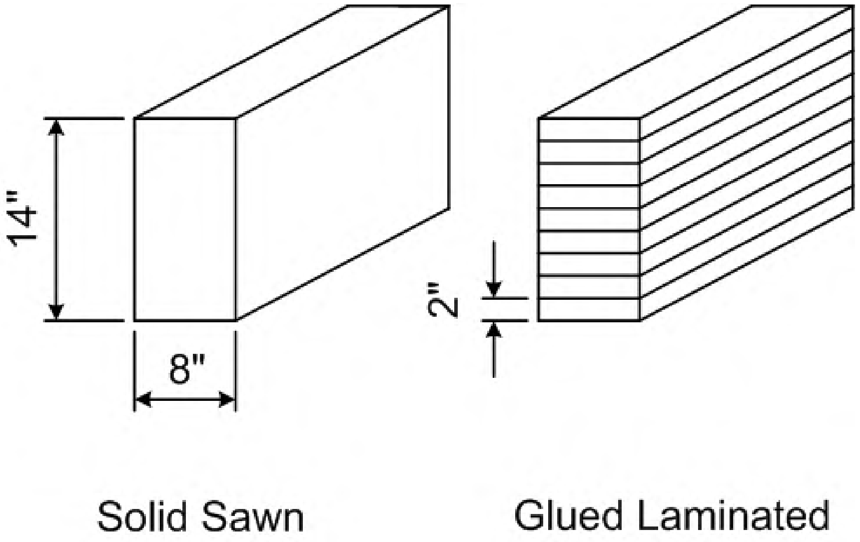


Figure 3.1.5 Timber Beams

Piles/Columns

Timber can also be used for piles or columns. Piles are normally round, slender columns that support the substructure footing or partially form the substructure. Piles may be partially above ground or completely buried.

Concrete Shapes

Basic ingredients, properties, reinforcement, deficiency, protective systems, and examination of concrete are covered in detail in Topic 6.2.

Figure 3.1.6 Unusual Concrete Shapes

Concrete is a unique material for bridge members because it can be formed into an infinite variety of shapes (see Figure 3.1.6). Concrete members are used to carry axial and bending loads. Since bending results in a combination of compressive and tensile stresses, concrete bending members are typically reinforced with either reinforcing steel bars (producing conventionally reinforced concrete) or with prestressing steel (producing prestressed concrete) in order to carry the tensile stresses in the member. Reinforcing steel is also added to increase the shear and torsion capacity of concrete members.

Cast-in-Place Flexural Shapes

The most common shapes of reinforced concrete members are (see Figure 3.1.7):

- Slabs/Decks
- Rectangular beams
- Tee beams
- Channel beams

Bridges utilizing these shapes and mild steel reinforcement have been constructed and were typically cast-in-place (CIP). Many of the designs are obsolete, but the structures remain in service. Concrete members of this type are used for short and medium span bridges.

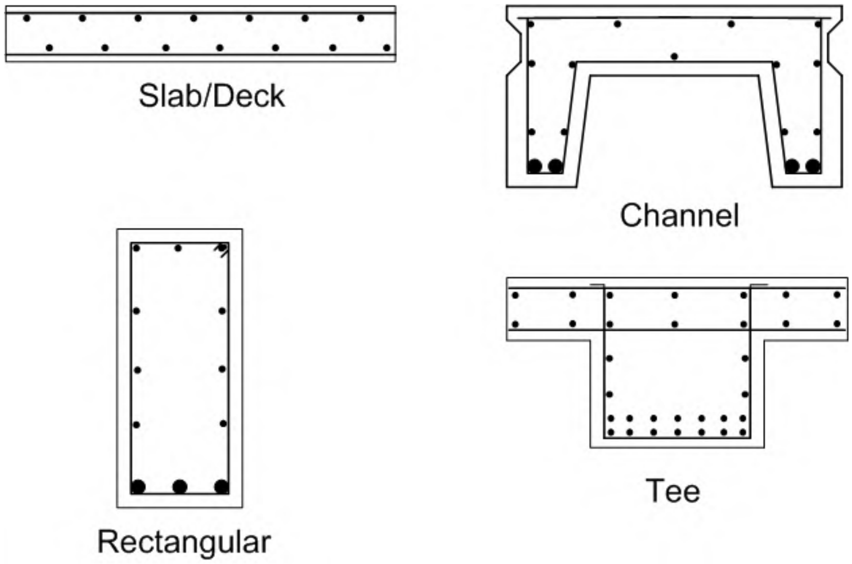


Figure 3.1.7 Reinforced Concrete Shapes

On concrete decks, the concrete spans the distance between superstructure members and is generally 7 to 9 inches thick. On slab bridges, the slab spans the distance between piers or abutments, forming an integral deck and superstructure. Slab bridge elements are usually 12 to 24 inches thick.

Rectangular beams are used for both superstructure and substructure bridge elements. Concrete pier caps are commonly rectangular beams which support the superstructure.

Tee beams are generally limited to superstructure elements. Distinguished by a "T" shape, tee beams combine the functions of a rectangular stem and flange to form an integral deck and superstructure.

Channel beams are generally limited to superstructure elements. This particular shape can be precast or cast-in-place. Channel beams are formed in the shape of a "C" and placed legs down when erected. They function as both superstructure and deck and are typically used for shorter span bridges.

Precast Flexural Shapes

The most common shapes of prestressed concrete members are (see Figure 3.1.8):

- I-beams
- Bulb-tees
- Voided or solid slabs
- Box beams
- Box girders

These shapes are used for superstructure members.

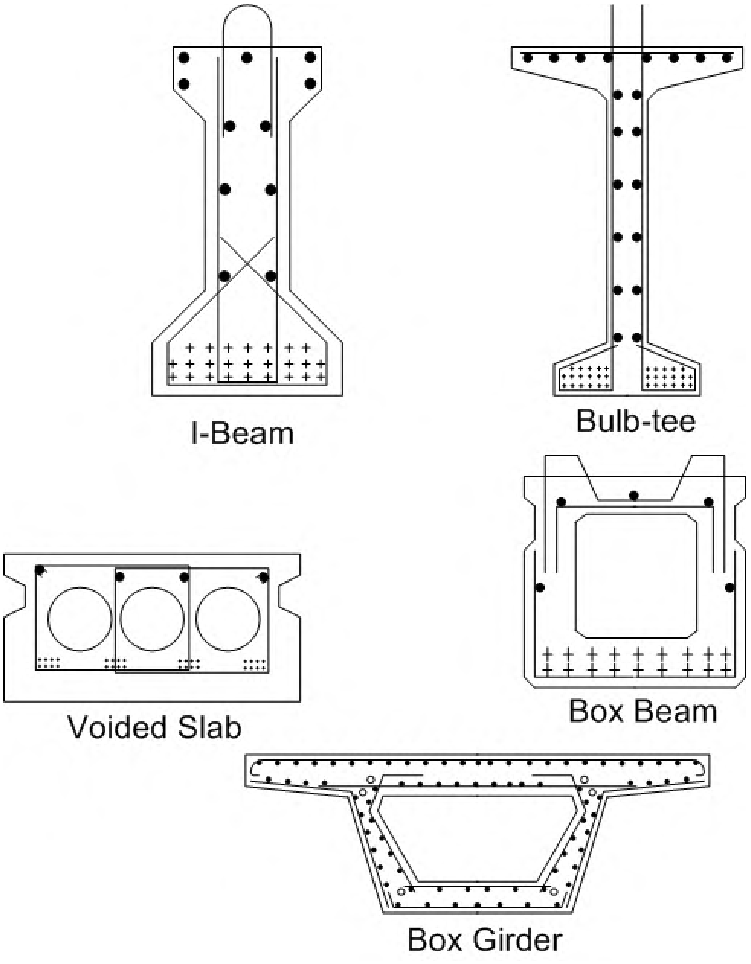

I-Beam
Bulb-tee
Voided Slab
Box Beam
Box Girder

Figure 3.1.8 Prestressed Concrete Shapes

Prestressed concrete beams can be precast at a fabricator's plant using high compressive strength concrete. Increased material strengths, more efficient shapes, the prestress forces and closely controlled fabrication allow these members to carry greater loads. Therefore, they are capable of spanning greater distances and supporting heavier live loads. Bridges using members of this type and material have been widely used in the United States since World War II.

Prestressed concrete is generally more economical than conventionally reinforced concrete because the prestressing force lowers the neutral axis, putting more of the concrete section into compression. Also, the prestress steel is very high strength, so fewer pounds of steel are needed (see Figure 3.1.9).

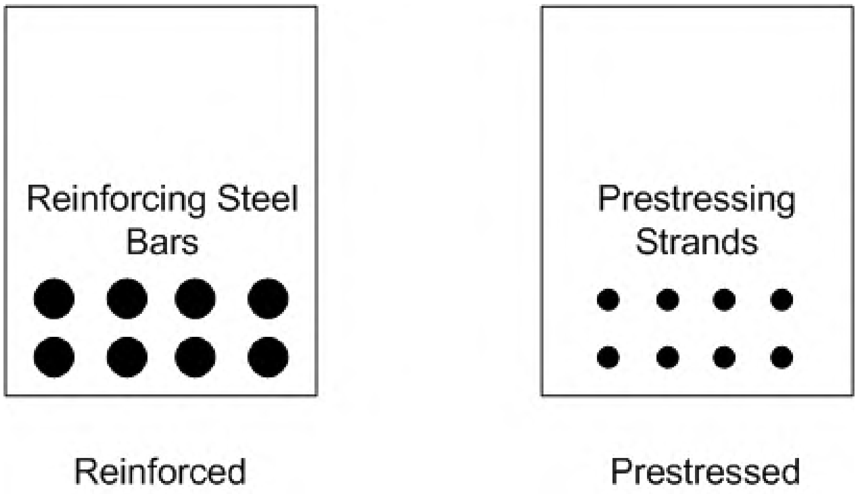


Figure 3.1.9 Non-prestressed Mild Steel Reinforced Concrete vs. Precast Prestressed Concrete

I-beams, distinguished by their "I" shape, function as superstructure members and support the deck. This type of beam can be used for spans as long as 150 feet.

Bulb-tee beams are distinguished by their "T" shapes, with a bulb-shaped section (similar to the bottom flange of an I-beam) at the bottom of the vertical leg of the tee. This type of beam can be used for spans as long as 200 feet.

Box beams, distinguished by a square or rectangular shape, usually have a beam depth greater than 17 inches. Box beams can be adjacent or spread, and they are typically used for short and medium span bridges. Adjacent box beams have practical span lengths that range 40 to 130 feet and spread box beams have practical span lengths that range up to 130 feet.

Box girders, distinguished by their trapezoidal or rectangular box shapes, function as both deck and superstructure. Box girders are used for long span or curved bridges and can be precast and erected in segments or cast in place. Spans lengths can range from 130 to 1000 feet.

Voided slabs, distinguished by their rectangular shape and their interior voids, are generally precast units supported by the substructure. The interior voids are used to reduce the dead load. Voided slabs can be used for spans up to 60 feet.

Axially-Loaded Compression Members

Concrete axially-loaded compression members are used in bridges in the form of:

- Columns
- Arches
- Piles

These members are conventionally reinforced to carry bending forces and to augment their compression load capacity.

Columns are straight members which can carry axial load, horizontal load, and bending and are used as substructure elements. Columns are commonly square, rectangular, or round.

An arch can be thought of as a curved column and is commonly used as a superstructure element. Concrete superstructure arches are generally square or rectangular in cross section.

Piles are slender columns that support the substructure footing or partially form the substructure. Piles may be partially above ground but are usually completely buried (see Figure 3.1.10). Concrete piles may be conventionally reinforced or prestressed.

Figure 3.1.10 Concrete Pile Bent

Iron Shapes

Iron was used predominately as a bridge material between 1850 and 1900. Stronger and more fire resistant than wood, iron was widely used to carry the expanding railroad system during this period.

There are two types of iron members: cast iron and wrought iron. Cast iron is formed by casting, whereas wrought iron is formed by forging or rolling the iron into the desired form.

Cast Iron

Historically, cast iron preceded wrought iron as a bridge material. The method of casting molten iron to form a desired shape was more direct than forging wrought iron.

Casting allowed iron to be formed into almost any shape. However, because of cast iron's brittleness and low tensile strength, bridge members of cast iron were best used to carry axial compression loads. Therefore, cast iron members were usually cylindrical or box-shaped to efficiently resist axial loads.

Wrought Iron

In the late 1800's, wrought iron virtually replaced the use of cast iron. The two primary reasons for this were that wrought iron was better suited to carry tensile loads and advances in rolling technology made wrought iron shapes easier to obtain and more economical to use. Advances in technology made it possible to form a variety of shapes by rolling, including:

- Rods and wire
- Bars
- Plates
- Angles
- Channels
- I-Beams

Steel Shapes

Steel bridge members began to be used in the United States in the late 1800’s and, by 1900, had virtually replaced iron as a bridge material. The replacement of iron by steel was the result of advances in steel making (see Figure 3.1.11). These advances yielded a steel material that surpassed iron in both strength and elasticity. Steel could carry heavier loads and better withstand the shock and vibration of ever-increasing live loads. Since the early 1900’s, the quality of steel has continued to improve. Stronger and more ductile A36, A572, A588, and, more recently, HPS steels have replaced early grades of steel, such as A7.

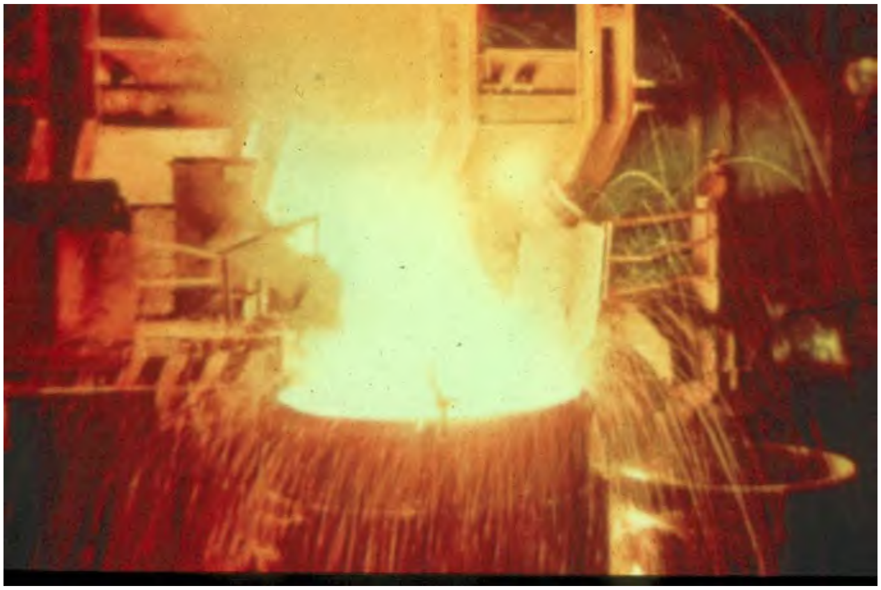


Figure 3.1.11 Steel Making Operation

Due to their strength, steel bridge members are used to carry axial forces as well as bending forces. Steel shapes are generally either rolled or built-up.

Rolled Shapes

Rolled steel shapes commonly used on bridges include (see Figure 3.1.12):

- Bars and plates
- Angles
- Channels
- S Beams (American standard "I" beams)
- W Beams (Wide flange "I" beams

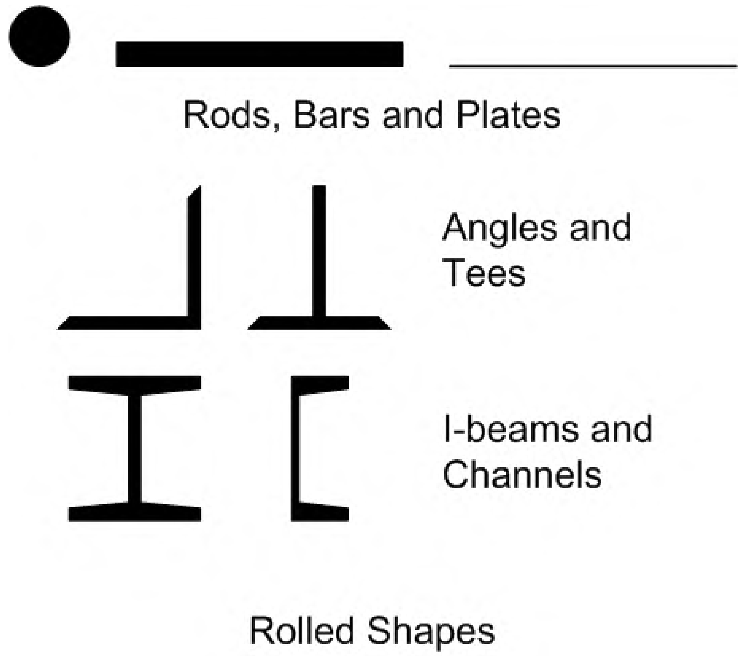


Figure 3.1.12 Common Rolled Steel Shapes

The standard weights and dimensions of these shapes can be found in the American Institute of Steel Construction (AISC) *Manual of Steel Construction*.

Bars and plates are flat pieces of steel. Bars are normally considered to be up to 8 inches in width. Common examples of bars include lacing bars on a truss and steel eyebars. Plates are designated as flat plates if they are over 8 inches in width. A common example of a plate is the gusset plate on a truss. Bars and plates are dimensioned as follows: width x thickness x length. Examples of bar and plate dimensions include:

- Lacing bar: 2" x 3/8" x 1'-3"
- Gusset plate: 21" x 1/2" x 4'-4”

Angles are “L”-shaped members, the sides of which are called “legs”. Each angle has two legs, and the width of the legs can either be equal or unequal. When dimensioning angles, the two leg widths are given first, followed by the thickness and the length. Examples of angle dimensions include:

- L 4" x 4" x ¼" x 3'-2"
- 2L’s 5" x 3" x 3/8" x 1'-1"

Angles range in size from 1"x1"x1/4" to 8"x8"x1-1/8". Angles range in weight from less than 1 pound per foot to almost 60 pounds per foot.

Angles, bars, and plates are commonly connected to form bracing members (see Figure 3.1.13).

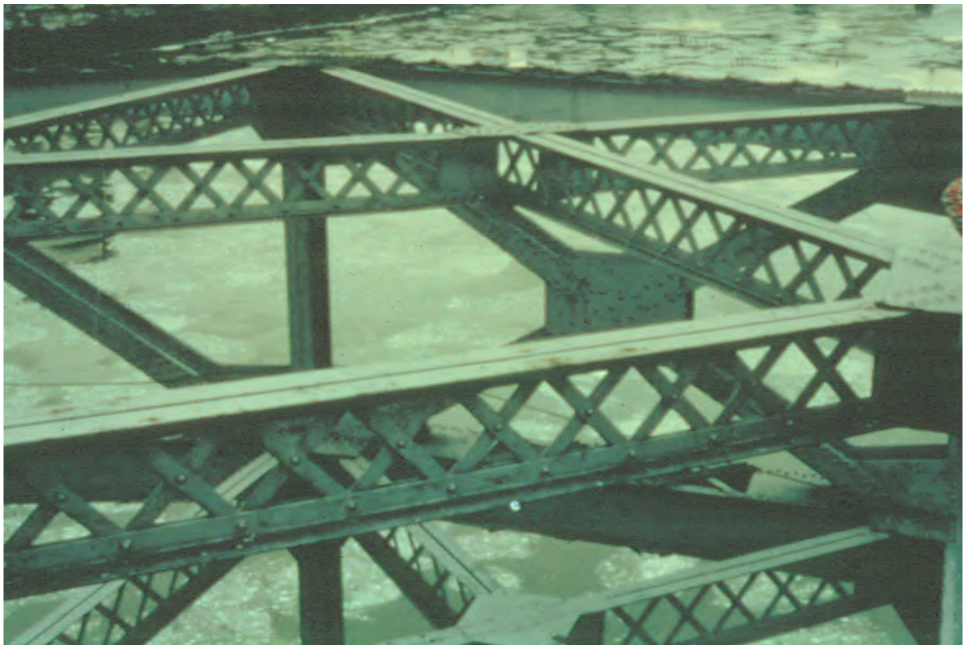


Figure 3.1.13 Bracing Members Made from Angles, Bars, and Plates

Channels are squared-off "C"-shaped members and are used as diaphragms, struts, or other bracing members. The top and bottom parts of a channel are called the flanges. Channels are dimensioned by the depth (the distance between outside edges of the flanges) in inches, the weight in pounds per foot, and the length in inches. Examples of channel dimensions include:

- C 9 x 15 x 9'-6"
- C 12 x 20.7 x 11'-2-1/2"

When measuring a channel, it is not possible for the inspector to know how much the channel section weighs. In order to identify a channel, measurements of the average thickness, flange width, the web depth, and the thickness are needed. From this information, the inspector can then determine the true channel designation through the use of reference books such as American Institute of Steel Construction (AISC) *Manual of Steel Construction*.

Standard channels range in depth from 3 inches to 15 inches, and weights range from less than 5 pounds per foot to 50 pounds per foot. Nonstandard sections (called miscellaneous channels or MC) are rolled to depths of up to 18 inches, weighing up to 60 pounds per foot.

Beams are “I”-shaped sections used as main load-carrying members. The load-carrying capacity generally increases as the member size increases. The early days of the iron and steel industry saw the various manufacturers rolling beams to their own standards. It was not until 1896 that beam weights and dimensions were standardized when the Association of American Steel Manufacturers adopted the American Standard beam. Because of this, I-beams are referred to by many designations, depending on their dimensions and the time period in which the particular shape was rolled. Today all I-beams are dimensioned according to their depth and weight per unit length.

Examples of beam dimensions include:

- S15x50 - an American Standard (hence the "S") beam with a depth of 15 inches and a weight of 50 pounds per foot
- W18x76 - a wide (W) flange beam with a depth of 18 inches and a weight of 76 pounds per foot

Some of the more common designations for rolled I-beams are:

- S = American Standard beam
- W = Wide flange beam
- WF = Wide flange beam
- CB = Carnegie beam
- M = Miscellaneous beam
- HP = H-pile

To identify an I-beam, measurements of the depth, the flange width and thickness, and the web thickness (if possible) are needed. With this information, the inspector can then determine the beam designation from reference books such as American Institute of Steel Construction (AISC) *Manual of Steel Construction*.

These beams normally range in depth from 3 to 36 inches and range in weight from 6 to over 300 pounds per foot. There are some steel mills that can roll beams up to 44 inches deep.

Built-up Shapes

Built-up shapes offer a great deal of flexibility in designing member shapes. As such, they allow the bridge engineer to customize the members for their particular need. Built-up shapes are fabricated by either riveting, bolting or welding techniques.

The practice of riveting steel shapes began in the 1800's and continued through the 1950's. Typical riveted shapes include truss members, girders and boxes.

Riveted girders are large I-beam members fabricated from plates and angles. These girders were used when the largest rolled beams were not large enough as required by design (see Figure 3.1.14).

Riveted boxes are large rectangular shapes fabricated from plates, angles, or channels. These boxes are used for cross-girders, truss chord members, and substructure members (see Figure 3.1.15).

As technology improved, riveting was replaced by high strength bolting and welding. Popular since the early 1960's, welded steel shapes include girders and boxes.

Welded girders are large I-beam members fabricated from plates. They are referred to as welded plate girders and have replaced the riveted girder (see Figure 3.1.16).

Welded boxes are large, rectangular-shaped members fabricated from plates. Welded boxes are commonly used for superstructure girders, truss members, and cross girders. Welded box shapes have replaced riveted box shapes (see Figure 3.1.17).

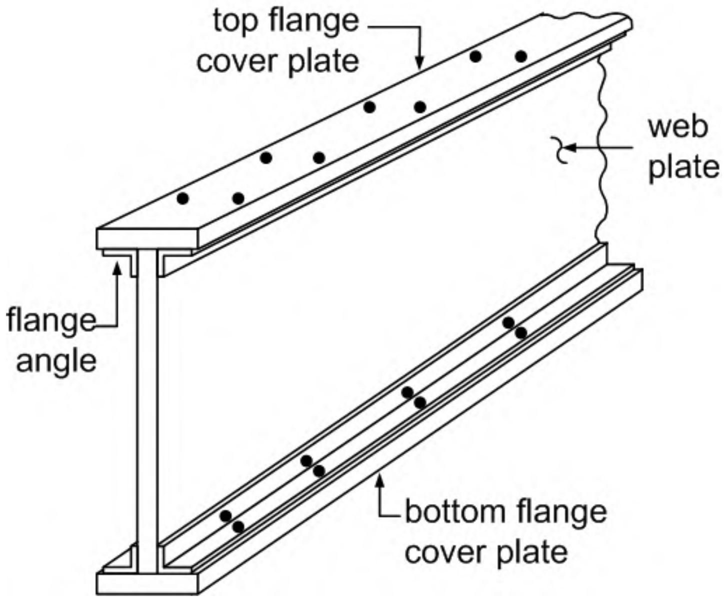


Figure 3.1.14 Riveted Plate Girder

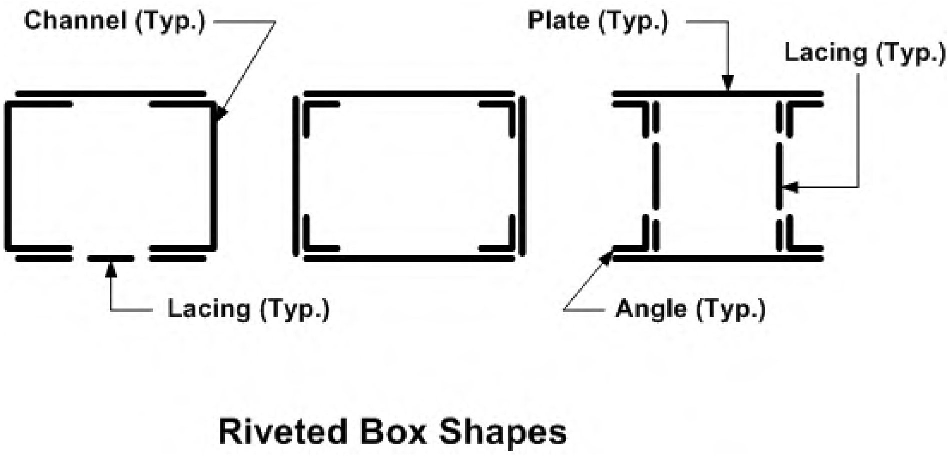


Figure 3.1.15 Riveted Box Shapes

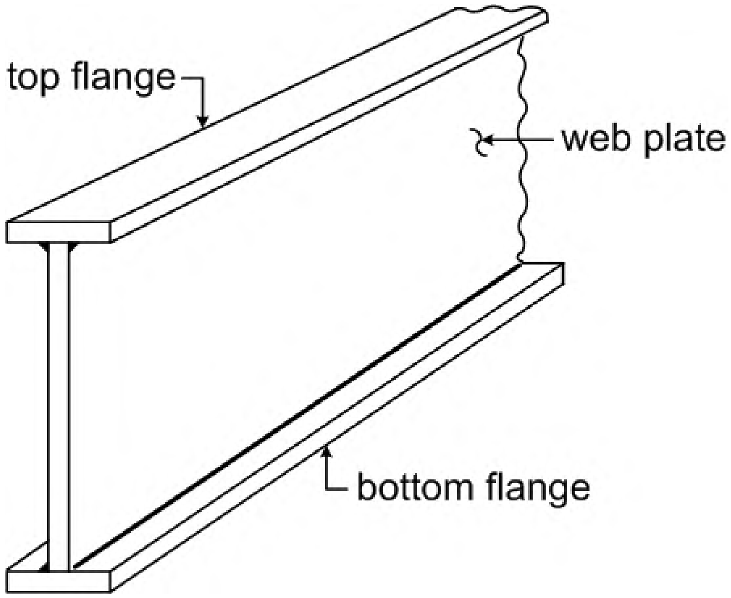


Figure 3.1.16 Welded I-Beam

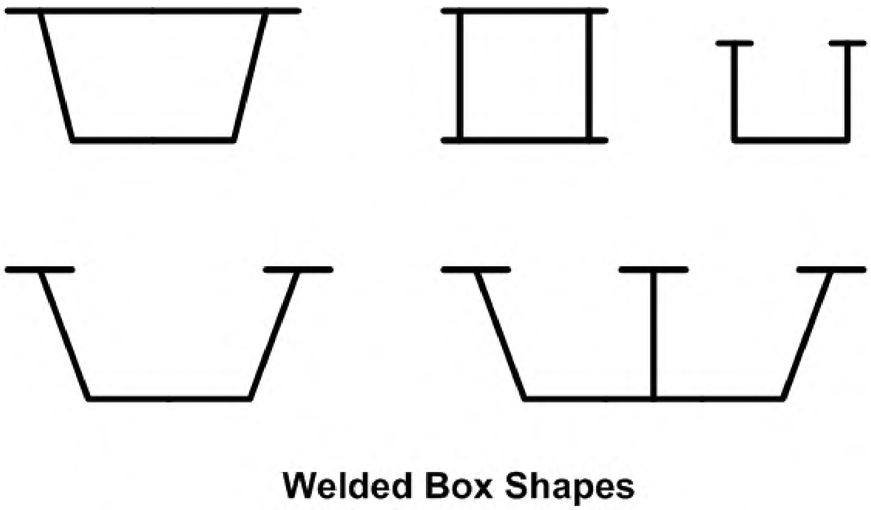


Figure 3.1.17 Welded Box Shapes

Cables

Steel cables (see Figure 3.1.18) are tension members and are used in suspension, tied-arch, and cable-stayed bridges. They are used as main cables and hangers of these bridge types (see Figure 3.1.19 and 3.1.20). Refer to Topic 16.1 for a more detailed description of cable-supported bridges.

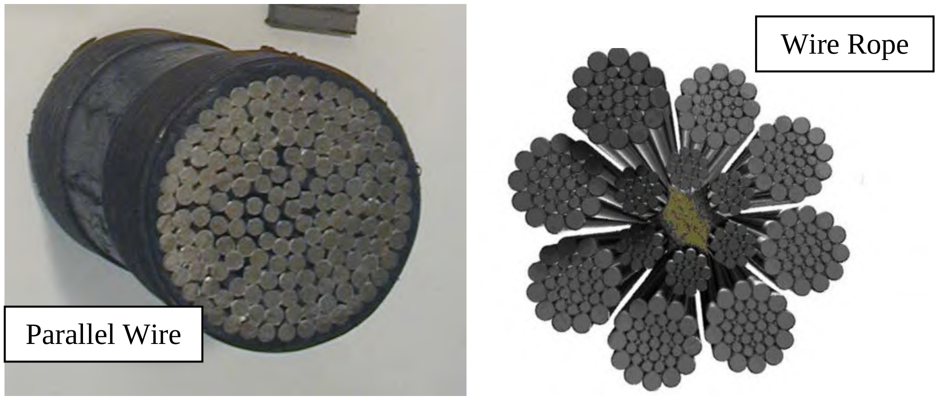


Figure 3.1.18 Cable Cross-Sections

Figure 3.1.19 Cable-Supported Bridge: Suspension Cables and Hangers

Figure 3.1.20 Cable-Supported Bridge: Cable Stayed

3.1.6 Connections

Rolled and built-up steel shapes are used to make stringers, floorbeams, girders, trusses, frames, arches and other bridge members. These members require structural joints, or connections, to transfer loads between members. There are several different types of bridge member connections:

- Pin connections
- Riveted connections
- Bolted connections
- Welded connections
- Pin and hanger assemblies
- Splice connections

Pin Connections

Pins are cylindrical bars produced by forging, casting, or cold-rolling. The pin sizes and configurations are as follows (see Figure 3.1.21):

- A small pin, 1-1/4 to 4 inches in diameter, is usually made with a cotter pin hole at one or both ends
- A medium pin, up to 10 inches in diameter, usually has threaded end projections for recessed retainer nuts
- A large pin, over 10 inches in diameter, is held in place by a recessed cap at each end and is secured by a bolt passing completely through the caps and pin

Pins are often surrounded by a protective sleeve, which may also act as a spacer to separate member elements. Pin connections are commonly used in eyebar trusses, hinged arches, pin and hanger assemblies, and bearing supports (see Figure 3.1.22).

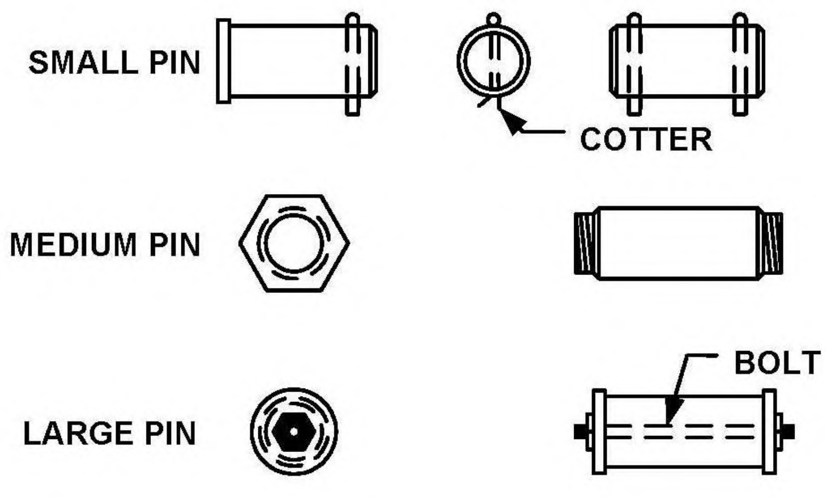


Figure 3.1.21 Sizes of Bridge Pins

Figure 3.1.22 Pin-Connected Eyebars

The major advantages of using pin connection details are the design simplicity and to facilitate rotation. The design simplicity afforded by pin connections reduces the amount and complexity of design calculations. By allowing for end rotation, pin connections reduce the level of stress in the member.

The major disadvantages of pin connection details are the result of vibration, pin wear, unequal eyebar tension, unseen corrosion, and poor inspectability. Vibrations increase with pin connections because they allow more movement than more rigid types of connections. As a result of increased vibration, moving parts are subject to wear.

Pin connections were commonly used in trusses, suspended girder spans and some bearings. These pin connections are susceptible to freezing due to corrosion. This results in changes in structural behavior and undesirable stresses when axially-loaded members must resist bending.

Some pins connect multiple eyebars. Since the eyebars may have different lengths, they may experience different levels of tension. In addition, because parts of the pin surface are hidden from view by the eyebars, links, or connected parts, an alternate method of completely inspecting the pin may be needed (e.g., ultrasonic testing or pin removal).

Riveted Connections

The rivet was the primary fastener used in the early days of iron and steel bridges. High strength bolts replaced rivets by the early 1960's.

The standard head is called a high-button or acorn-head rivet. Flat-head and countersunk-head rivets were also used in areas of limited clearance, such as a hanger connection (see Figure 3.1.23).

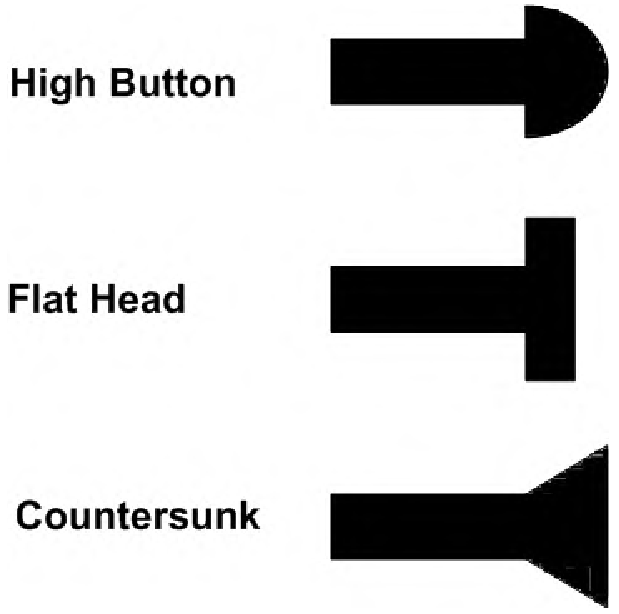


Figure 3.1.23 Types of Rivet Heads

There are two grades of rivets typically found on bridges:

- ASTM A502 Grade 1 (formerly ASTM A141) low carbon steel
- ASTM A502 Grade 2 (formerly ASTM A195) high strength steel

The rivet sizes most often used on bridges were 3/4, 7/8, or 1-inch shank diameters. Rivet holes were generally 1/16-inch larger than the rivet shank. While the hot rivet was being driven, the shank would increase slightly, filling the hole. As the rivet cooled, it would shrink in length, clamping together the connected elements.

When the inspector can feel vibration on one head of the rivet while hitting the other rivet head with a hammer, this generally indicates that the rivet is loose. This method may not work with sheared rivets clamped between several plates.

Bolted Connections

Research into the use of high strength bolts began in 1947. The first specifications for the use of such bolts were published in 1951. The economic and structural advantages of bolts over rivets led to their rapid use by bridge engineers. Bridges constructed in the late 1950's may have a combination of riveted (shop) and bolted (field) connections (see Figure 3.1.24).

Structural bolts consist of three basic material designations:

- ASTM A307 low carbon steel
- ASTM A325 (AASHTO M 164) high strength steel
- ASTM A490 (AASHTO M 253) high strength alloy steel

For further information on the bolts listed above or any other material properties visit the American Society for Testing and Materials International website at: www.astm.org .

Figure 3.1.24 Shop Rivets and Field Bolts

The most commonly used bolts on bridges are 3/4, 7/8, and 1-inch in diameter. Larger bolts are often used to anchor the bearings. Bolt holes are typically 1/16-inch larger than the bolt. However, oversized and slotted holes are also permissible if properly detailed.

Tightening high strength bolts puts them in tension, which clamps the member elements together. Although proper installation of new high strength bolts can be verified the use of a torque wrench, this method does not have any merit when inspecting high strength bolts on in-service bridges. The torque is dependent on factors such as bolt diameter, bolt length, connection design (bearing or friction), use of washers, paint and coatings, parallelism of connected parts, dirt, and corrosion. Simple methods, such as visual observation, striking with a hammer and listening or feeling for loose bolts, are the most common methods used by inspectors when inspecting bolts.

Welded Connections

Pins, rivets, and bolts are examples of mechanical fasteners. A welded connection is not mechanical but rather is a rigid one-piece construction. A properly designed and executed welded joint, in which two pieces are fused together, is as strong as the joined materials.

Similar to mechanical fasteners, welds are used to make structural connections between members and also to connect elements of a built-up member. Welds have also been used in the fabrication and erection of bridges as a way to temporarily hold pieces together prior to field riveting, bolting, or welding. Small temporary erection welds, known as tack welds, can cause serious fatigue problems to certain bridge members (see Figure 3.1.25). Fatigue and fracture of steel bridge members are discussed in detail in Topic 6.4 (refer to 6.4.3 for factors affecting fatigue crack initiation). Welding is also used as a means of sealing joints and seams from moisture.

Figure 3.1.25 Close-up of Tack Weld on a Riveted Built-up Truss Member

The first specification for using welds on bridges appeared in 1936. Welding eventually replaced rivets for fabricating built-up members. Welded plate girders, hollow box-like truss members, and shear connectors for composite decks are just a few of the advances attributed to welding technology.

Welds need to be carefully inspected for cracks or signs of cracks (e.g., broken paint or rust stains) in both the welds and the adjoining base metal elements.

Pin and Hanger Assemblies

A pin and hanger assembly is a type of hinge consisting of two pins and two hangers. Pin and hanger assemblies are used in an articulated (continuous bridge with hinges) or a suspended span configuration. The location of the assembly varies depending on the type of bridge. In I-beam bridges, a hanger is located on either side of the webs (see Figure 3.1.26). In suspended span truss bridges, each assembly has a hanger which is similar in shape to the other connecting members (with the exception of the pinned ends). Pin and hangers were used to simply design before computer programs were developed to aid design of continuous bridges.

Figure 3.1.26 Pin and Hanger Assembly

Pin and hanger assemblies must be carefully inspected for signs of wear and corrosion. A potential problem can occur if corrosion of the pin and hanger causes the assembly to "freeze," inhibiting free rotation. This condition does not allow the pin to rotate and results in additional stresses in the pin and hanger and adjacent members. The failure of a pin and hanger assembly may cause a partial or complete failure of the bridge.

Splice Connections

A splice connection is the joining of two sections of the same member, either in the fabrication shop or in the field. This type of connection can be made using rivets, bolts, or welds. Bolted splices are common in multi-beam superstructures due to the limited allowable shipping lengths (see Figure 3.1.27). Shop welded flange splices are common in large welded plate girders and long truss members.

Figure 3.1.27 Bolted Field Splice

3.1.7
Decks

The deck is that component of a bridge to which the live load is directly applied. Refer to Chapter 7 for a detailed explanation on the inspection and evaluation of decks.

Deck Purpose

The purpose of the deck is to provide a smooth and safe riding surface for the traffic utilizing the bridge (see Figure 3.1.28).

Figure 3.1.28 Bridge Deck with a Smooth Riding Surface

The function of the deck is to transfer live loads and dead loads of and on the deck to other bridge components commonly referred to as the superstructure (see Figure 3.1.29). However, on some bridges (e.g., a concrete slab bridge), the deck and the superstructure are one unit which distributes the live load directly to the substructure.

Figure 3.1.29 Underside View of a Bridge Deck

Deck Types

Decks function in one of two ways:

- Composite decks - act together with their supporting members and increase superstructure capacity (see Figures 3.1.30 and 3.1.31)
- Non-composite decks - are not integral with their supporting members and do not contribute to structural capacity of the superstructure

An inspector reviews the plans to determine if the deck is composite with the superstructure.

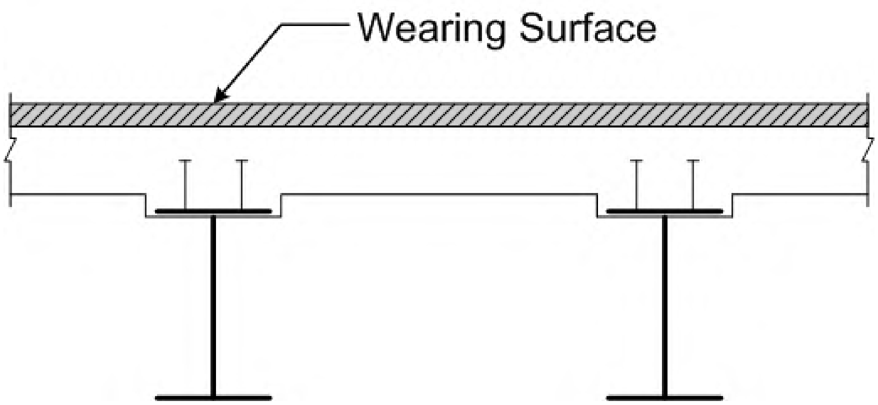


Figure 3.1.30 Composite Deck and Steel Superstructure

Figure 3.1.31 Shear Studs on Top Flange of Girder (before Concrete Deck is Placed)

Deck Materials

There are three common materials used in the construction of bridge decks:

- Timber
- Concrete
- Steel

Fiber Reinforced Polymer (FRP) has been used, but are not as common.

Timber Decks

Timber decks are often referred to as decking or timber flooring, and the term is limited to the roadway portion which receives vehicular loads. Refer to Topic 7.1 for a detailed explanation on the inspection and evaluation of timber decks.

Five basic types of timber decks are:

- Plank deck (see Figure 3.1.32)
- Nailed laminated deck
- Glued-laminated deck planks
- Stressed-laminated decks
- Structural composite lumber decks

Figure 3.1.32 Plank Deck

Concrete Decks

Concrete permits casting in various shapes and sizes and has provided the bridge designer and the bridge builder with a variety of construction methods. Because concrete is weak in tension, it is used together with reinforcement to resist tensile stresses (see Figure 3.1.33). Refer to Topic 7.2 for a detailed explanation on the inspection and evaluation of concrete decks.

There are several common types of concrete decks:

- Conventionally reinforced cast-in-place - removable or stay-in-place forms
- Precast conventionally reinforced
- Precast prestressed
- Precast prestressed deck panels with cast-in-place topping

Figure 3.1.33 Concrete Deck

Steel Decks

Steel decks are decks composed of either solid steel plate or steel grids (see Figure 3.1.34). Refer to Topic 7.4 for a detailed explanation on the inspection and evaluation of steel decks.

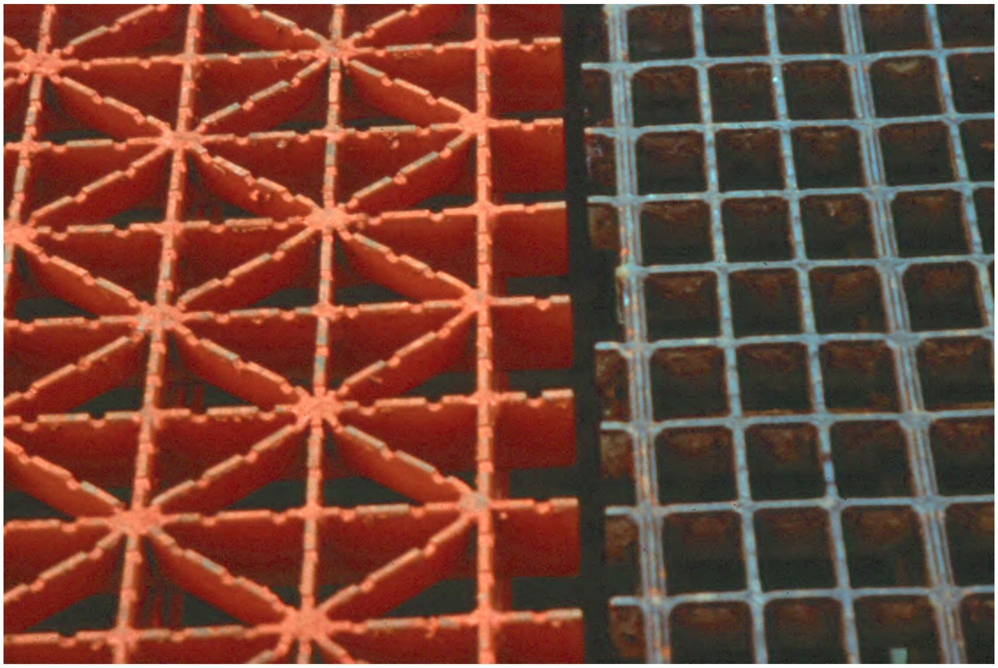


Figure 3.1.34 Steel Grid Deck

There are four common types of steel decks:

- Orthotropic deck
- Buckle plate deck (still exist on some older bridges but are no longer used)
- Corrugated steel flooring
- Grid Deck - open, filled, or partially filled

Fiber Reinforced Polymer (FRP) Decks

With the rise of technological development, innovative material such as fiber-reinforced polymer (FRP) bridge decking has begun replacing existing highway bridge decks. Though FRP material is more expensive than conventional bridge materials such as concrete, it has several advantages. These include lighter weight for efficient transport, better resistance to earthquakes, and easier installation. FRP bridge decking is also less affected by water and de-icing salts, which corrode steel and deteriorate concrete (see Figure 3.1.35). Refer to Topic 7.3 for a detailed explanation on the inspection and evaluation of FRP decks.

Figure 3.1.35 Fiber Reinforced Polymer (FRP) Deck

Wearing Surfaces

Constant exposure to the elements makes weathering a significant cause of deck deficiency. In addition, vehicular traffic produces damaging effects on the deck surface. For these reasons, a wearing surface is often applied to the surface of the deck. The wearing surface is the topmost layer of material applied to the deck to provide a smooth riding surface and to protect the deck from the effects of traffic and weathering.

A timber deck may have one of the following wearing surfaces:

- Timber planks – running boards
- Bituminous
- Concrete
- Gravel
- Polymers

Concrete decks may have wearing surfaces of:

- Concrete – latex modified concrete (LMC), low slump dense concrete (LSDC), lightweight concrete (LWC), fiber reinforced concrete (FRC), micro-silica modified concrete
- Bituminous (see Figure 3.1.36)
- Polymers - epoxy, polyester, methyl methacrylates

Figure 3.1.36 Asphalt Wearing Surface on a Concrete Deck

Steel decks may have wearing or riding surfaces of:

- Serrated steel
- Concrete
- Asphalt
- Polymers

Deck Appurtenances, Signing and Lighting

Deck Joints

The primary function of a deck joint is to accommodate the expansion, contraction, and rotation of the superstructure. The joint must also provide a smooth transition from an approach roadway to a bridge deck, or between adjoining segments of bridge deck. Refer to Topic 7.5 for detailed explanation on the inspection and evaluation of deck joints.

There are six categories of deck joints:

- Strip seal expansion joints (see Figure 3.1.37)
- Pourable joint seals
- Compression joint seals (see Figure 3.1.38)
- Assembly joints with seal (Modular)
- Open expansion joints
- Assembly joints without seals (finger plate and sliding plate joints) (see Figure 3.1.39)

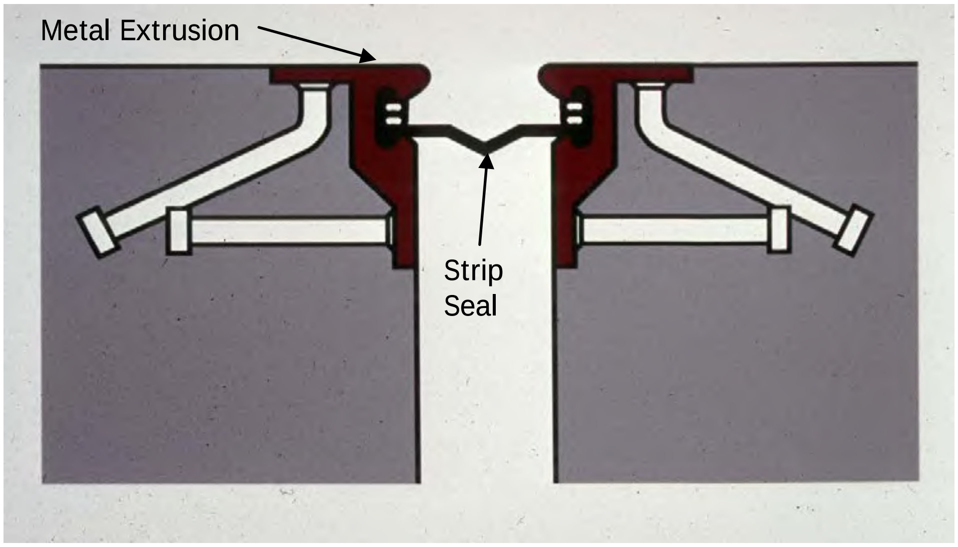


Figure 3.1.37 Strip Seal Expansion Joint

Figure 3.1.38 Top View of an Armored Compression Seal in Place

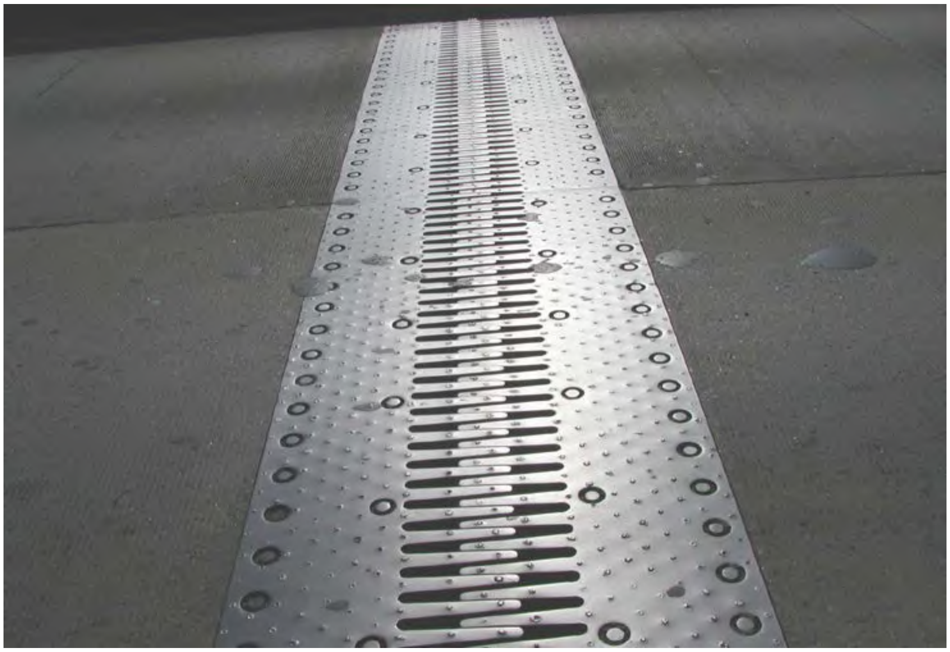


Figure 3.1.39 Top View of a Finger Plate Joint

Drainage Systems

The primary function of a drainage system is to remove water from the bridge deck, from under unsealed deck joints and from behind abutments and wingwalls. Refer to Topic 7.5 for detailed explanation on the inspection and evaluation of drainage systems.

A deck drainage system has the following components:

- Grade and cross slope
- Inlets
- Outlet pipes
- Downspout pipes - to transport runoff to storm sewers
- Cleanout plugs - for maintenance
- Drainage troughs
- Support brackets/hardware

A joint drainage system is typically a separate gutter or trough used to collect water passing through a finger plate or sliding plate joint.

Combining all these drainage components forms a complete deck drainage system.

Substructure drainage allows the fill material behind an abutment or wingwall to drain any accumulated water.

Substructure drainage is accomplished with weep holes or substructure drain pipes.

Traffic Safety Features

The proper and effective use of traffic barriers minimizes hazards for traffic on the bridge, on the highways, and waterways beneath the bridge.

Bridge barriers can be broken down into two categories:

- Bridge railing - to guide, contain, and redirect errant vehicles
- Pedestrian railing - to protect pedestrians

Examples of railing include:

- Timber plank rail
- Steel angles and bars
- Concrete pigeon hole parapet
- Combination bridge-pedestrian aluminum or steel railing
- New Jersey barrier - a very common concrete barrier (see Figure 3.1.40)

Refer to Topic 7.6 for detailed explanation on the inspection and evaluation of traffic safety features.

Figure 3.1.40 New Jersey Barrier

Sidewalks and Curbs

The function of sidewalks and curbs is to provide access to and maintain safety for pedestrians and to direct water to the drainage system. Curbs serve to lessen the chance of vehicles crossing onto the sidewalk and endangering pedestrians.

Signing

Signing serves to inform the motorist about bridge or roadway conditions that may be hazardous. Refer to Topic 7.5 for detailed explanation on the inspection and evaluation of signing.

Several signs likely to be encountered are:

- ➢ Weight limit and/or lane restrictions (see Figure 3.1.41)
- ➢ Speed traffic marker
- ➢ Vertical clearance
- ➢ Lateral clearance
- ➢ Narrow underpass
- ➢ Informational and directional
- ➢ Object markers

Figure 3.1.41 Weight Limit Sign and Object Marker Signs

Lighting

Types of lighting that may be encountered on a bridge include the following (see Figure 3.1.42):

- Highway lighting
- Traffic control lights
- Aerial obstruction lights
- Navigation lights
- Signing lights
- Illumination and drawbridge operation flashing lights

Refer to Topic 7.5 for detailed explanation on the inspection and evaluation of lighting systems.

Figure 3.1.42 Bridge Lighting

3.1.8

Superstructure

Superstructure Purpose

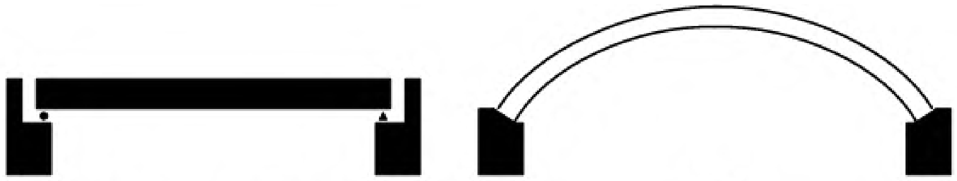
The basic purpose of the superstructure is to carry loads from the deck across the span and to the bridge supports commonly referred to as the substructure. The superstructure is that component of the bridge which supports the deck or riding surface of the bridge, as well as the loads applied to the deck.

The function of the superstructure is to span a feature and to transmit loads from the deck to the bridge supports commonly referred to as the substructure. Bridges are categorized by their superstructure type. Superstructures may be characterized with regard to their function (i.e., how they transmit loads to the substructure). Loads may be transmitted through tension, compression, bending, or a combination of these three.

Superstructure Types

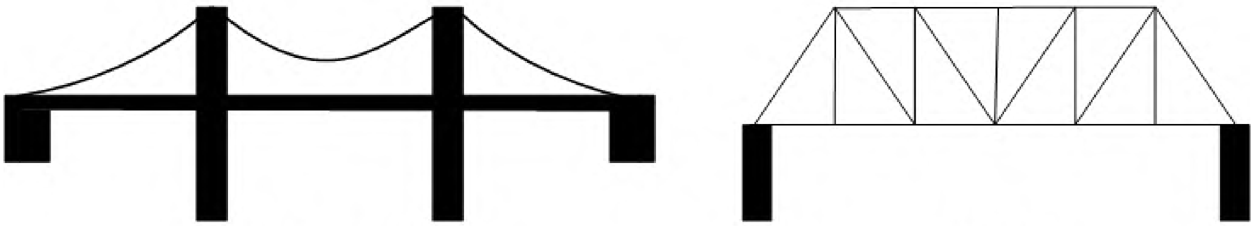
There are many different superstructure types such as:

- Slabs
- Single web beams/girders
- Box beams/girders (multi-web)
- Trusses
- Arches
- Rigid frames
- Cable-supported bridges
- Movable bridges
- Floating bridges



Slab/Beam/Girder

Arch



Cable Supported

Truss

Figure 3.1.43 Four Basic Bridge Types

Slab Bridges

In slab bridges, loads from the slab are transmitted vertically to the substructure (see Figure 3.1.44).

Figure 3.1.44 Slab Bridge

Single Web Beam/Girder Bridges

In the case of beam and girder bridges, loads from the superstructure are transmitted vertically to the substructure. Examples of beam bridges include:

- Beams (timber, concrete, or steel) (see Figures 3.1.45, 3.1.49, 3.1.50)
- Girders (concrete or steel) (see Figures 3.1.46, 3.1.47, 3.1.48, 3.1.51)

Figure 3.1.45 Beam Bridge

Figure 3.1.46 Multi-Girder Bridge

Figure 3.1.47 Girder Floorbeam Stringer Bridge

Figure 3.1.48 Curved Girder Bridge

Figure 3.1.49 Tee Beam Bridge

Figure 3.1.50 Adjacent Box Beam Bridge

Figure 3.1.51 Box Girder Bridge

Trusses

Truss members including chords, verticals, and diagonals primarily carry axial tension and compression loads. Trusses can be constructed from timber or steel (see Figures 3.1.52 and 3.1.53).

Figure 3.1.52 Deck Truss Bridge

Figure 3.1.53 Through Truss Bridge

Arches

In the case of arch bridges, the loads from the superstructure are transmitted diagonally to the substructure. True arches are in pure compression. Arch bridges can be constructed from timber, concrete, or steel (see Figures 3.1.54 and 3.1.55).

Figure 3.1.54 Deck Arch Bridge

Figure 3.1.55 Through Arch Bridge

Rigid Frames

Rigid frame superstructures are characterized by rigid (moment) connections between the horizontal girder and the legs. This connection allows the transfer of both axial forces and moments into vertical or sloping elements, which may be classified as superstructure or substructure elements depending on the exact configuration. Similar to beam/girder or slab configurations, rigid frame systems may be multiple parallel frames or may contain transverse floorbeams and longitudinal stringers to support the deck. (see Figure 3.1.56)

Figure 3.1.56 Rigid Frame

Cable-Supported Bridges

In the case of cable-supported bridges, the superstructure loads are resisted by cables which act in tension. The cable forces are then resisted by the substructure anchorages and towers. Cable-supported bridges can be either suspension or cable-stayed (see Figures 3.1.57 and 3.1.58). Refer to Topic 16.1 for a more detailed explanation on cable-supported bridges.

Figure 3.1.57 Suspension Bridge

Figure 3.1.58 Cable-stayed Bridge

Movable Bridges

Movable bridges are constructed across designated "Navigable Waters of the United States," in accordance with "Permit Drawings" approved by the U.S. Coast Guard or other agencies. The purpose of a movable bridge is to provide the appropriate channel width and underclearance for passing water vessels when fully opened. Refer to Topic 16.2 for a more detailed explanation on movable bridges.

Movable bridges can be classified into three general groups:

- Bascule (see Figure 3.1.59)
- Swing (see Figure 3.1.60)
- Lift (see Figure 3.1.61)

Figure 3.1.59 Bascule Bridge

Figure 3.1.60 Swing Bridge

Figure 3.1.61 Lift Bridge

Floating Bridges

Although uncommon, some states have bridges that are not supported by a substructure (see Figure 3.1.62). Instead, they are supported by water. The elevation of the bridge will change as the water level fluctuates.

Figure 3.1.62 Floating Bridge

Superstructure Materials

There are three common materials used in the construction of bridge superstructures:

- Timber
- Concrete
- Steel

Primary Members

Typical primary members carry primary live load from trucks and typically consist of the following:

- Girders (see Figure 3.1.63)
- Floorbeams (see Figure 3.1.63)
- Stringers (see Figure 3.1.63)
- Trusses
- Spandrel girders (see Figure (3.1.64)
- Spandrel columns (see Figure (3.1.64) or bents
- Arch ribs
- Rib chord bracing
- Hangers
- Frame girder
- Frame leg
- Frame knee
- Pin and hanger links

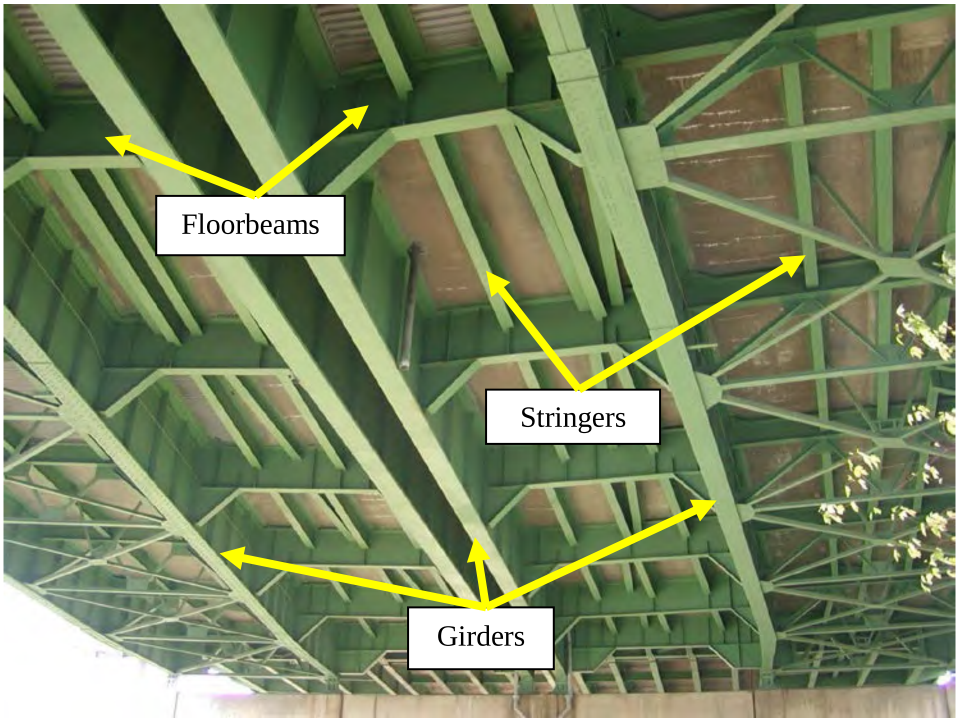


Figure 3.1.63 Floor System and Main Supporting Members

Additionally, diaphragms for curved girders may also be considered primary members. Vehicular live load is transmitted between the mains supporting members through the diaphragms in a curved multi-girder arrangement.

Figure 3.1.64 Main Supporting Members of Deck Arch

Secondary Members

Secondary members do not normally carry traffic loads directly. Typical secondary elements are:

- Diaphragms (see Figure 3.1.65)
- Cross or X-bracing (see Figure 3.1.66)
- Lateral bracing (see Figure 3.1.67)
- Sway-portal bracing (see Figure 3.1.67)
- Pin and hanger assemblies - Through bolts**,** pin caps, nuts, cotter pins on small assemblies, spacer washers, doubler plates

Figure 3.1.65 Diaphragms

Figure 3.1.66 Cross or X-Bracing

Figure 3.1.67 Top Lateral Bracing and Sway Bracing

3.1.9

Bearings

Bearing Purpose

A bridge bearing is an element which provides an interface between the superstructure and the bridge supports referred to as the substructure.

There are three primary functions of a bridge bearing:

- Transmit all loads from the superstructure to the substructure
- Permit longitudinal movement of the superstructure due to thermal expansion and contraction
- Allow rotation caused by dead and live load deflection

Bearings that do not allow for horizontal movement of the superstructure are referred to as fixed bearings. Bearings that allow for horizontal movement of the superstructure are known as expansion bearings. Both fixed and expansion bearings permit rotation. Refer to Topic 11.1 for more detailed explanation on expansion/fixed bearings.

Bearing Types

There are six bearing types that are utilized to accommodate superstructure movement and rotation:

- Elastomeric bearings
- Moveable bearings (roller, sliding, etc.)
- Enclosed/concealed bearings
- Fixed bearings
- Pot bearings
- Disk bearing

Refer to Topic 11.1 for detailed explanations on bridge bearing types.

Bearing Materials

There are two common materials used in the construction of bridge bearings:

- Steel
- Neoprene

Bearing Elements

A bridge bearing can be normally categorized into four basic elements (see Figure 3.1.68):

- Sole plate
- Bearing device
- Masonry plate
- Anchor bolts

Refer to Topic 11.1 for detailed explanations of these four bearing elements.

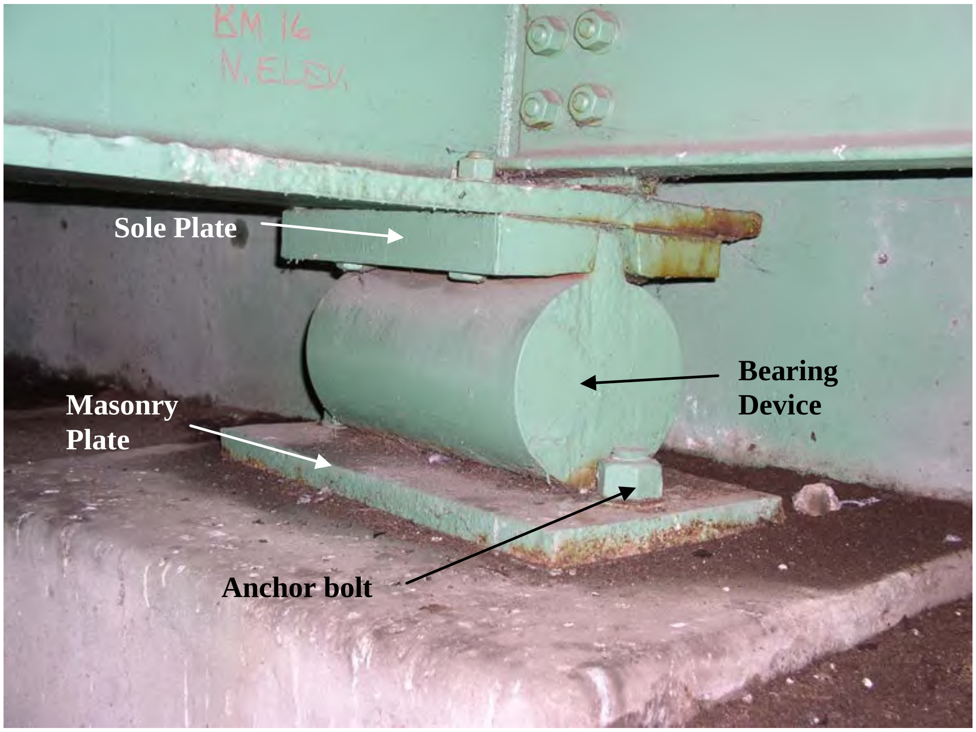


Figure 3.1.68 Steel Roller Bearing Showing Four Basic Elements

3.1.10 Substructure

The substructure is the component of a bridge which includes all the elements which support the superstructure.

Substructure Purposes

The purpose of the substructure is to transfer the loads from the superstructure to the foundation soil or rock. Typically the substructure includes all elements below the bearings. The loads are then distributed to the earth.

Substructure units function as both axially-loaded and bending members. These units resist both vertical and horizontal loads applied from the superstructure and roadway embankment. Substructures are divided into two basic categories:

- Abutments
- Piers and bents

Abutments provide support for the ends of the superstructure and retain the roadway approach embankment (see Figure 3.1.69). Piers and bents provide support for the superstructure at intermediate points along the bridge spans (see Figure 3.1.70).

Figure 3.1.69 Abutment

Figure 3.1.70 Pier

Substructure Types

Abutments

Basic types of abutments include:

- Cantilever or full height abutment - extends from the grade line of the roadway or waterway below, to that of the road overhead (see Figure 3.1.71).
- Stub, semi-stub, or shelf abutment - located within the topmost portion of the end of an embankment or slope. In the case of a stub, less of the

abutment stem is visible than in the case of the full height abutment. Most new construction uses this type of abutment. These abutments may be supported on deep foundations (see Figure 3.1.72).

- Spill-through or open abutment - consists of columns and has no solid wall, but rather is open to the embankment material. The approach embankment material is usually rock (see Figure 3.1.73).
- Integral abutment – superstructure and substructure are integral and act as one unit without an expansion joint or bearings. Relative movement of the abutment with respect to the backfill allows the structure to adjust to thermal expansions and contractions. Pavement relief joints at the ends of approach slabs are provided to accommodate the thermal movement between bridge deck and the approach roadway pavement (see Figure 3.1.74)

Figure 3.1.71 Cantilever Abutment (or Full Height Abutment)

Figure 3.1.72 Stub Abutment

Figure 3.1.73 Spill-Through or Open Abutment

Figure 3.1.74 Integral Abutment

Refer to Topic 12.1 for a more detailed explanation on bridge abutments.

Piers and Bents

A pier has only one footing at each substructure unit (the footing may serve as a pile cap). A bent has several footings or no footing, as is the case with a pile bent. Refer to Topic 12.2 for a more detailed explanation on bridge piers and bents.

There are four basic types of piers:

- Solid shaft pier (see Figures 3.1.75 and 3.1.76)
- Column pier (see Figure 3.1.77)
- Column pier with web wall (see Figure 3.1.78)
- Cantilever or hammerhead pier (see Figure 3.1.79)

Figure 3.1.75 Solid Shaft Pier

Figure 3.1.76 Solid Shaft Pier

Figure 3.1.77 Column Pier

Figure 3.1.78 Column Pier with Web Wall and Cantilevered Pier Caps

Figure 3.1.79 Cantilever or Hammerhead Pier

There are two basic types of bents:

- Column bent (see Figure 3.1.80)
- Pile bent (see Figure 3.1.81)

Figure 3.1.80 Column Bent

Figure 3.1.81 Pile Bent

Substructure Materials

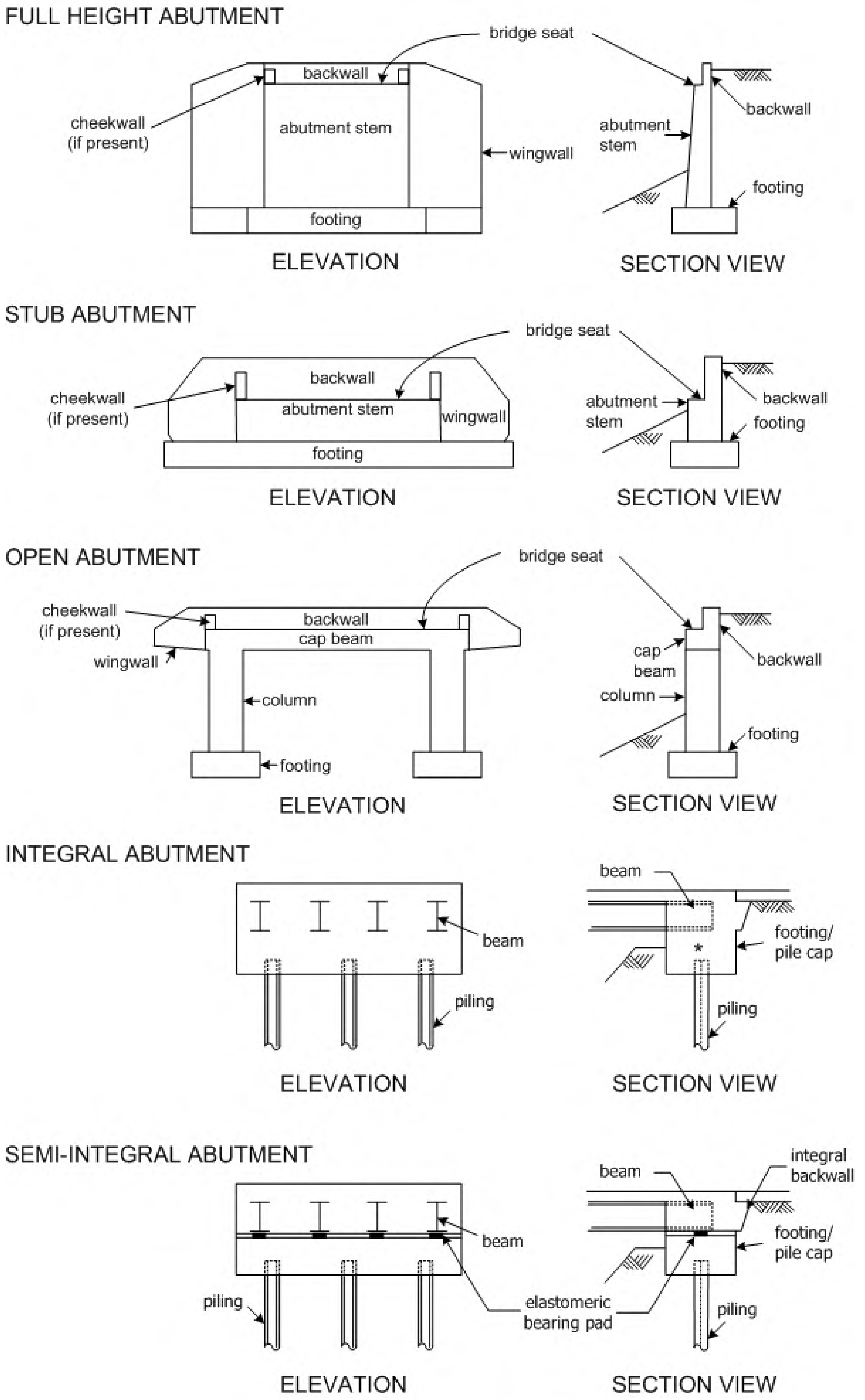
There are four common materials used in the construction of bridge substructures:

- Timber
- Concrete
- Steel
- Masonry

Substructure Elements

A bridge substructure can consist of several different elements (see Figure 3.1.82). Typical elements can include:

- Abutments
    - Backwall
    - Stem/bridge seat
    - Footing
    - Integral backwall



* Some states weld beam and piles prior to concrete placement

Figure 3.1.82 Schematic of Common Abutment Types

- Pier/Bents
  - Pier caps
  - Columns/Piles
  - Walls
  - Footing

Refer to Topics 12.1 and 12.2 for a detailed explanation of abutment, pier and bent elements.

3.1.11
Culverts

Culverts are often viewed as small bridges, being constructed entirely below and independent of the roadway surface. However, culverts do not have a deck, superstructure, or substructure. Culverts that are 20 feet or greater are defined as a bridge, according the NBIS definition for bridge length (see Topic 3.1.3).

Culvert Purpose

A culvert is primarily a hydraulic structure, and its main purpose is to transport water flow efficiently.

Culvert Materials

There are several common materials used in the construction of culverts:

- Concrete
- Masonry
- Steel
- Aluminum
- Timber
- Plastic

Refer to Topic 14.1 for a detailed explanation about culvert characteristics.

Culvert Types

Rigid Culverts

Rigid culverts can carry the load the same way a frame or an arch does by resisting the loads in bending and shear or frame an arch action (see Figure 3.1.83). Refer to Topic 14.2 for a detailed explanation of rigid culverts.

Figure 3.1.83 Rigid Culvert

Flexible Culverts

Flexible culverts will require lateral earth pressure to help maintain their shape. The loads are distributed through the flexible culvert and backfill. The backfill is critical to a flexible culverts performance (see Figure 3.1.84). Refer to Topic 14.3 for a detailed explanation of flexible culverts.

Figure 3.1.84 Flexible Culvert

Table of Contents

Chapter 5
Bridge Mechanics

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Basic Equations of Bridge Mechanics

$$f_a = \frac{P}{A}$$ (Page 5.1.11)

$$f_b = \frac{Mc}{I}$$ (Page 5.1.13)

$$f_v = \frac{V}{A_w}$$ (Page 5.1.14)

$$\sigma = \frac{F}{A}$$ (Page 5.1.16)

$$\varepsilon = \frac{\Delta L}{L}$$ (Page 5.1.17)

$$E = \frac{\sigma}{\varepsilon}$$ (Page 5.1.18)

where:
A = area; cross-sectional area
A_w = area of web
c = distance from neutral axis to extreme fiber (or surface) of beam
E = modulus of elasticity
F = force; axial force
f_a = axial stress
f_b = bending stress
f_v = shear stress
I = moment of inertia
L = original length
M = applied moment
S = stress
V = vertical shear force due to external loads
ΔL = change in length
ε = strain

Common units:
p = pounds
in = inches
ft = feet = 12 inches
k = kip = 1000 pounds
psi = pounds per square inch
ksi = kips per square inch

$$Bridge\ Rating\ Factor\,(RF) = \frac{C - A_1 D}{A_2 L(1 + I)}$$ (Page 5.1.23)

$$Bridge\ Rating\ Factor\,(RF) = \frac{C - (\gamma_{DC})(DC) - (\gamma_{DW})(DW) \pm (\gamma_P)(P)}{(\gamma_L)(LL + IM)}$$ (Page 5.1.23)

Chapter 5
Bridge Mechanics

Topic 5.1 Bridge Mechanics

5.1.1
Introduction

Mechanics is the branch of physical science that deals with energy and forces and their relation to the equilibrium, deformation, or motion of bodies. The bridge inspector is primarily concerned with statics, or the branch of mechanics dealing with solid bodies at rest and with forces in equilibrium.

The two most important reasons for a bridge inspector to study bridge mechanics are:

- To understand how bridge members function
- To recognize the impact a defect or deterioration may have on the load-carrying capacity of a bridge component or element

While this topic presents the basic principles of bridge mechanics, the references listed in the bibliography should be referred to for a more complete presentation of this subject.

5.1.2
Bridge Design Loadings

A bridge is designed to carry or resist design loadings in a safe and economical manner. Loads may be concentrated or distributed depending on the way in which they are applied to the structure.

A concentrated load, or point load, is applied at a single location or over a very small area. Vehicle truck loads are normally considered concentrated loads.

A distributed load is applied to all or part of the member, and the amount of load per unit of length is generally constant. The weight of superstructures, bridge decks, wearing surfaces, and bridge parapets produce distributed loads. Secondary loads, such as wind, stream flow, earth cover and ice, are also usually distributed loads.

Highway bridge design loads are established by the American Association of State Highway and Transportation Officials (AASHTO). For many decades, the primary bridge design code in the United States was the AASHTO *Standard Specifications for Highway Bridges* (*Specifications*), as supplemented by agency criteria as applicable.

During the 1990’s AASHTO developed and approved a new bridge design code, entitled *AASHTO LRFD Bridge Design Specifications*. It is based upon the principles of Load and Resistance Factor Design (LRFD), as described in Topic 5.1.7.

Bridge design loadings can be divided into two principal categories:

- Permanent loads
- Transient loads

Permanent Loads

Permanent loads are loads and forces that are constant for the life of the structure. They consist of the weight of the materials used to build the bridge (see Figure 5.1.1). Permanent load includes both the self-weight of structural members and other permanent external loads. They do not move and do not change unless the bridge is modified. Permanent loads can be broken down into two groups, dead loads and earth loads.

Dead loads are a static load due to the weight of the structure itself. They include both the self-weight of the structural members and other permanent loads. Any feature may or may not contribute to the strength of the structure. Those features that may contribute to the strength of the structure include girders, floorbeams, trusses, and decks. Features that may not contribute to the strength of the bridge include median barriers, parapets, railings and utilities. Earth loads are permanent loads and are considered in the design of structures such as retaining walls and abutments. Earth pressure is a horizontal load which can be very large and it tends to cause abutments to slide and/or tilt forward. Earth surcharge is a vertical load that can increase the amount of horizontal load and is caused by the weight of the earth.

Example of self-weight: A 20-foot long beam weighs 50 pounds per linear foot. The total weight of the beam is 1000 pounds. This weight is called the self-weight of the beam.

Example of an external permanent load: If a utility such as a water line is permanently attached to the beam in the previous example, then the weight of the water line is an external permanent load. The weight of the water line plus the self weight of the beam comprises the total permanent load.

Total permanent load on a structure may change during the life of the bridge due to additions such as deck overlays, parapets, utility lines, and inspection catwalks.

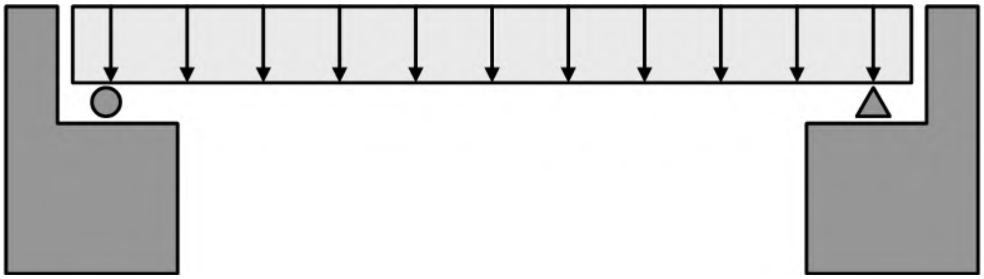


Figure 5.1.1 Permanent Load on a Bridge

Primary Transient Loads

A transient load is a temporary load and force that is applied to a structure which changes over time. In bridge applications, transient live loads are moving vehicular or pedestrian loads (see Figure 5.1.2). Standard AASHTO vehicle live loads do not represent actual vehicles, but it does provide a good approximation for bridge design and rating. AASHTO has designated standard pedestrian loads for design of sidewalks and other pedestrian structures.

To account for the affects of speed, vibration, and momentum, truck live loads are typically increased for vehicular dynamic load allowance. Vehicular dynamic load allowance is expressed as a percentage of the static truck live load effects.

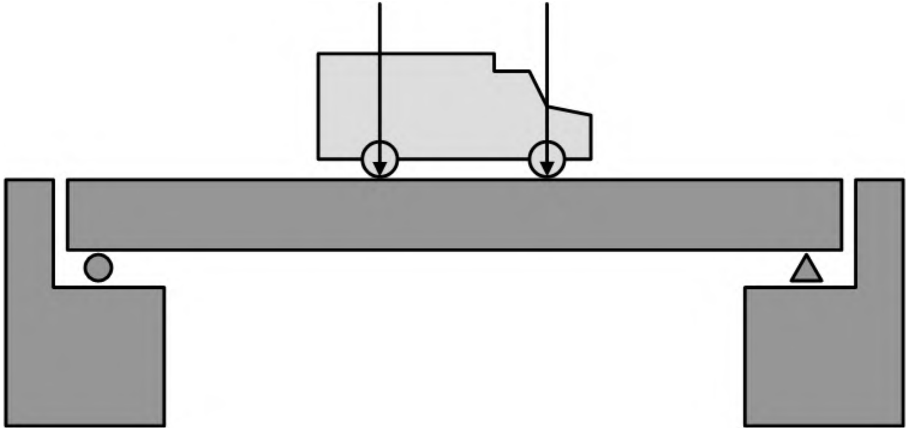


Figure 5.1.2 Vehicle Transient Load on a Bridge

AASHTO Truck Loadings

Standard vehicle live loads have been established by AASHTO for use in bridge design and rating. There are two basic types of standard truck loadings described in the current *AASHTO Specifications*. A third type of loading is used for AASHTO Load and Resistance Factor Design and Rating.

The first type is a single unit vehicle with two axles spaced at 14 feet and designated as a highway truck or “H” truck (see Figure 5.1.3). The weight of the front axle is 20% of the gross vehicle weight, while the weight of the rear axle is 80% of the gross vehicle weight. The “H” designation is followed by the gross tonnage of the particular design vehicle. The AASHTO LRFD design vehicular live load, designated HL-93, is a modified version of the HS-20 highway loadings from the *AASHTO Standard Specifications*.

Example of an H truck loading: H20-35 indicates a 20 ton vehicle with a front axle weighing 4 tons, a rear axle weighing 16 tons, and the two axles spaced 14 feet apart. This standard truck loading was first published in 1935. The 1935 truck loading used a train of trucks that imitated the railroad industry’s standards.

As trucks grew heavier during World War II, AASHTO developed the new concept of hypothetical trucks. These fictitious trucks are used only for design and do not resemble any real truck on the road. The loading is now performed by placing one truck, per lane, per span. The truck is moved along the span to determine the point where it produces the maximum shear and moment. The current designation is H20-44 published in 1944.

The second type of standard truck loading is a two unit, three axle vehicle comprised of a highway tractor with a semi-trailer. It is designated as a highway semi-trailer truck or “HS” truck (see Figure 5.1.4).

The tractor weight and wheel spacing is identical to the H truck loading. The semi-trailer axle weight is equal to the weight of the rear tractor axle, and its spacing from the rear tractor axle can vary from 14 to 30 feet. The “HS” designation is followed by a number indicating the gross weight in tons of the tractor only.

Figure 5.1.3 AASHTO H20 Truck

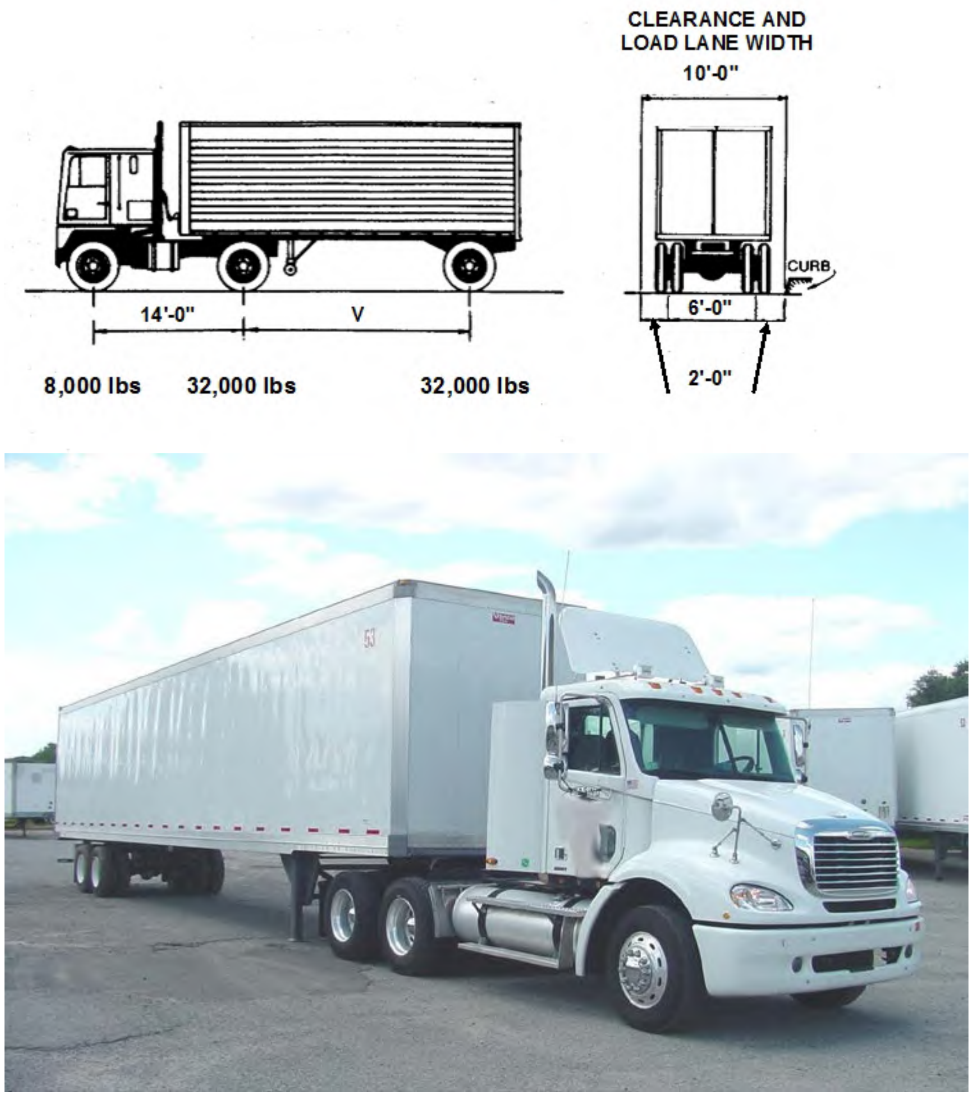


Figure 5.1.4 AASHTO HS20 Truck

Example of an HS truck loading: HS20-44 indicates a vehicle with a front tractor axle weighing 4 tons, a rear tractor axle weighing 16 tons, and a semi-trailer axle weighing 16 tons. The tractor portion alone weighs 20 tons, but the gross vehicle weight is 36 tons. This standard truck loading was first published in 1944.

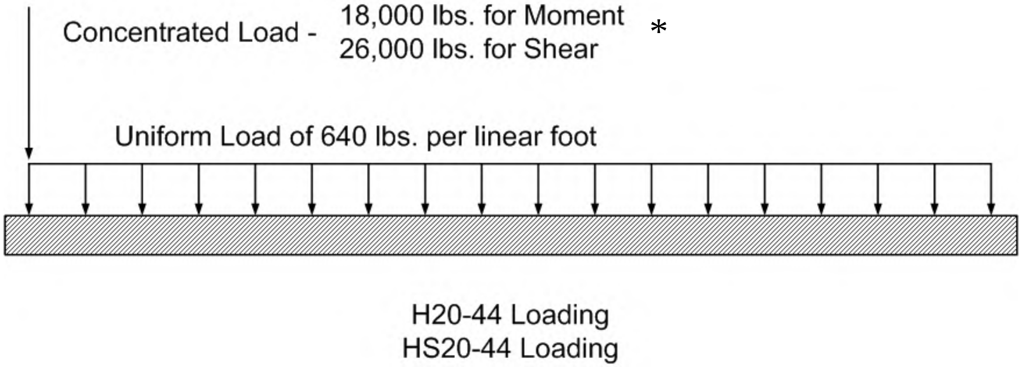
In specifications prior to 1944, a standard loading of H15 was used. In 1944, the policy of affixing the publication year of design loadings was adopted. In specifications prior to 1965, the HS20-44 loading was designated as H20-S16-44, with the S16 identifying the gross axle weight of the semi-trailer in tons.

The H and HS vehicles do not represent actual vehicles, but can be considered as "umbrella" loads. The wheel spacings, weight distributions, and clearance of the Standard Design Vehicles were developed to give a simpler method of analysis, based on a good approximation of actual live loads. These loads are used for the design of bridge members. Depending on such items as highway classification, truck usage and span classification, for example, an appropriate design load is chosen to determine the most economical member. Bridge posting is determined by performing a load rating analysis using the current member condition of an in-service bridge. Various rating methods will be discussed further in Topic 5.1.8.

AASHTO Lane Loadings

In addition to the standard truck loadings, a system of equivalent lane loadings was developed in order to provide a simple method of calculating bridge response to a series, or "train" of trucks. Lane loading consists of a uniform load per linear foot of traffic lane combined with a concentrated truck load located on the span to produce the most critical situation in the structure (see Figure 5.1.5).

For design and load capacity rating analysis, make an investigation of both a truck loading and a lane loading to determine which produces the greatest stress for each particular member. Lane loading will generally govern over truck loading for longer spans. Both the H and HS loadings have corresponding lane loads.



* Use two concentrated loads for negative moment in continuous spans (Refer to *AASHTO LRFD Bridge Design Specifications 5th edition*, 2010 Interim; Article 3.6.1.2)

Figure 5.1.5 AASHTO Lane Loadings

LRFD Live Loads

Under HS-20 loading as described earlier, the truck or lane load is applied to each loaded lane. Under HL-93 loading, the design truck or tandem is combined with the lane load and applied to each loaded lane.

The LRFD design truck is exactly the same as the AASHTO HS-20 design truck. The LRFD design tandem, on the other hand, consists of a pair of 25 kip axles spaced 4 feet apart. The transverse wheel spacing of all of the trucks is 6 feet.

The magnitude of the HL-93 lane load is equal to that of the HS-20 lane load. The lane load is 0.64 kips per linear foot longitudinally and it is distributed uniformly over a 10 foot width in the transverse direction. The difference between the HL-93 lane load and the HS-20 lane load is that the HL-93 lane load does not include a point load. The HL-93 design load consists of a combination of the design truck or design tandem, and design lane load (see Figure 5.1.6).

Finally, for LRFD live loading, the dynamic load allowance, or impact, is applied to the design truck or tandem but is not applied to the design lane load. It is typically 33 percent of the design vehicle.

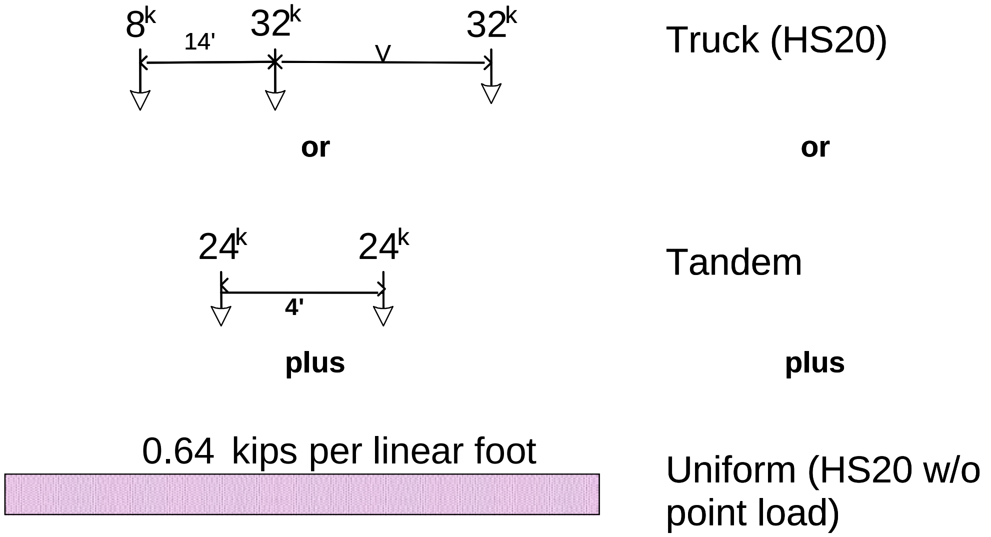


Figure 5.1.6 AASHTO LRFD Loading

Alternate Military Loading

The Alternate Military Loading is a single unit vehicle with two axles spaced at 4 feet and weighing 12 tons (or 24 kips) each. It has been part of the AASHTO *Specifications* since 1977. Bridges on interstate highways or other highways which are potential defense routes are designed for whichever produces the greatest stress (see Figure 5.1.7).

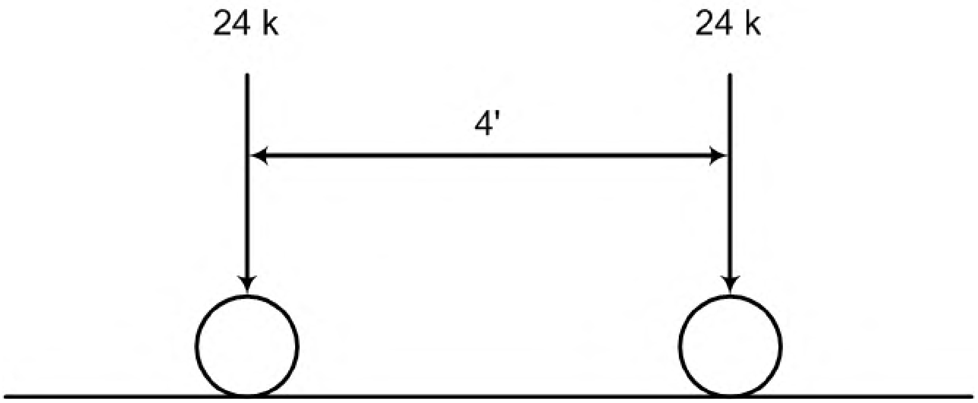


Figure 5.1.7 Alternate Military Loading

Permit Vehicles

Permit vehicles are overweight vehicles which, in order to travel a state's highways, must apply for a permit from that state. They are usually heavy trucks (e.g., combination trucks, construction vehicles, or cranes) that have varying axle weights and spacings depending upon the design of the individual truck. To ensure that these vehicles can safely operate on existing highways and bridges, most states require that bridges be designed for a permit vehicle or that the bridge be checked to determine if it can carry a specific type of vehicle. For safe and legal operation, agencies issue permits upon request that identify the required gross weight, number of axles, axle spacing, and maximum axle weights for a designated route (see Figure 5.1.8).

Figure 5.1.8 Permit Vehicle

Secondary Transient Loads

In bridge applications, the transient loads are temporary dynamic loads and can consist of the following:

- **Vehicular braking force** - a force in the direction of the bridge caused by braking of live load vehicles
- **Vehicular centrifugal force -** an outward force that a live load vehicle exerts on a curved bridge
- **Vehicular collision force** – the force caused by the collision of a vehicle into either the superstructure or substructure of a bridge
- **Vessel collision force** – the force caused by the collision of a water vessel into either the superstructure or substructure of a bridge
- **Earthquake load -** bridge structures are built so that motion during an earthquake will not cause a collapse
- **Friction load** – a force that is due to friction based upon the friction coefficient between the sliding surfaces
- **Ice load** - a horizontal force created by static or floating ice jammed against bridge components
- **Vehicular dynamic load allowance** – loads that account for vibrations and resonance between bridge, live load, and vibrations due to surface discontinuities (i.e. deck joints, potholes, cracks)
- **Vehicular live load** – AASHTO standard live loads placed upon the bridge due to vehicles
- **Live load surcharge** – a load where vehicular live load is expected on the surface of backfill within a distance to one-half the wall height behind the back face of the wall
- **Pedestrian live load** – AASHTO standard live load placed upon a bridge due to pedestrians which include sidewalks and other structures
- **Forces effect due to settlement -** a horizontal force acting on earth-retaining substructure units, such as abutments and retaining walls
- **Temperature -** since materials expand as temperature increases and contract as temperature decreases, the force caused by these dimensional changes must be considered
- **Water load** - a horizontal force acting on bridge components constructed in flowing water
- **Wind load on live load** - wind effects transferred through the live load vehicles crossing the bridge
- **Wind load on structure -** wind pressure on the exposed area of a bridge

A bridge may be subjected to several of these loads simultaneously. AASHTO LRFD *Specifications* have established a table of Load Combination Limit States. For each Limit State, a set of load combinations are considered with a load factor to be applied to each particular load.

5.1.3

Bridge Response to Loadings

Each member of a bridge is intended to respond to loads in a particular way. It is important to understand the manner in which loads are applied to each member in order to evaluate if it functions as intended. Once the inspector understands a bridge member's response to loadings, the inspector will be able to determine if a member defect has an adverse effect on the load-carrying capacity of that member.

Bridge members respond to various loadings by resisting four basic types of forces. These are:

- Axial forces (compression and tension)
- Bending forces (flexure)
- Shear forces
- Torsional forces

Equilibrium

In calculating these forces, the analysis is governed by equations of equilibrium. Equilibrium equations represent a balanced force system and may be expressed as:

$$\sum V = 0$$
$$\sum H = 0$$
$$\sum M = 0$$

where:
$\sum$ = summation of
V = vertical forces
H = horizontal forces
M = moments (bending forces)

Axial Forces

An axial force is a push or pull type of force which acts parallel to the longitudinal axis of a member. An axial force causes compression if it is pushing and tension if it is pulling (see Figure 5.1.9). Axial forces are generally expressed in English units of pounds or kips.

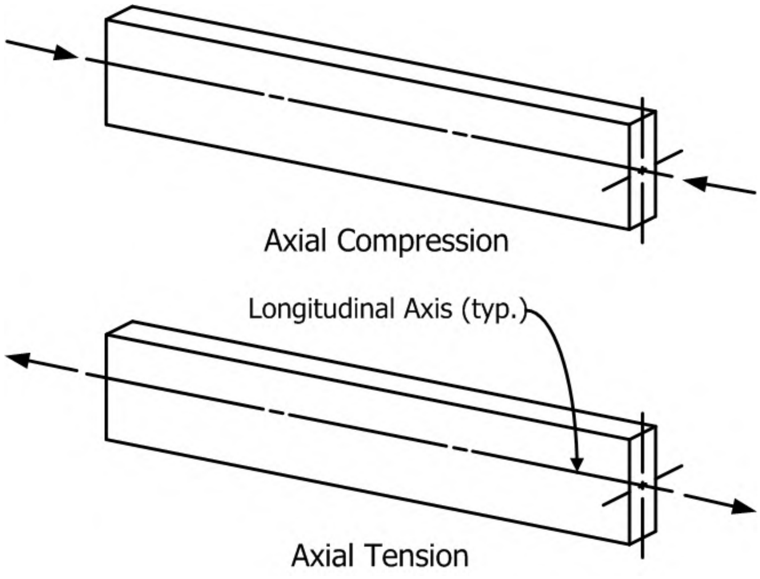


Figure 5.1.9 Axial Forces

Examples of axial forces: A man sitting on top of a fence post is exerting an axial force that causes compression in the fence post. A group of people playing tug-of-war exerts an axial force that causes tension in the rope.

Truss members are common bridge elements which carry axial loads. They are designed for either compression or tension forces.. Cables are designed for axial forces in tension.

True axial forces act uniformly over a cross-sectional area. Therefore, axial stress can be calculated by dividing the force by the area on which it acts.

$$f_a = \frac{P}{A}$$

where: f_a = axial stress (kips per square inch)
P = axial force (kips)
A = cross-sectional area (square inches)

When bridge members are designed to resist axial forces, the cross-sectional area will vary depending on the magnitude of the force, whether the force is tensile or compressive, and the type of material used.

For tension and compression members, the cross-sectional area has to satisfy the previous equation for an acceptable axial stress. However, the acceptable axial compressive stress is generally lower than that for tension because of a phenomenon called buckling.

Bending Forces

Bending forces in bridge members are caused when a load is applied perpendicular to the longitudinal or neutral axis. A moment is commonly developed by the perpendicular loading which causes a member to bend. The greatest bending moment that a beam can resist is generally the governing factor which determines the size and material of the member. Bending moments can be positive or negative and produce both compression and tension forces at different locations in the member (see Figure 5.1.10). Moments are generally expressed in English units of pound-feet or kip-feet.

Example of bending moment: When a rectangular rubber eraser is bent, a moment is produced in the eraser. If the ends are bent upwards, the top half of the eraser can be seen to shorten, while the bottom half can be seen to lengthen. Therefore, the moment produces compression forces in the top layers of the eraser and tension forces in the bottom layers.

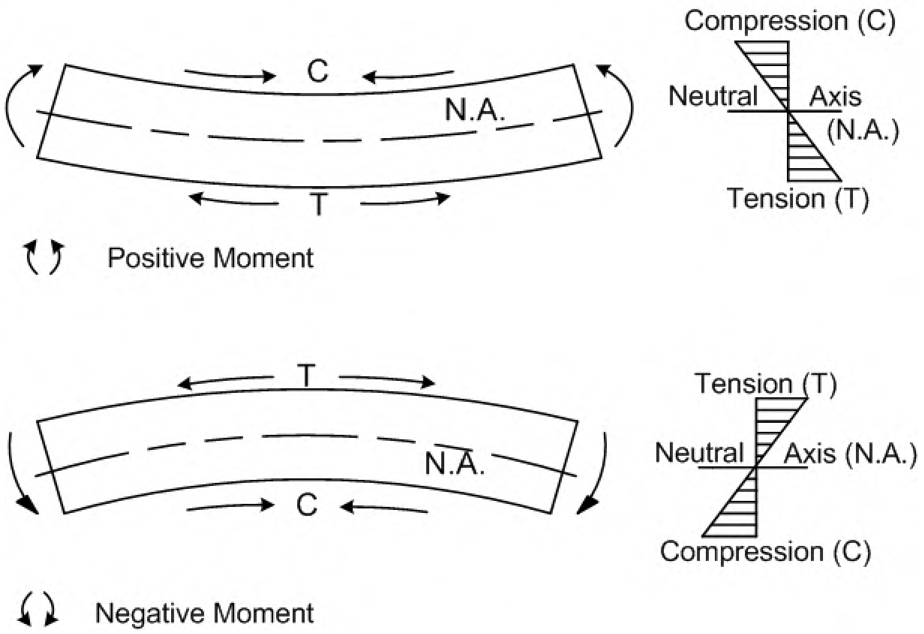


Figure 5.1.10 Positive and Negative Moment

Beams and girders are the most common bridge elements used to resist bending moments. The flanges are most critical because they provide the greatest resistance to the compressive and tensile forces developed by the moment (see Figure 5.1.11).

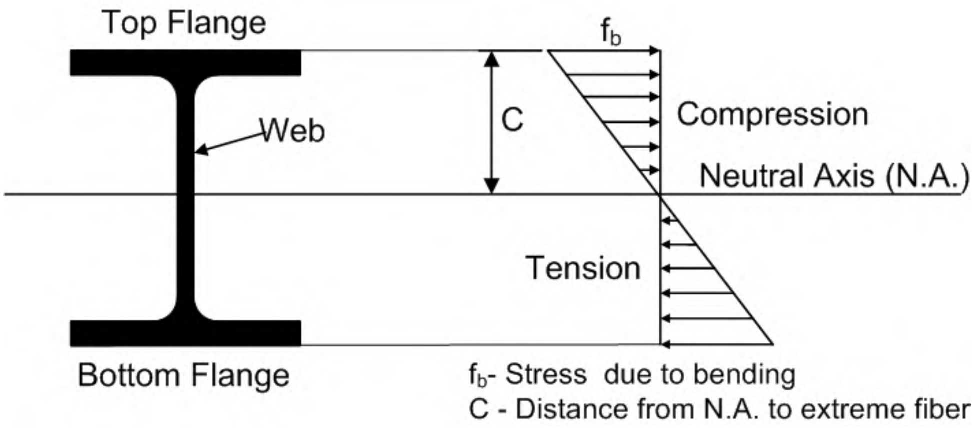


Figure 5.1.11 Girder Cross Section Resisting Positive Moment

Bending stress is normally considered zero at the neutral axis. On a cross section of a member, bending stresses vary linearly with respect to the distance from the neutral axis (see Figures 5.1.10 and 5.1.11).

The formula for maximum bending stress is (see Figure 5.1.11):

$$f_b = \frac{Mc}{I}$$

where: f_b = bending stress on extreme fiber (or surface) of beam (kips per square inch)
M = applied moment (inch · lbf)

c = distance from neutral axis to extreme fiber (or surface) of beam (inches)
I = moment of inertia (a property of the beam cross-sectional area and shape) (lbf · square inch)

Shear Forces

Shear is a force, which results from equal but opposite transverse forces, which tend to slide one section of a member past an adjacent section (see Figure 5.1.12). Shear forces are generally expressed in English units of pounds or kips.

Example of shear: When scissors are used to cut a piece of paper, a shear force has caused one side of the paper to separate from the other. Scissors are often referred to as shears since they exert a shear force.

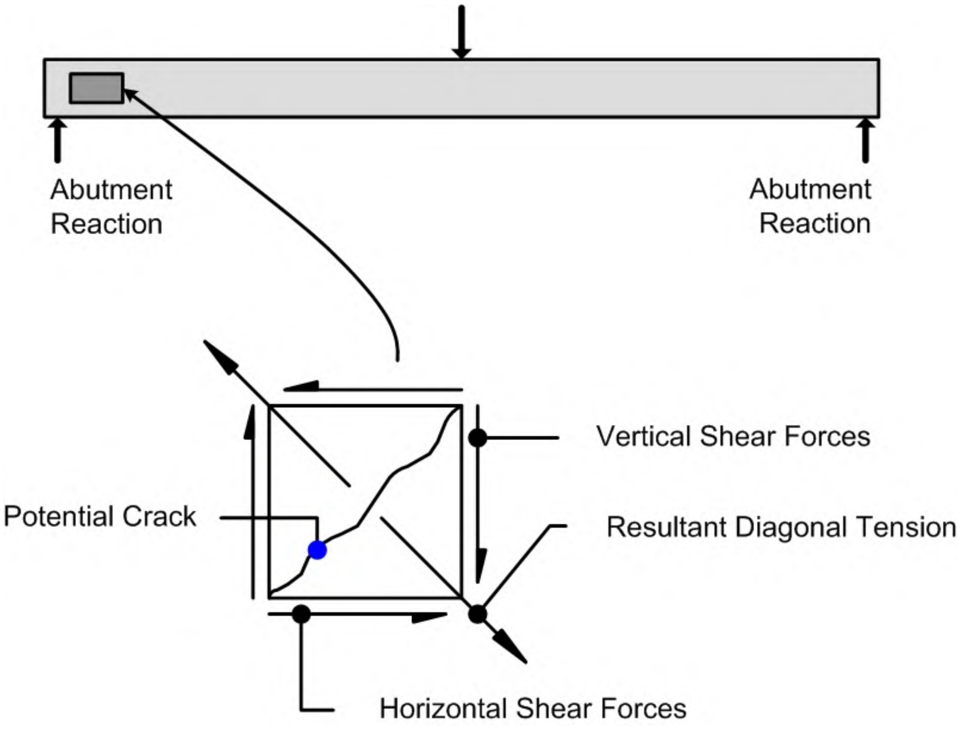


Figure 5.1.12 Shear Forces in a Member Element

Beams and girders are common shear resisting members. In an I- or T-beam, most of the shear is resisted by the web (see Figures 5.1.11 and 5.1.12). The shear stress produced by the transverse forces is manifested in a horizontal shear stress which is accompanied by a vertical shear stress of equal magnitude. The horizontal shear forces are required to keep the member in equilibrium (not moving). Vertical shear strength is generally considered in most design criteria. The formula for vertical shear stress in I- or T-beams is:

$$f_v = \frac{V}{A_W}$$

where:
f_v = shear stress (kips per square inch)
V = vertical shear due to external loads (kips)
A_w = area of web (square inches)

Torsional Forces

Torsion is a force resulting from externally applied moments which tend to rotate or twist a member about its longitudinal axis. Torsional force is commonly referred to as torque and is generally expressed in English units of pound-feet or kip-feet.

Example of torsion: One end of a long rectangular bar is clamped horizontally in a vise so that the long side is up and down. Using a large wrench, a moment is applied to the other end, which causes it to rotate so that the long side is now left to right. The steel bar is resisting a torsional force or torque which has twisted it 90° with respect to its original orientation (see Figure 5.1.13).

Torsional forces develop in bridge members, which are interconnected and experience unbalanced loadings. Bridge elements are generally not designed as torsional members. However, in some bridge superstructures where elements are framed together, torsional forces can occur in longitudinal members. When these members experience differential deflection, adjoining transverse members apply twisting moments resulting in torsion. In addition, curved bridges are generally subject to torsion (see Figure 5.1.14).

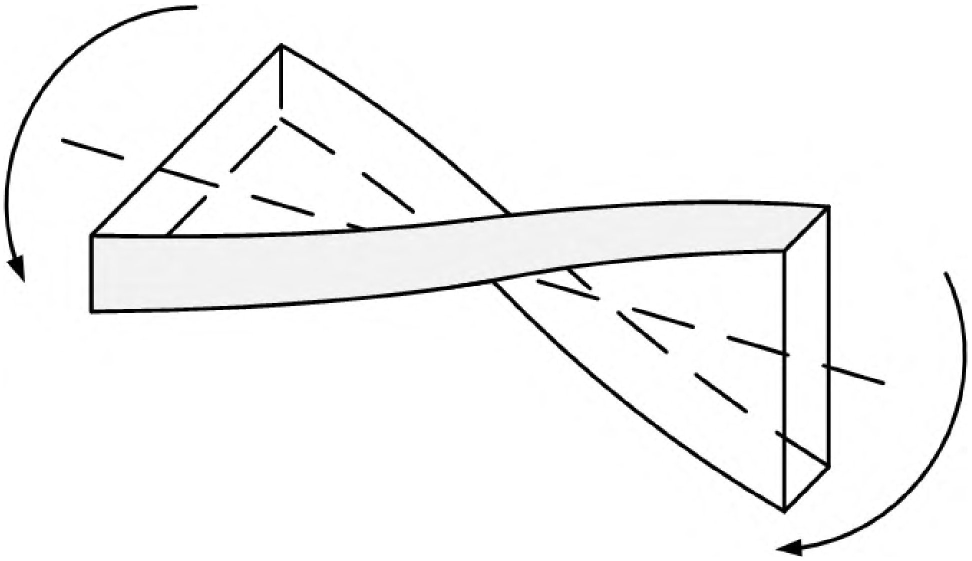


Figure 5.1.13 Torsion

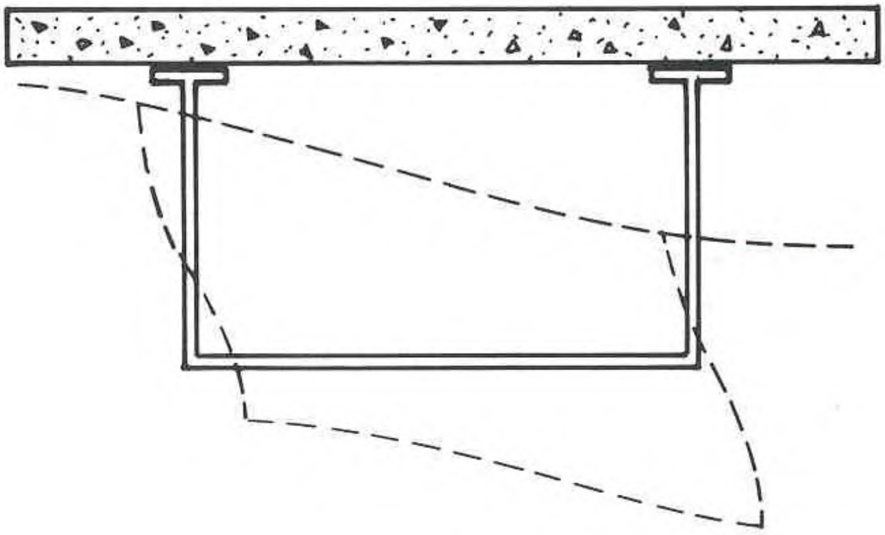


Figure 5.1.14 Torsional Distortion

Reactions

A reaction is a force provided by a support that is equal but opposite to the force transmitted from a member to its support (see Figure 5.1.15). Reactions are most commonly vertical forces, but a reaction can also be a horizontal force. The reaction at a support is the measure of force that it transmits to the ground. A vertical reaction increases as the loads on the member are increased or as the loads are moved closer to that particular support. Reactions are generally expressed in English units of pounds or kips.

Example of reactions: Consider a bookshelf consisting of a piece of wood supported at its two ends by bricks. The bricks serve as supports, and the reaction is based on the weight of the shelf and the weight of the books on the shelf. As more books are added, the reaction provided by the bricks will increase. As the books are shifted to one side, the reaction provided by the bricks at that side will increase, while the reaction at the other side will decrease.

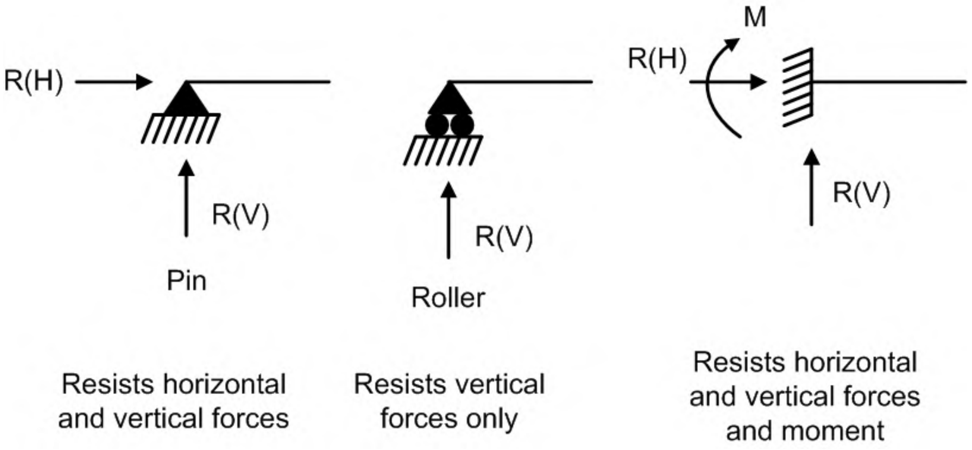


Figure 5.1.15 Types of Supports

The provided reactions at the bridge supports equal the applied permanent or transient loads. The equilibrium keeps the bridge in place.

5.1.4

Response to Loadings

Each bridge member has a unique purpose and function, which directly affects the selection of material, shape, and size for that member. Certain terms are used to describe the response of a bridge material to loads. A working knowledge of these terms is essential for the bridge inspector to be effective in their job.

Force

A force is the action that one body exerts on another body. Force has three aspects: magnitude, direction and point of application (see Figure 5.1.16). Every force can be divided into 3 distinct components or directions: vertical, transverse, and longitudinal. The combination of these three can produce a resultant force. Forces are generally expressed in English units of pounds or kips.

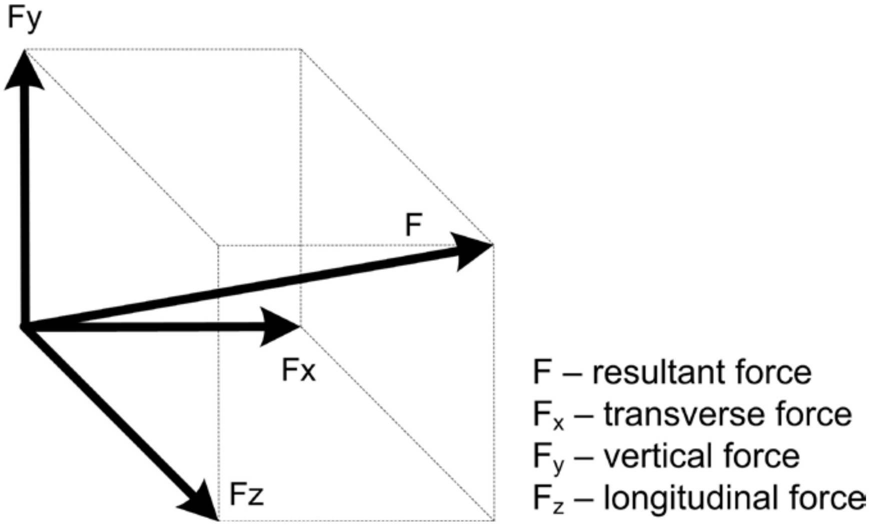


Figure 5.1.16 Basic Force Components

Stress

Stress is a basic unit of measure used to denote the intensity of an internal force. When a force is applied to a material, an internal stress is developed. Stress is defined as a force per unit of cross-sectional area.

$$Stress\,(\sigma) = \frac{Force\,(F)}{Area\,(A)}$$

The basic English unit of measure for stress is pounds per square inch (abbreviated as psi). However, stress can also be expressed in kips per square inch (ksi) or in any other units of force per unit area. An allowable unit stress is generally established for a given material.

Example of a stress: If a 30,000 lb. force acts uniformly over an area of 10 square inches, then the stress caused by this force is 3000 psi (or 3 ksi).

Deformation

Deformation is the local distortion or change in shape of a material due to stress.

Strain

Strain is a basic unit of measure used to describe an amount of deformation. It denotes the ratio of a material's deformed dimension to a material's original dimensions. For example, strain in a longitudinal direction is computed by dividing the change in length by the original length.

$$Strain\ (\varepsilon) = \frac{Change\ in\ Length\ (\Delta L)}{Original\ Length\ (L)}$$

Strain is a dimensionless quantity. However, it can also be expressed as a percentage or in units of length per length (e.g., inch/inch).

Example of strain: If a force acting on a 20 foot long column causes an axial deformation of 0.002 feet, then the resulting axial strain is 0.002 feet divided by 20 feet, or 0.0001 foot/foot. This strain can also be expressed simply as 0.0001 (with no units) or as 0.0l%.

Elastic Deformation

Elastic deformation is the reversible distortion of a material. A member is elastically deformed if it returns to its original shape upon removal of the force. Elastic strain is sometimes termed reversible strain because it disappears after the stress is removed. Bridges are designed to deform elastically and return to their original shape after the live loads are removed.

Example of elastic deformation: A stretched rubber band will return to its original shape after being released from a taut position. Generally, if the strain is elastic, there is a direct proportion between the amount of strain and the applied stress.

Plastic Deformation

Plastic deformation is the irreversible or permanent distortion of a material. A material is plastically deformed if it retains a deformed shape upon removal of a stress. Plastic strain is sometimes termed irreversible or permanent strain because it remains after the stress is removed. Plastic strain is not directly proportional to the given applied stress as is the case with the elastic strain.

Example of plastic deformation: If a car crashed into a brick wall, the fenders and bumpers would deform. This deformation would remain even after the car is backed away from the wall. Therefore, the fenders and bumpers have undergone plastic deformation.

Creep

Creep is a form of plastic deformation that occurs gradually at stress levels normally associated with elastic deformation. Creep is defined as the gradual, continuing irreversible change in the dimensions of a member due to the sustained application of load. It is caused by the molecular readjustments in a material under constant load. The creep rate is the change in strain (plastic deformation) over a certain period of time.

Example of creep: If heavy paint cans remain left untouched on a thin wooden shelf for several months, the shelf will gradually deflect and change in shape. This deformation is due to the sustained application of a constant dead load and illustrates the effects of creep.

Thermal Effects

In bridges, thermal effects are most commonly experienced in the longitudinal expansion and contraction of the superstructure. It is possible to design for deformations caused by thermal effects when members are free to expand and contract. However, there may be members for which expansion and contraction is inhibited or prevented in certain directions. Consider any thermal changes in these members since they can cause significant stresses.

Materials expand as temperature increases and contract as temperature decreases. The amount of thermal deformation in a member depends on:

- A coefficient of thermal expansion, unique for each material
- The temperature change
- The member length

Example of thermal effects: Most thermometers operate on the principle that the material within the glass bulb expands as the temperature increases and contracts as the temperature decreases.

Stress-Strain Relationship

For most structural materials, values of stress and strain are directly proportional (see Figure 5.1.17). However, this proportionality exists only up to a particular value of stress called the elastic limit. Two other frequently used terms, which closely correspond with the elastic limit, are the proportional limit and the yield point.

When applying stress up to the elastic limit, a material deforms elastically. Beyond the elastic limit, deformation is plastic and strain is not directly proportional to a given applied stress. The material property, which defines its stress-strain relationship, is called the modulus of elasticity, or Young's modulus.

Modulus of Elasticity

Each material has a unique modulus of elasticity, which defines the ratio of a given stress to its corresponding strain. It is the slope of the elastic portion of the stress-strain curve.

$$Modulus\ of\ Elasticity\ (E) = \frac{Stress\ (\sigma)}{Strain\ (\varepsilon)}$$

The modulus of elasticity applies only as long as the elastic limit of the material has not been reached. The units for modulus of elasticity are the same as those for stress (i.e., psi or ksi for English).

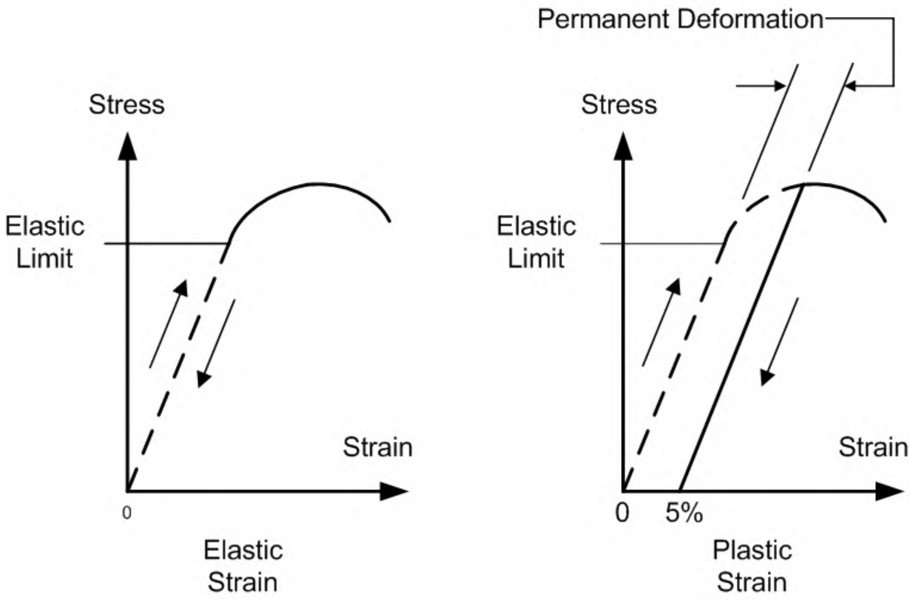


Figure 5.1.17 Stress-Strain Diagram

Example of modulus of elasticity: If a stress of 2900 psi is below the elastic limit and causes a strain of 0.0001 in/in, then the modulus of elasticity can be computed based on these values of stress and strain.

$$E = \frac{2{,}900\ psi}{0.0001 in/in} = 29{,}000{,}000\ psi = 29{,}000\, ksi$$

This is approximately equal to the modulus of elasticity for steel. The modulus of elasticity for concrete is approximately 3000 to 4500 ksi, and for commonly used grades of timber it is approximately 1600 ksi.

Overloads

Overload damage may occur when members are overstressed. Overload occurs when the stresses applied are greater than the elastic limit for the material.

Buckling

Buckling is the tendency of a member to crush or bend out of plane when subjected to a compressive force. As the length and slenderness of a compression member increases, the likelihood of buckling also increases.

Compression members require additional cross-sectional area or bracing to resist buckling.

Example of buckling: A paper or plastic straw compressed axially at both ends with an increasing force will eventually buckle.

Elongation

Elongation is the tendency of a member to extend, stretch or crack when subjected to a tensile force. Elongation can be either elastic or plastic.

Example of elongation: A piece of taffy pulled will stretch in a plastic manner.

Critical Finding

An overload in a bridge member may be considered a critical finding. Critical findings are presented in Topic 4.5 and defined as "a structural or safety related deficiency that requires immediate follow-up inspection or action."

Ductility and Brittleness

Ductility is the measure of plastic (permanent) strain that a material can endure. A ductile material will undergo a large amount of plastic deformation before breaking. It will also have a greatly reduced cross-sectional area before breaking.

Example of ductility: A baker working with pizza dough will find that the dough can be stretched a great deal before it will break into two sections. Therefore, pizza dough is a ductile material. When the dough finally does break, it will have a greatly reduced cross-sectional area.

Structural materials for bridges that are generally ductile include:

- Steel
- Aluminum
- Copper
- Wood

Brittle, or non-ductile, materials will not undergo significant plastic deformation before breaking. Failure of a brittle material occurs suddenly, with little or no warning.

Example of brittleness: A glass table may be able to support several magazines and books. However, if more and more weight is piled onto the table, the glass will eventually break with little or no warning. Therefore, glass is a brittle material.

Structural materials for bridges that are generally brittle include:

- Concrete
- Cast iron
- Stone
- Fiber Reinforced Polymer

Fatigue

Fatigue is a material response that describes the tendency of a material to break when subjected to repeated loading. Fatigue failure occurs within the elastic range of a material after a certain number and magnitude of stress cycles have been applied.

Each material has a hypothetical maximum stress value to which it can be loaded and unloaded an infinite number of times. This stress value is referred to as the fatigue limit and is usually lower than the breaking strength for infrequently applied loads.

Ductile materials such as steel and aluminum have high fatigue limits, while brittle materials such as concrete have low fatigue limits. Wood has a high fatigue limit.

Example of fatigue: If a rubber band is stretched and then allowed to return to its original position (elastic deformation), it is unlikely that the rubber band will break. However, if this action is repeated many times, the rubber band will eventually break. The rubber band failure is analogous to a fatigue failure.

For a description of fatigue categories for various steel details, refer to Topic 6.4.

Isotropy

A material that has the same mechanical properties regardless of which direction it is loaded is said to be isotropic.

Example of isotropy: Plain, unreinforced concrete, and steel.

For a description of isotropic materials, refer to Topics 6.2 and 6.3.

5.1.5

Mechanics of Materials

Materials respond to loadings in a manner dependent on their mechanical properties. In characterizing materials, define certain mechanical properties.

Yield Strength

The ability of a material to resist plastic (permanent) deformation is called the yield strength. Yield strength corresponds to stress level defined by a material's yield point.

Tensile Strength

The tensile strength of a material is the stress level defined by the maximum tensile load that it can resist without failure. Tensile strength corresponds to the highest ordinate on the stress-strain curve and is sometimes referred to as the ultimate strength.

Toughness

Toughness is a measure of the energy required to break a material. It is related to ductility. Toughness is not necessarily related to strength. A material might have high strength but little toughness. A ductile material with the same strength as a non-ductile material will require more energy to break and thus exhibit more toughness. For highway bridges, the CVN (Charpy V-notch) toughness is the toughness value usually used. It is an indicator of the ability of the steel to resist crack propagation in the presence of a notch or flaw. The unit for toughness is ft-lbs @ degrees F.

5.1.6

Bridge Movements

Bridges move because of many factors; some are anticipated, but others are not. Unanticipated movements generally result from settlement, sliding, and rotation of foundations. Anticipated movements include live load deflections, thermal expansions and contractions, shrinkage and creep, earthquakes, rotations, wind drifting, and vibrations. Of these movements, the three major anticipated movements are live load deflections, thermal movements. and rotational movements.

Live Load Deflections

Deflection produced by live loading should not be excessive because of aesthetics, user discomfort, and possible damage to the whole structure. Several factors control the amount of deflection: strength of material, depth and shape of structural member, and length of a member

In the absence of other criteria, the following limitations may be considered:

Limitations are generally expressed as a deflection-to-span ratio. AASHTO generally limits live load bridge deflection for steel and concrete bridges to 1/800 (i.e.,1inch vertical movement per 67 feet of span length). For bridges that have sidewalks, AASHTO limits live load bridge deflection to 1/1000 (i.e., 1-inch vertical movement per 83 feet of span length).

Thermal Movements

The longitudinal expansion and contraction of a bridge is dependent on the range of temperature change, material, and most importantly, length of bridge used in construction. Thermal movements are frequently accommodated using expansion joints and movable bearings. To accommodate thermal movements, it is recommended the designer allow 1-1/4 inches of movement for each 100 feet of span length for steel bridges and 1-3/16 inches of movement for each 100 feet of span length for concrete bridges.

Rotational Movements

Rotational movement in bridges is a direct result of live load deflection and occurs with the greatest magnitude at the bridge supports. This movement can be accommodated using bearing devices that permit rotation.

5.1.7

Design Methods

Bridge engineers use various design methods that incorporate safety factors to account for uncertainties and random deviations in material strength, fabrication, construction, durability, and loadings.

Allowable Stress Design

The Allowable Stress Design (ASD) or Working Stress Design (WSD) is a method in which the maximum stress a particular member may carry is limited to an allowable or working stress. The allowable or working stress is determined by applying an appropriate factor of safety to the limiting stress of the material. For example, the allowable tensile stress for a steel tension member is 0.55 times the steel yield stress. This results in a safety factor of 1.8. The capacity of the member is based on either the inventory rating level or the operating rating level. AASHTO currently has ten possible WSD group loadings. See Topic 5.1.8 for inventory and operating rating levels.

Load Factor Design

Load Factor Design (LFD) is a method in which the ultimate strength of a material is limited to the combined effect of the factored loads. The factored loads are determined from the applied loadings, which are increased by selected multipliers that provide a factor of safety. The load factors for AASHTO Group I are 1.3(DL+1.67(LL+I)). AASHTO currently has ten possible LFD group loadings.

Load and Resistance Factor Design

Load and Resistance Factor Design (LRFD) is a design procedure based on the actual strength, rather than on an arbitrary calculated stress. It is an ultimate strength concept where both working loads and resistance are multiplied by factors, and the design performed by assuming the strength exceeds the load. (The load multipliers used in LRFD are not the same multipliers that are used in LFD.)

These design methods are conservative due to safety factors and limit the stress in bridge members to a level well within the material's elastic range, provided that the structural members are in good condition. That is why it is important for inspectors to accurately report any deficiency found in the members.

5.1.8

Bridge Load Ratings

One of the primary functions of a bridge inspection is to collect information necessary for a bridge load capacity rating. Therefore, understand the principles of bridge load ratings. Bridge load rating methods and guidelines are provided by AASHTO in the *AASHTO Manual for Bridge Evaluation*.

A bridge load rating is used to determine the usable live load capacity of a bridge. Each member of a bridge has a unique load rating, and the bridge load rating represents the most critical one. Bridge load rating is generally expressed in units of tons, and it is computed based on the following basic formula:

$$Bridge\,Rating\;Factor\,(RF) = \frac{C - A_1 D}{A_2 L(1 + I)}$$

where:

RF= the rating factor for the live-load carrying capacity; the rating factor multiplied by the rating vehicle in tons gives the rating of the structure
C = the capacity of the member
D = the dead load effect on the member
L = the live load effect on the member
I = the impact factor to be used with the live load effect
A_1 = factor for dead loads
A_2 = factor for live loads

Bridge load rating for Load and Resistance Factor Rating (LRFR) is computed based on the following basic formula:

$$Bridge\,Rating\;Factor\,(RF) = \frac{C - (\gamma_{DC})(DC) - (\gamma_{DW})(DW) \pm (\gamma_P)(P)}{(\gamma_L)(LL + IM)}$$

where:

RF= rating factor
C = capacity
DC = dead load effect due to structural components and attachments
DW= dead load effect due to wearing surface and utilities
P = permanent load other than dead loads
LL = live load effect
IM = dynamic load allowance
γ_{DC} = LRFD load factor for structural components and attachments
γ_{DW} = LRFD load factor for wearing surfaces and utilities
γ_P = LRFD load factor for permanent loads other than dead loads = 1.0
γ_L = evaluation live-load factor

Both of the formulas above determine a rating factor for the controlling member of the bridge. For either case, the safe load capacity in tons can be calculated as follows:

$$RT = RF \times W$$

where:

RT= rating in tons for truck used in computing live-load effect
RF= rating factor
W = weight in tons of truck used in computing live-load effect

Note that when LRFR lane loading controls the rating, the equivalent truck weight (W) to be used in calculating the safe load capacity in tons is 40 tons.

Inventory Rating

The inventory rating level generally corresponds to the customary design level of stresses but reflects the existing bridge and material conditions with regard to deterioration and loss of section. Load ratings based on the inventory level allow comparisons with the capacity for new structures and, therefore, results in a live load, which can safely utilize an existing structure for an indefinite period of time. For the allowable stress method, the inventory rating for steel used to be based on 55% of the yield stress. Inventory ratings have been refined to reflect the various material and load types. See the *AASHTO Manual for Bridge Evaluation* (Section 6B.6.2 for Allowable Stress Inventory Ratings and Section 6B.6.3 for Load Factor Inventory Ratings).

The LRFD design level is comparable to the traditional Inventory rating. Bridges that pass HL-93 screening at the Inventory level are capable of carrying AASHTO legal loads and state legal loads within the AASHTO exclusion limits described in the *LRFD Bridge Design Specifications*.

Operating Rating

Load ratings based on the operating rating level generally describe the maximum permissible live load to which the structure may be subjected. Allowing unlimited numbers of vehicles to use the bridge at operating level may shorten the life of the bridge. For steel, the allowable stress for operating rating used to be 75% of the yield stress. Operating ratings have been refined to reflect the various material and load types. See the *AASHTO Manual for Bridge Evaluation* (Section 6B.6.2 for Allowable Stress Operating Ratings and Section 6B.6.3 for Load Factor Operating Ratings).

Permit Loading

Special permits for heavier than normal vehicles may occasionally be issued by a governing agency. The load produced by the permit vehicle is to not exceed the structural capacity determined by the operating rating.

The second level rating is a legal load rating providing a single safe load capacity for a specific truck configuration. The second level rating is comparable to the traditional Operating rating. Bridges that pass HL-93 screening at the Operating level are capable of carrying AASHTO legal loads, but may not rate for state legal loads especially those that are considerably heavier than AASHTO trucks.

The third level rating is used to check the serviceability and safety of bridges in the review of permit applications. Permits are required for vehicles above the legal load. Only apply this third level rating to bridges with sufficient capacity for AASHTO legal loads. Calibrated load factors by permit type and traffic conditions are specified for checking the effect of the overweight vehicle. Guidance on checking serviceability criteria are also given.

Rating Vehicles

Rating vehicles are truck loads applied to the bridge to establish the inventory and operating ratings. These rating vehicles (see Figure 5.1.18) include:

- H loading
- HS loading
- HL-93
- Alternate Interstate Loading (Military Loading)
- Type 3 unit
- Type 3-S2 unit

- Type 3-3 unit
- The maximum legal load vehicles of the state
- State routine permit loads

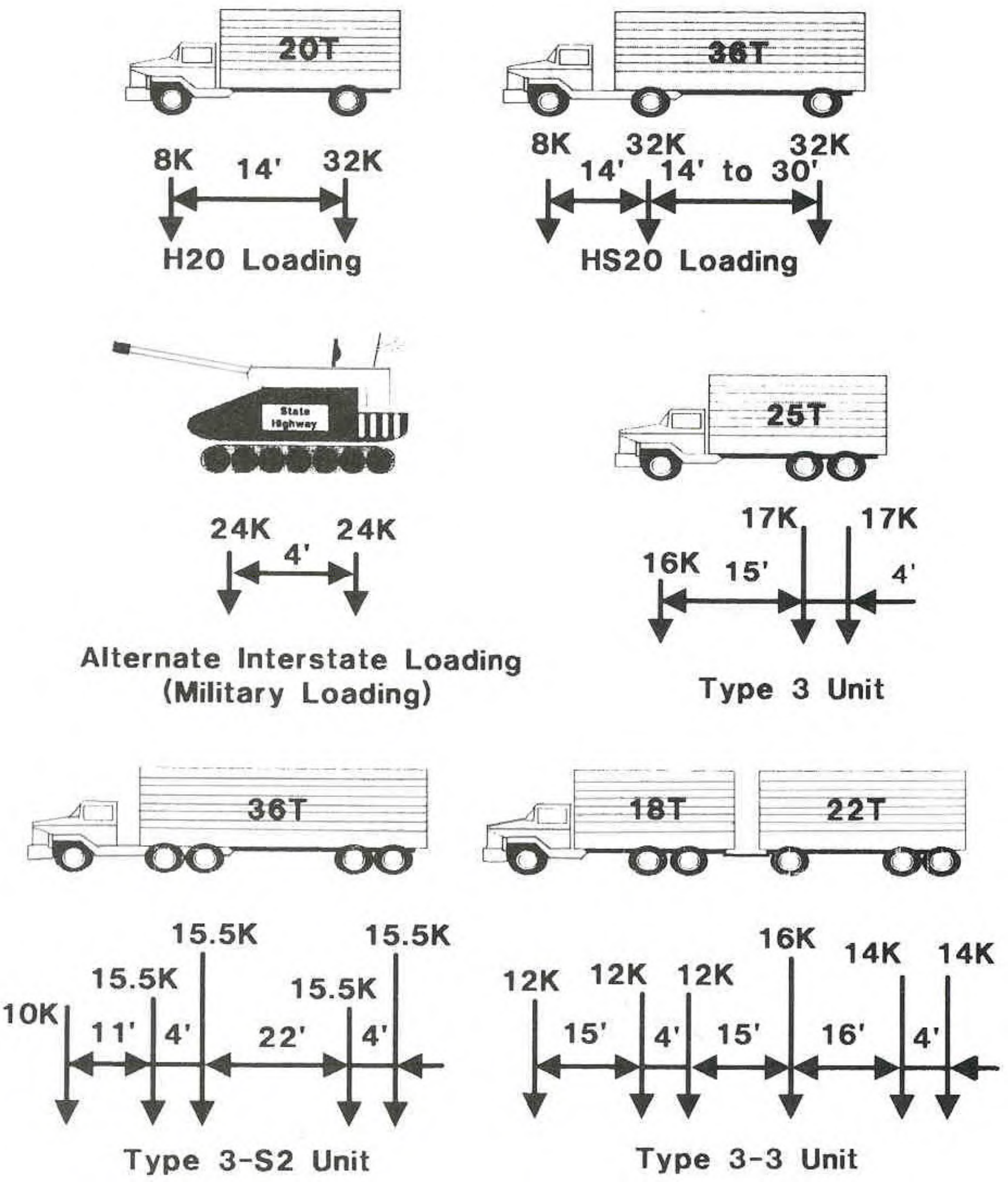


Figure 5.1.18 Rating Vehicles

The axle spacing and weights of the Type 3 unit, Type 3-S2 unit, and Type 3-3 unit are based on actual vehicles. However, as described previously, the H and HS loadings do not represent actual vehicles.

These standard rating vehicles were chosen based on load regulations of most states and governing agencies. However, individual states and agencies may also establish their own unique rating vehicles.

Bridge Posting

Bridge loads are posted to warn the public of the load capacity of a bridge, to avoid safety hazards, and to adhere to federal law. Federal regulation requires highway bridges on public roads to be inspected every twenty-four months for lengths greater than 20 feet. Post or restrict the bridge in accordance with the AASHTO Manual or in accordance with State law, when the maximum unrestricted legal loads or State routine permit loads exceed that allowed under the operating rating or equivalent rating factor.. It is the inspector’s responsibility to gather and provide information that the structural engineer can use to analyze and rate the bridge.

The safe load-carrying capacity of a bridge considers the following criteria:

- Physical condition
- Potential for fatigue damage
- Type of structure/configuration
- Truck traffic data (include State legal loads and routine permit loads)

Bridge postings show the maximum allowable load by law for single vehicles and combinations while still maintaining an adequate safety margin (see Figure 5.1.19).

Figure 5.1.19 Bridge Weight Limit Posting

Failure to comply with bridge posting may result in fines, tort suits/financial liabilities, accidents, or even death. In addition, bridges may be damaged when postings are ignored (see Figure 5.1.20).

Figure 5.1.20 Damaged Bridge due to Failure to Comply with Bridge Posting

5.1.9
Span Classifications

Bridges are classified into three span classifications that are based on the nature of the supports and the interrelationship between spans. These classifications are:

- Simple
- Continuous
- Cantilever

Simple

A simple span is a span with only two supports, each of which is at or near the end of the span (see Figure 5.1.21).

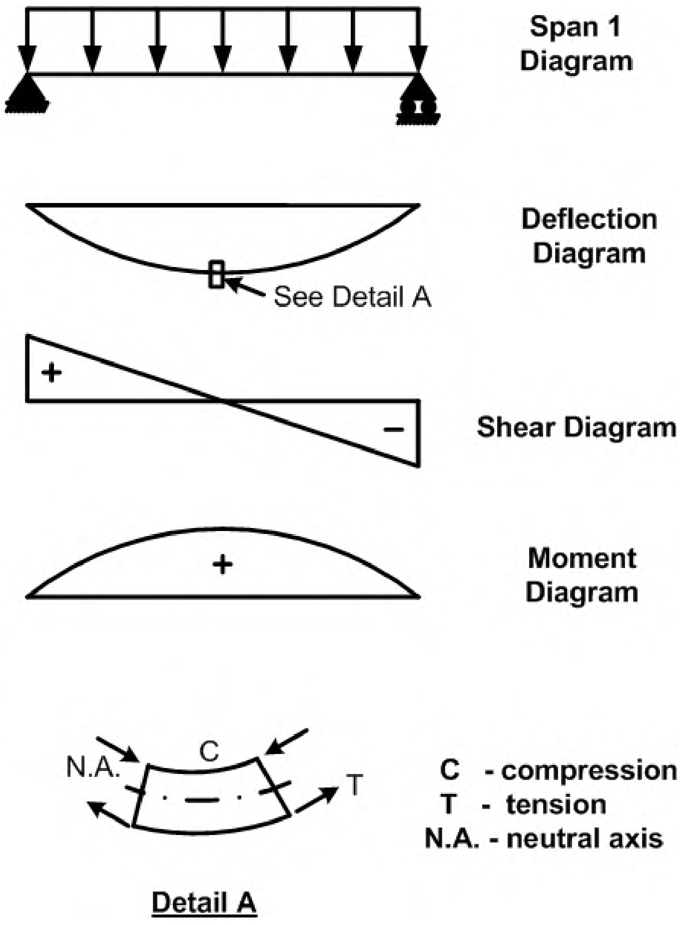


Figure 5.1.21 Simple Bridge

A simple span bridge can have a single span supported at the ends by two abutments or multiple spans with each span behaving independently of the others. Some characteristics of simple span bridges are:

- When loaded, the span deflects downward and rotates at the supports
- The sum of the reactions provided by the two supports equals the entire load
- Shear forces are maximum at the supports and zero at or near the middle of the spans
- Bending moment throughout the span is positive and maximum at or near the middle of the span (the same location at which shear is zero); bending moment is zero at the supports
- The part of the superstructure below the neutral axis is in tension while the portion above the neutral axis is in compression

A simple span bridge is easily analyzed using equilibrium equations. However, it does not always provide the most economical design solution.

Continuous

A continuous span is a configuration in which a bridge has one or more intermediate supports and the behavior of each individual span is dependent on its adjacent spans (see Figure 5.1.22).

A continuous span bridge is one which is supported at the ends by two abutments and which spans uninterrupted over one or more intermediate supports. Some characteristics of continuous span bridges are:

- When loaded, the spans deflect downward and rotate at the supports
- The reactions provided by the supports depend on the span configuration and the distribution of the loads
- Shear forces are maximum at the supports and zero at or near the middle of the spans
- Positive bending moment is greatest at or near the middle of each span
- Negative bending moment is greatest at the intermediate supports; the bending moment is zero at the end supports; there are also two locations per intermediate support at which bending moment is zero, known as inflection points
- For positive bending moments, compression occurs on the top portion of the bridge member and tension occurs on the bottom portion of the bridge member
- For negative bending moments, tension occurs on the top portion of the bridge member and compression occurs on the bottom portion of the bridge member

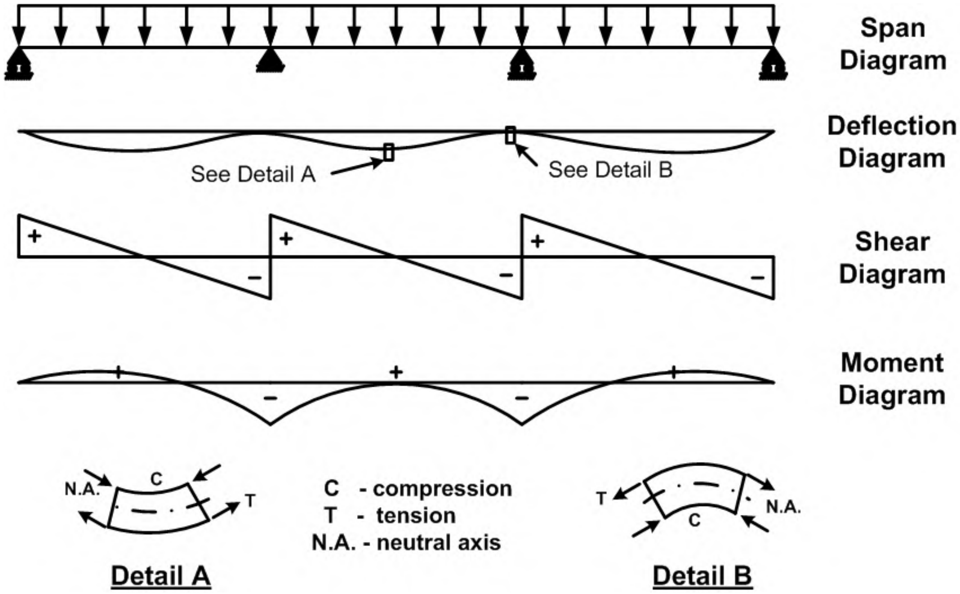


Figure 5.1.22 Continuous Bridge

A continuous span bridge allows longer spans and is more economical than a bridge consisting of many simple spans. This is due to its efficient design with members that are shallower. However, a continuous bridge is more difficult to analyze than a simple span bridge and is more susceptible to overstress conditions if the supports experience differential settlement.

Cantilever

A cantilever span is a span with one end restrained against rotation and deflection and the other end completely free (see Figure 5.1.23). The restrained end is also known as a fixed support.

While a cantilever generally does not form an entire bridge, portions of a bridge can behave as a cantilever (e.g., cantilever bridges and bascule bridges). Some characteristics of cantilevers are:

- When loaded, the span deflects downward, but there is no rotation or deflection at the support
- The fixed support reaction consists of a vertical force and a resisting moment
- The shear is maximum at the fixed support and is zero at the free end
- The bending moment throughout the span is negative and maximum at the fixed support; bending moment is zero at the free end

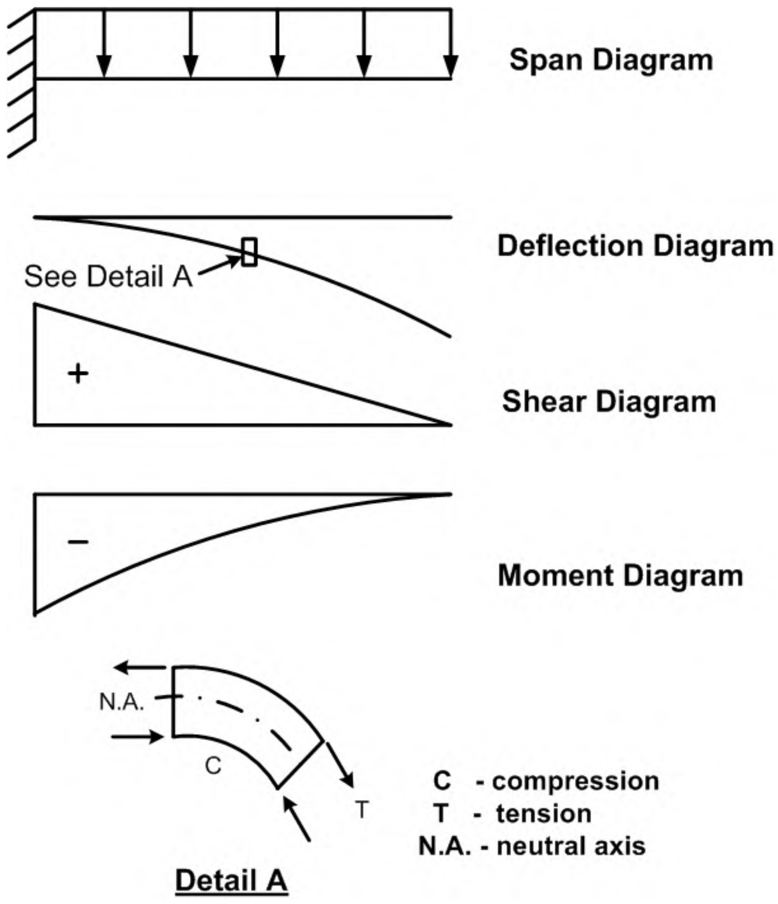


Figure 5.1.23 Cantilever Span

When cantilever spans are incorporated into a bridge, they are generally extensions of a continuous span. Therefore, moment and rotation at the cantilever support will be dependent on the adjacent span (see Figure 5.1.24).

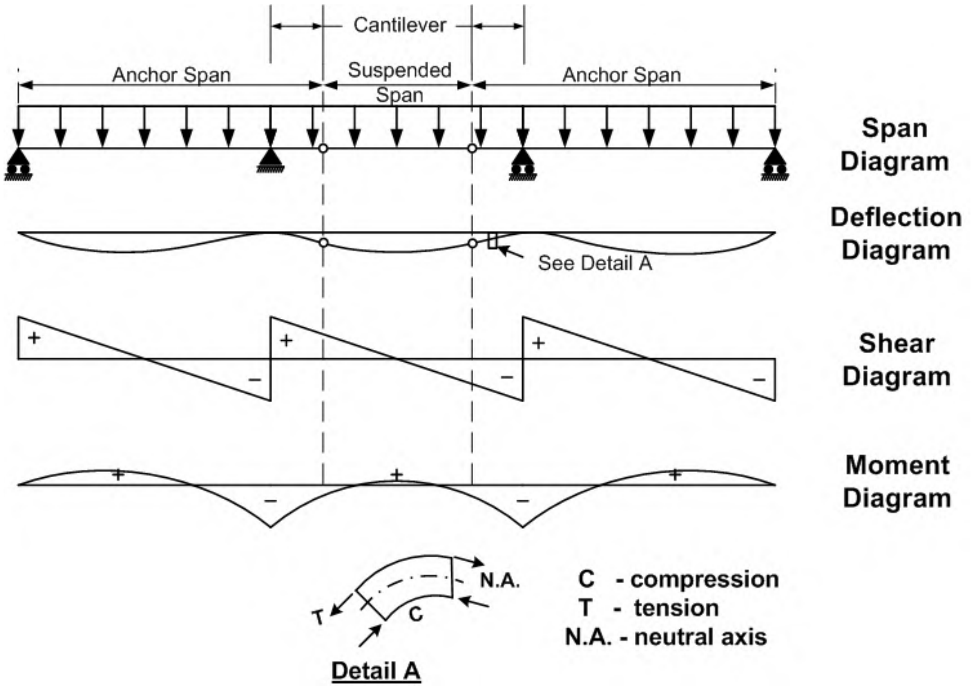


Figure 5.1.24 Cantilever Bridge

5.1.10 Bridge Deck Interaction

Bridges also have four classifications that are based on the relationship between the deck and the superstructure. These classifications are:

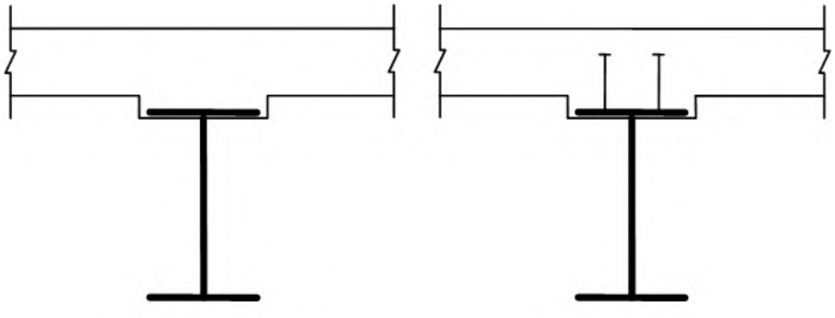
- Non-composite
- Composite
- Integral
- Orthotropic

Non-composite

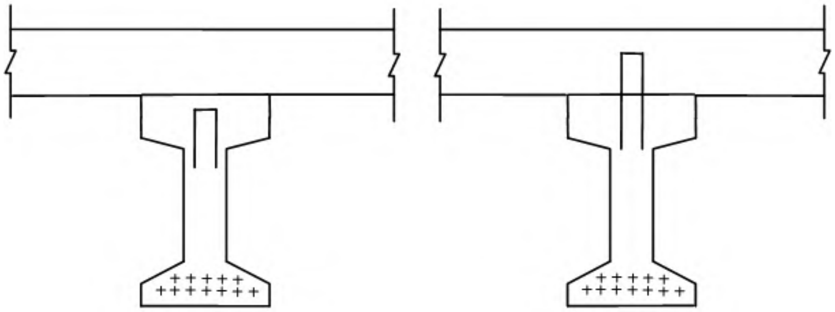
A non-composite structure is one in which the superstructure acts independently of the deck. Therefore, the superstructure alone resists all of the loads applied to them, including the permanent loads and the transient loads.

Composite

A composite structure is one in which the deck acts together with the superstructure to resist the loads (see Figure 5.1.25). The deck material is strong enough to contribute significantly to the overall strength of the section. The deck material is different than the superstructure material. The most common combinations are concrete deck on steel superstructure and concrete deck on prestressed concrete superstructure. Shear connectors such as studs, spirals, channels, or stirrups that are attached to the superstructure and are embedded in a deck provide composite action. This ensures that the superstructure and the deck will act as a unit by preventing slippage between the two when a load is applied.



Non-Composite   Composite



Non-Composite   Composite

Figure 5.1.25 Non-Composite or Composite Concrete Deck on Steel Beams and Pretressed Concrete Beams

Composite action is achieved only after the concrete deck has hardened. Therefore, some of the permanent load is resisted by the non-composite action of the superstructure alone. These permanent loads include the weight of:

- The superstructure itself
- Any diaphragms and cross-bracing
- The concrete deck
- Any concrete haunch between the superstructure and the deck
- Any other loads which are applied before the concrete deck has hardened

Other permanent loads, known as superimposed dead loads, are resisted by the superstructure and the concrete deck acting compositely. Superimposed dead loads include the weight of:

- Any anticipated future deck pavement
- Parapets
- Railings
- Any other loads which are applied after the concrete deck has hardened

Since live loads are applied to the bridge only after the deck has hardened, they are also resisted by the composite section.

The bridge inspector can identify a simple span, a continuous span, and a cantilever span based on their configuration. However, the bridge inspector can not identify the relationship between the deck and the superstructure while at the bridge site. Therefore, review the bridge plans to determine whether a structure is non-composite or composite.

Integral

On an integral bridge deck, the deck portion of the beam is constructed to act integrally with the stem, providing greater stiffness and allowing increased span lengths (see Figures 5.1.26 and 5.1.27).

Integral configurations are similar to composite decks in that the deck contributes to the superstructure capacity. However, integral decks are not considered composite since the deck (or top flange) is constructed of the same material. Example of an integral bridge is a conventionally reinforced T-beam and is described in detail in Topic 9.2.

Figure 5.1.26 Integral Bridge

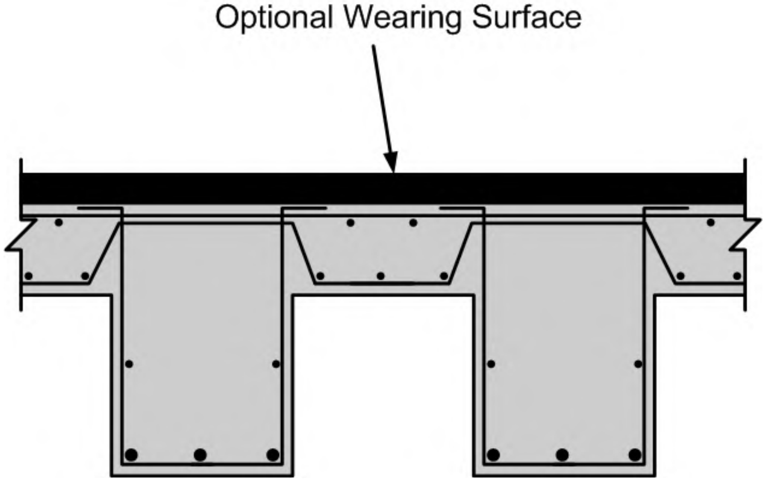


Figure 5.1.27 Cross Section of an Integral Bridge

Orthotropic

An orthotropic deck consists of a flat, thin steel plate stiffened by a series of closely spaced longitudinal ribs at right angles to their supports. The deck acts integrally with the steel superstructure. An orthotropic deck becomes the top flange of the entire floor system. Orthotropic decks are occasionally used on large bridges (see Figure 5.1.28).

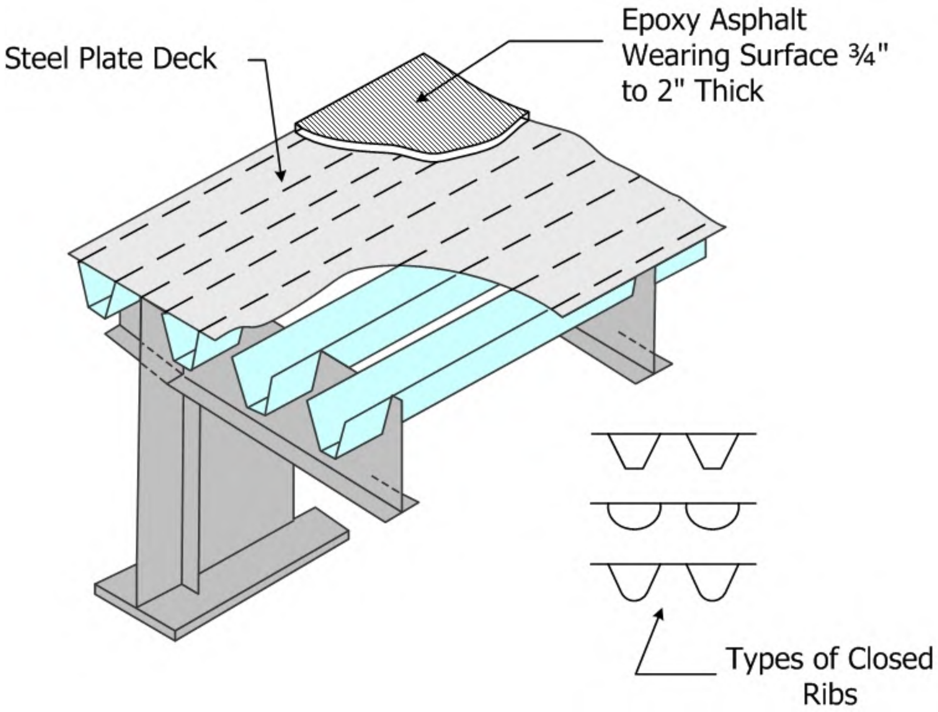


Figure 5.1.28 Orthotropic Bridge Deck

5.1.11

Redundancy

According to AASHTO Manual for Bridge Evaluation, bridge redundancy is the capability of a bridge structural system to carry loads after damage to or the failure of one or more of its members.

There are three types of redundancy in bridge design.

Load Path Redundancy

Bridge designs that are load path redundant have three or more main load-carrying members or load paths between supports. If one member were to fail, load would be redistributed to the other members and bridge failure would not be expected. Bridge designs that are non-redundant have two or fewer main load carrying members or load paths.

Structural Redundancy

Most bridge designs, which provide continuity of load path from span to span are referred to as structurally redundant. Some continuous span two-girder bridge designs are structurally redundant. In the event of a member failure, loading from that span can be redistributed to the adjacent spans and total bridge failure may not occur. A minimum of three continuous spans are needed to achieve structural redundancy in the interior spans.

Internal Redundancy

Internal redundancy is when a bridge member contains three or more elements that are mechanically fastened together so that multiple independent load paths are formed. Failure of one member element would not cause total failure of the member.

Nonredundant Configuration

Bridge inspectors are concerned primarily with load path redundancy and can neglect structural and internal redundancy when identifying fracture critical members. Nonredundant bridge configurations in tension contain fracture critical members. Many states currently perform 3-dimensional finite element analysis to help determine redundancy.

Redundancy is discussed in greater detail in Topic 6.4.

5.1.12

Foundations

Foundations are critical to the stability of the bridge since the foundation ultimately supports the entire structure. There are two basic types of bridge foundations:

- Shallow foundations commonly referred to as spread footings
- Deep foundations

Spread Footings

A spread footing is used when the bedrock layers are close to the ground surface or when the soil is capable of supporting the bridge. A spread footing is typically a rectangular slab made of reinforced concrete. This type of foundation "spreads out" the loads from the bridge to the underlying rock or well-compacted soil. While a spread footing is usually buried, it is generally covered with a minimal amount of soil. In cold regions, the bottom of a spread footing will be just below the recognized maximum frost line depth for that area (see Figure 5.1.29).

Deep Foundations

A deep foundation is used when the soil is not suited for supporting the bridge or when the bedrock is not close to the ground surface. A pile is a long, slender support that is typically driven into the ground but can be partially exposed. It is made from steel, concrete, or timber. Various numbers and configurations of piles can be used to support a bridge foundation. This type of foundation transfers load to sound material well below the surface or, in the case of friction piles, to the surrounding soil (see Figure 5.1.30). “Caissons”, “drilled caissons”, and “drilled shafts” are frequently used to transmit loads to bedrock in a manner similar to piles.

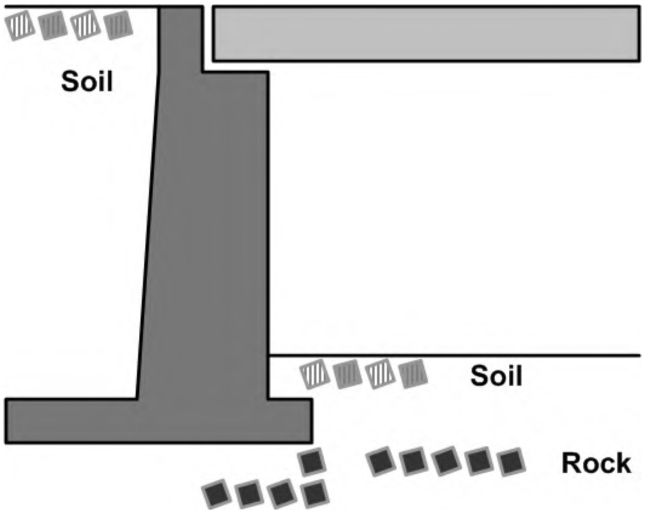


Figure 5.1.29 Spread Footing

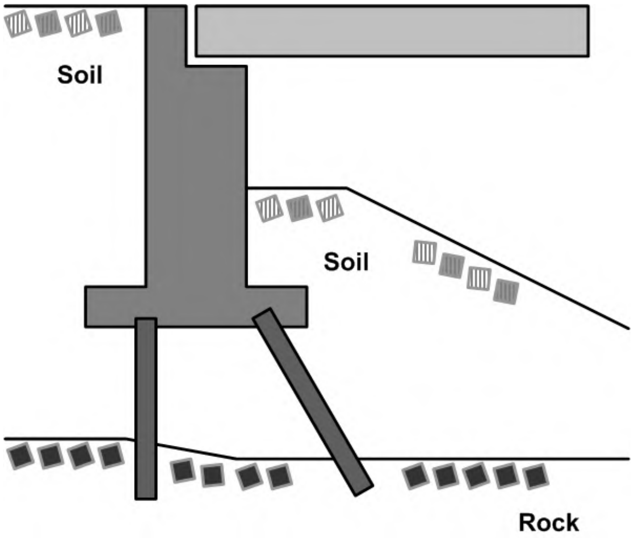


Figure 5.1.30 Deep Foundation