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Chapter 3 - Bridge Anatomy

3.1 Bridge Components and Elements

This chapter provides a general overview of bridge anatomy. For additional information, readers are encouraged to use the FHWA *Bridge Inspector's Reference Manual (BIRM)*. The BIRM is referenced at the end of this chapter.

3.1.1 Introduction

Those involved with bridge maintenance should have a good understanding of bridge anatomy, including the ability to identify and understand the function of the major bridge components and their elements. Most bridges can be divided into three basic components (see Figure 3.1):

- Deck
- Superstructure
- Substructure

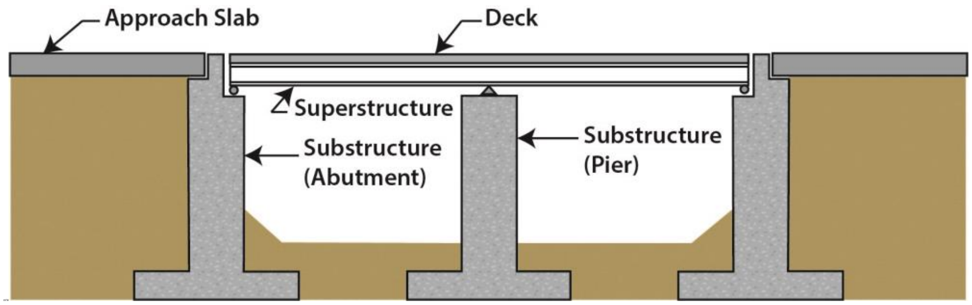

Figure 3.1 Major Bridge Components

3.1.2 Bridge Deck and Related Elements

Elements of the deck are described in the following sections.

3.1.2.1 Structural Deck/Slab

The deck is that portion of a bridge that provides direct support for vehicular and pedestrian traffic. The deck can be constructed from:

- Cast-In-Place (CIP) concrete
- Precast concrete
- Timber
- Steel plate
- Steel grating
- A combination of precast and CIP concrete
- The top flanges of side-by-side precast girders

While normally distributing load to a system of beams or girders, a deck may also be the main supporting element of a bridge. The AASHTO Manual for Bridge Element Inspection uses "slab" to distinguish between slab bridges where the slab transfers loads directly to the substructure and "decks" which transfer loads to the superstructure.

A steel grid deck is shown in Figure 3.2. Steel grid decks are popular for movable bridges since they are lighter in weight making them easier to lift.

Figure 3.2 Steel Grid Deck

Five basic types of timber decks are:

- Timber plank deck (shown in Figure 3.3)
- Nailed laminated deck
- Glued-laminated deck planks
- Stressed-laminated decks
- Structural composite lumber decks

Figure 3.3 Timber Plank Deck

3.1.2.2 Wearing Surface

The "wearing surface" of a deck is the riding surface for the traffic and is placed on top of the structural portion on the deck, as shown in Figure 3.4. There are also wearing courses placed integrally with the structural slab, and then the deck is referred to as a monolithic deck. A wearing surface could be used as a "sacrificial" part of the bridge deck, perhaps milled off and repaved every few years to maintain a smooth surface. Wearing surfaces can provide a barrier to protect the decks from road salts. The wearing surface could just be asphalt, but in that case a membrane might be placed in between the concrete and asphalt interface since asphalt is permeable. In other instances, a more impermeable material might be used.

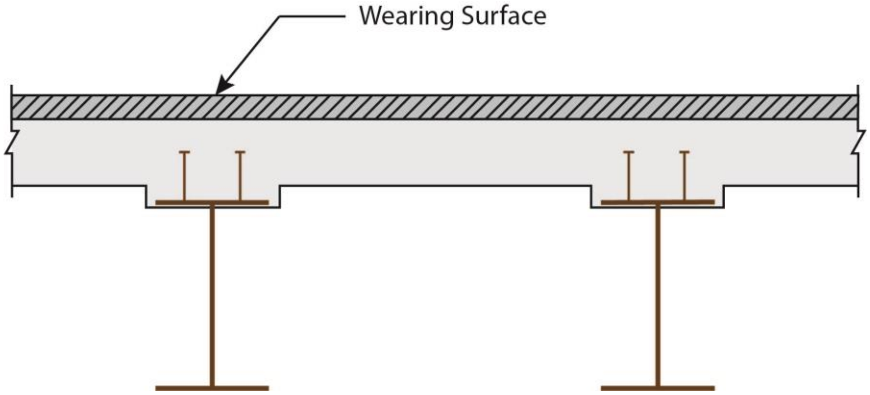

Figure 3.4 Composite Deck and Steel Superstructure Showing Wearing Surface

Materials used as wearing surfaces include:

- Plain concrete
- Modified concretes (polymers, latex, silica fume)
- Asphalt
- Asphalt with waterproofing membrane
- Gravel (tar stabilized or loose)
- Timber treads
- Thin bonded epoxy or methacrylate

When to Call the Engineer

An engineer should be consulted whenever the depth of the wearing surface is increased or the depth of integral concrete wearing surface is decreased due to maintenance operations.

3.1.2.3 Approach Slabs

Most bridge abutments are designed to have very little settlement. Approach embankments usually settle more than abutments. To mitigate this issue approach slabs are used to transition the riding surface from the roadway to the bridge deck. In general, the effectiveness of approach slabs increases with greater length of approach slab. Some approach slabs have secondary approach slabs commonly referred to as "sleeper" slabs.

Approach slabs are reinforced concrete slabs placed on the approach embankment adjacent to and usually resting on the abutment back wall. The function of the approach slab is to carry wheel loads on the approaches directly to the abutment, thereby transitioning any approach roadway misalignment due to approach embankment settlement.

Figure 3.5 Approach Slab to Roadway Approach

3.1.2.4 Joints

Joints accommodate the expansion, contraction, and rotation of the superstructure. Joints provide transitions from approach roadways to bridge decks, or between adjoining segments of bridge decks.

Joints are important to bridge maintenance. Leaking joints are a leading cause of reduced bridge service life. Deteriorating joints are a leading cause of poor wearing surfaces on bridges.

Types of deck joints include:

- Strip seal expansion joints
- Pourable joint seals
- Compression joint seals (see Figure 3.6)
- Assembly joints with seal (modular)
- Open expansion joints
- Assembly joints without seals (finger plate and sliding plate joints) (see Figure 3.7)
- Asphalt plug joints

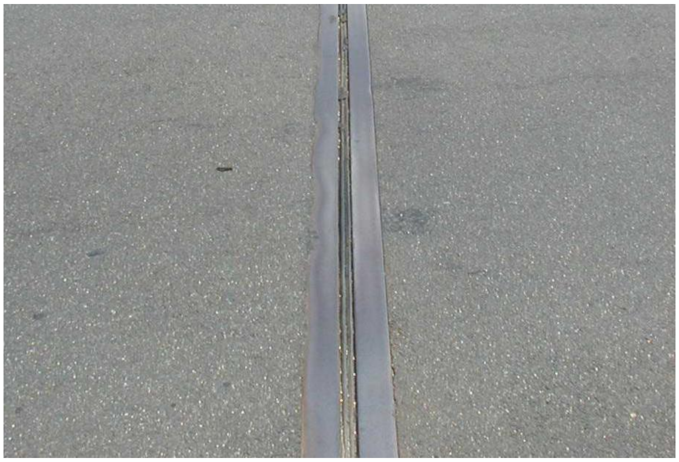

Figure 3.6 Top View of an Armored Compression Seal

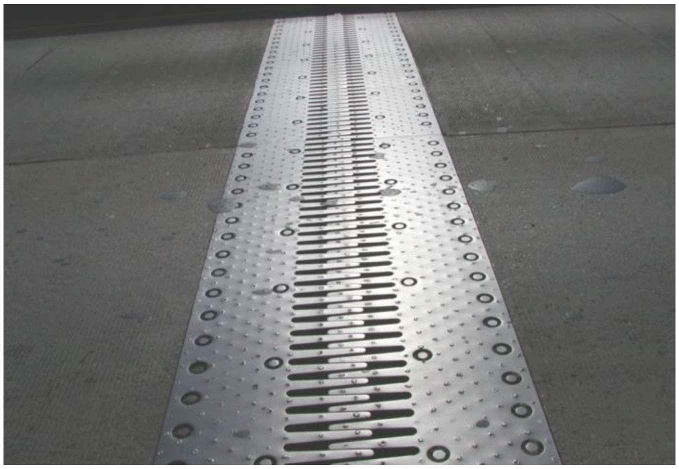

Figure 3.7 Top View of a Finger Plate Joint

Figure 3.8 shows a failed joint where drainage is occurring directly onto the bridge bearings and pier; this situation can cause substantial damage.

Figure 3.8 Leaky Joints Lead to Problems at Bearings and Pier Caps

3.1.2.5 Curbs and Sidewalks

Curbs are provided along sidewalks and safety walks. Curbs can be constructed of reinforced concrete (Figure 3.9), precut granite, timber, or steel plates. Precut granite is popular in areas where there is snowplow usage, since granite can withstand the scraping of the plow blade.

Sidewalks are provided on structures where pedestrian traffic warrants their use. Types of sidewalks are:

- Reinforced concrete
- Steel plate
- Wooden plank

Figure 3.9 Bridge Sidewalk Using Stamped Concrete for Aesthetics and Concrete Curb

3.1.2.6 Railing and Safety Features

Bridge barriers can be broken down into two categories including the bridge railing and the pedestrian railing. The bridge railing is used to guide, contain, and redirect errant vehicles. The pedestrian railing is used to protect pedestrians.

Examples of railings and materials include:

- Timber rail
- Metal angles, tubes, thrie beam bridge railing, and bars
- Combination bridge-pedestrian railing
- New Jersey barrier - a very common concrete barrier

Figure 3.10 End Termination of Metal Beam Guide Rail at Approach Transition

In addition to bridge railings, the transition to the bridge is an important safety feature that should be maintained.

Terms used for the approach guardrail include:

- Approach end treatment
- Approach systems

- Approach transition (see Figure 3.11)

The thrie beam bridge railing system (shown in Figure 3.11) stiffens the typical guardrail and has a larger surface area so vehicles will not get caught underneath.

Figure 3.11 Approach Guardrail Transition

End treatments, such as the example shown in Figure 3.12, are designed to slow and redirect the vehicle from hitting the bridge. They are also designed to absorb energy from the vehicle. Other end treatments include impact attenuators and sand-filled barrels.

Figure 3.12 Example of an Approach Guardrail End Treatment

While railings protect vehicles and pedestrians, another important safety feature on bridges is lighting. Lighting on bridges can consist of travelled way lighting, sign lights, traffic control lights, navigation lights, and aerial obstruction lights. The last two types of lights are special categories which are encountered only on bridges over navigable waterways or on bridges having high towers. Many bridges have no lighting.

3.1.2.7 Drainage

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. Bridge drainage is since ponded water, especially in colder climates, can damage to a bridge or become a safety concern. An effective system of drainage is essential to proper maintenance.

A deck drainage system has the following components:

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

Together these drainage components form a deck drainage system. A joint drainage system is a separate gutter or trough used to collect water passing through a finger plate or sliding plate joint.

Substructure drainage allows water in the fill material behind an abutment or wingwall to drain any accumulated water. Substructure drains are weep holes or substructure drain pipes.

3.1.3 Superstructure

The superstructure carries loads from the deck across the span and to the bridge supports. The superstructure is that component of the bridge which supports the deck or riding surface, as well as the loads applied to the deck.

There are many types of superstructure such as:

- Slabs
- Single web beams/girders (I Beams)
- Box beams/girders (Multi-web)
- Trusses
- Arches
- Rigid frames
- Cable-supported bridges
- Movable bridges
- Floating bridges
- Suspension
- Segmental
- Movable (Lift, Bascule, Swing)
- Tee Beam

Schematics of several of these bridge types are shown in Figure 3.13.

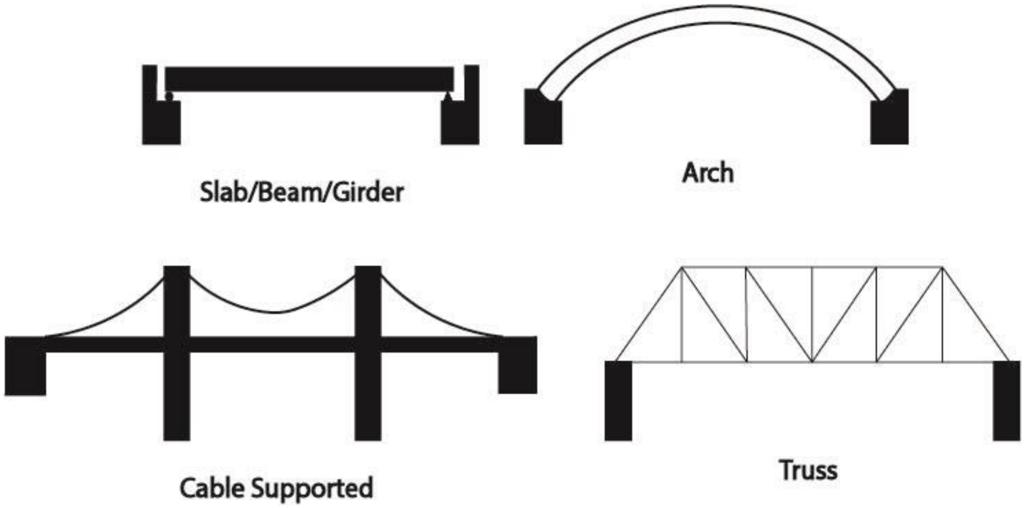

Figure 3.13 Schematics of Several Superstructure Types

3.1.3.1 Beams/Girders

Steel Beams/Girders

The term "steel rolled beams" comes from the "rolling" of the beams in one complete piece. Heated steel blocks are rolled into standard rolled shapes at the steel mill.

Steel built up I-shaped and box-shaped girders offer a great deal of flexibility. They allow the bridge engineer to customize the members for their particular need. Historically, I-girders were fabricated using rivets, plates, and angles. A schematic of a riveted I-girder is shown in Figure 3.14 (left). Riveting was replaced by high strength bolting and welding to produce built up shapes. A built up I shaped girder fabricated from plates welded together is commonly referred to as a Plate Girder. An example of a welded plate girder is shown above in Figure 3.14 (right).

Built up steel shapes can also be used for floor beams, trusses, and substructure members.

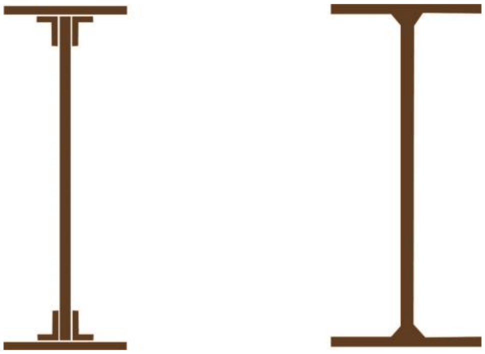

Figure 3.14 Riveted I-girder (left) and Welded Plate Girder (right)

Steel I-shaped and box built up girders are used for intermediate span lengths not requiring a truss or other bridge type capable of very long spans, and yet requiring a member larger than a rolled beam. The elements of these girders are a web plate welded to flange plates. The components of a plate girder are two flange plates, a web plate, and a set of vertical plates attached to the web plate called stiffeners. Stiffeners at concentrated loads are bearing stiffeners. An example is shown in Figure 3.15. Other stiffeners include transverse stiffeners, which improve shear strength of web plates and offer locations for connection of cross frames.

Examples are shown in Figure 3.16. Shear studs are used to provide composite action with concrete bridge decks. Shear studs are also used with rolled beams for this purpose (see Figure 3.17). Composite action will be defined in Chapter 4.

Figure 3.15 Bearing Stiffener

Figure 3.16 Intermediate Stiffeners


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Figure 3.17 Shear Studs Being Welded On

Steel box girders can be efficient for curved bridges due to their torsional stiffness; i.e., the ability to resist twisting. Torsion is further discussed in Chapter 4.

Concrete Beams/Girders

Common shapes of reinforced concrete members are:

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

Schematics of these shapes are shown in Figure 3.18.

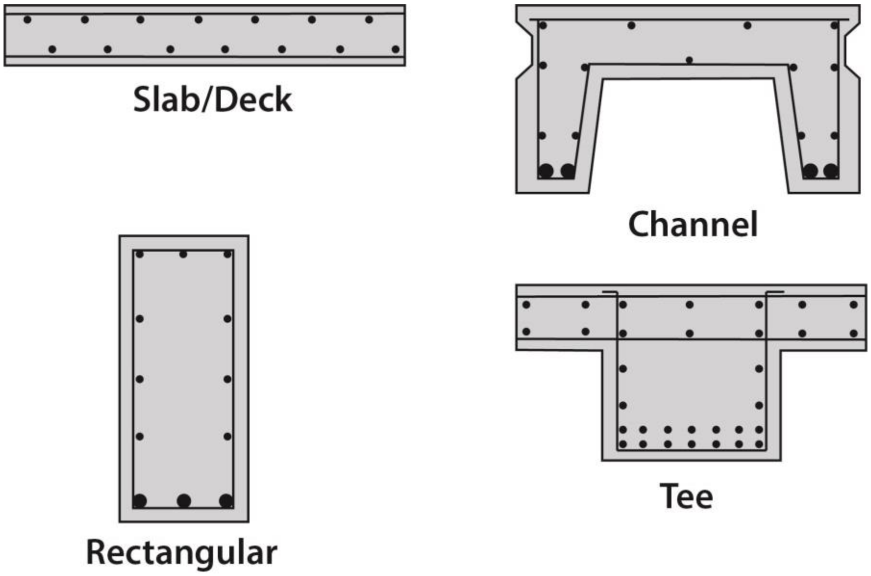


Figure 3.18 Typical Concrete Beam / Girder Shapes

Bridges using these shapes with mild steel reinforcement are often Cast-In-Place (CIP) concrete. Concrete members of this type are used for short and medium span bridges, usually less than 100 feet.

Prestressed concrete girders are produced using high strength concrete and steel tendons. Prestress means that during fabrication, compressive stress is introduced into areas of the beam that normally would be in tension when the beam is subjected to loads. Under loads, those initial compressive stresses are reduced instead of tension stresses being introduced. The prestressing introduces an initial clamping force into the concrete member.

Figure 3.19 shows the relative difference in reinforcing for comparable steel beams. Use of higher strength steel and prestressing requires less tension reinforcement than that required by a conventionally reinforced beam.

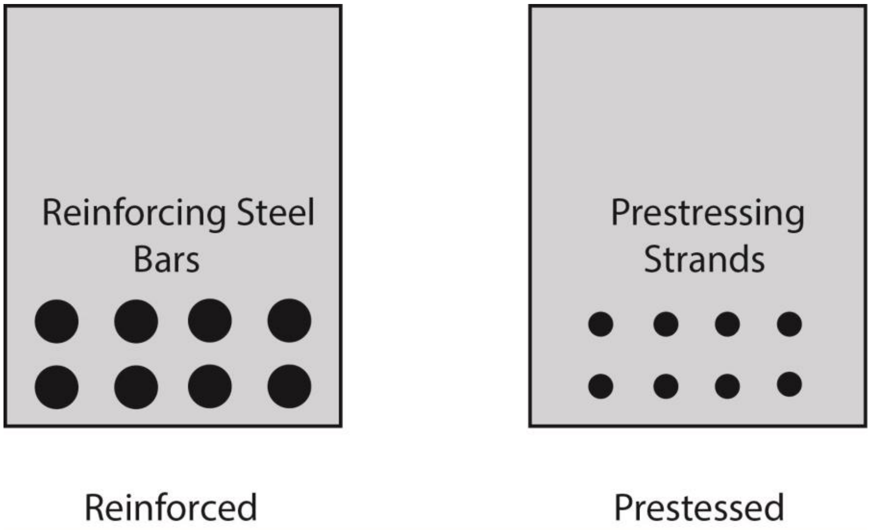


Figure 3.19 Non-Prestressed Reinforced Concrete vs. Precast Prestressed Concrete

See Figure 3.20 for typical prestressed concrete girder sections. The concepts of tension and compression are discussed in Chapter 4 Bridge Mechanics.

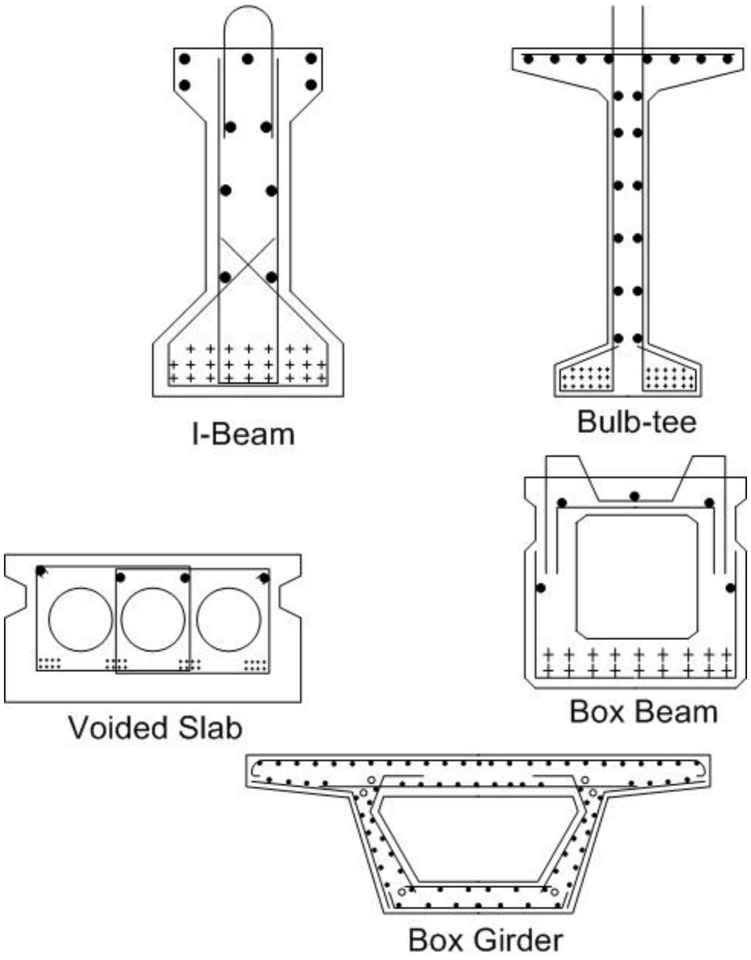


Figure 3.20 Typical Prestressed Concrete Girder Sections

Prestressed concrete is generally more economical than conventionally reinforced concrete due to the benefits of the prestressing, and because prestressing steel is very high strength, fewer pounds of steel are needed. However, prestressed strand repair is difficult.

There are two types of prestressed concrete members: pre-tensioned or pre-stressed and post-tensioned. In a pre-tensioned member, the strands are tensioned before the concrete is placed around them; whereas in a post-tensioned member, the strands are stressed after concrete has cured. For post-tensioning, the concrete is poured first with ducts providing a void for the strands to be passed through later. The strands (rubber band) are then anchored to one end of the girder, tensioned, and anchored at the tensioning end, imposing compression on the girder.

Concrete I-beams, distinguished by their "I" shape, are superstructure members and support the deck. This type of beam is 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 has been used for spans as long as 200 feet.

Box beams are distinguished by a square or rectangular shape and internal void, and are typically 18 inches or greater in depth. Box beam bridges may be adjacent or spread, and have a practical span lengths of 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 exceed 150 feet with segmental construction.

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.

A segmental concrete bridge is fabricated piece-by-piece. An example of a segmental bridge is presented in Figure 3.21. The pieces, or segments, are post tensioned together during the construction of the bridge. The superstructure is constructed of precast concrete.

Several characteristics are common to most segmental bridges:

- Used for long span bridges
- Generally comprised of box girder segments
- Each segment is the full width and depth of the bridge
- For very wide decks, many segmental box girders may consist of two-cell boxes or adjacent single boxes
- The lengths of the segments are determined by the available construction methods and equipment

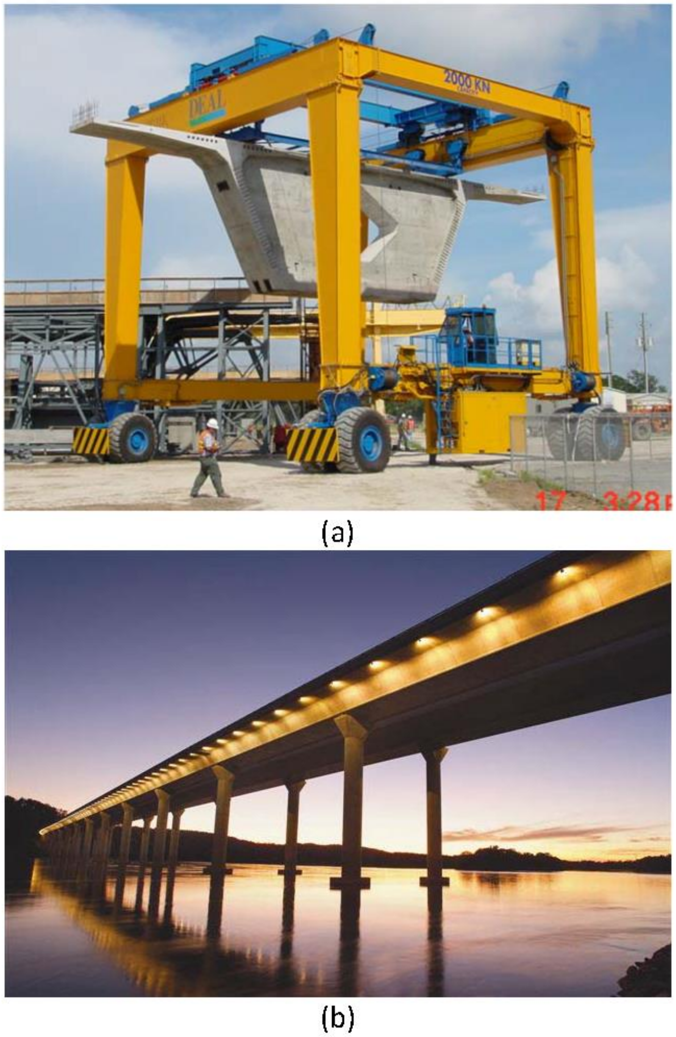


Figure 3.21 Segmental Precast Concrete Box Girder Bridge Examples (a) Precast Segment, (b) Completed Bridge

Timber Beams/Girders

Timber superstructures are still common on secondary and local roads, as well as on forest and logging roads. In 2013, four percent of highway bridge superstructures were timber, and seven percent of highway decks were timber. These include covered bridges found in the northeastern states, as well as timber decks on timber beams, and concrete decks on timber beams. Timber deck bridges are also common, along with timber trusses, arch, and suspension superstructures. Some covered bridges built in the mid-1800s are still in service. Many use a truss framework for the superstructure, although some use arches.

Log beam bridges are constructed from round logs that have been debarked, but are otherwise used in their natural shape. Sawn lumber planks are spiked into the logs to form the roadway surface. In a few cases, soil and rocks are used in place of the planks. A log is sometimes installed at midspan under the log beams to better distribute the live load.

Log beams are generally 20 to 60 feet in length, depending on the length and diameter of available logs. Log bridges are used on logging and low-volume roads, with life cycles of 10 to 20 years.

Sawn lumber beams are fabricated using timbers that usually are 4 to 8 inches wide and 12 to 18 inches in depth. Timber beam bridges employ timber blocking to keep the beams vertical and laterally supported. Common spans are 15 to 25 feet, with a maximum span of 30 feet for general highway use. Longer bridges use intermediate piers to support multiple simple spans of sawn lumber beams. Service life of timber beam bridges can be 40 to 70 years with proper maintenance.

Glulam (Glued-Laminated) timber beams have been available for about 60 years and allow for longer spans up to 140 feet and fewer beams per bridge. Typical spans are 20 to 80 feet.

3.1.3.2 Timber Longitudinal Deck Superstructures

Longitudinal deck superstructures use glulam or nail-laminated sawn lumber or stress laminated sawn lumber with the width of the boards turned vertical to act as both deck and beam in one unit. Typically used with distributor beams at midspan, like the much older log beams, longitudinal deck superstructures are often used for lightweight deck replacements. Similar in application to concrete slab bridges, they have a maximum clear span of 35 feet. These bridges are typically well-suited for crossings where it is desirable to maximize vertical clearance or reduce superstructure dead load.

Nail-laminated deck superstructures use sawn lumber that is either 2 or 4 inch nominal width by 8 to 16 inches deep and is nailed to the adjacent two boards in three alternating patterns repeating on every third board. Rails are often mounted from the underside of the deck or use posts through the edge of the deck by creating “notches” with shorter boards in the nail-lamination.

Figure 3.22 (left) shows the use of a pre-fabricated nail-laminated deck superstructure as a lighter alternative to concrete decks, used here to replace a former open steel grid deck and allow a previously closed single-lane roadway bridge to be re-opened for a multi-use trail bridge. On this bridge, the timbers were not topped by asphalt for a wearing surface due to weight concerns.

An example of a site-constructed nail-laminated bridge is shown in Figure 3.22 (right). The bridge also features the typical waterproof membrane and asphalt pavement to smooth out the uneven edges between the individual timber boards. A note of caution with asphalt overlays is that they tend to crack along the edges of the boards in the laminations, due to expansion and contraction of the wood. These superstructures have been used in other locations to replace roadway bridge superstructures and to extend the life of roadway bridges for vehicular traffic as well.

Figure 3.22 Nail-Laminated Decks. Pre-Fabricated (left) and Site-Constructed (right)

3.1.3.3 Trusses

A truss is a form of structural system that provides high load carrying capacities and can be used to span greater lengths than rolled beams and girders. A schematic of a steel truss is shown in Figure 3.23. Truss members (e.g., chords, verticals, and diagonals) carry axial tension and compression loads. Truss members are selected for their strength in tension or compression, and loads that will introduce bending moment in them should generally not be applied.

Trusses can be constructed from timber or steel, and some smaller truss bridges have been constructed of Fiber Reinforced Polymer (FRP). Usually members in tension are smaller in cross section than compression members. Channels, steel rods or angles are often used for tension members. Examples of compression members include built up girders, latticed channels, or steel box sections.

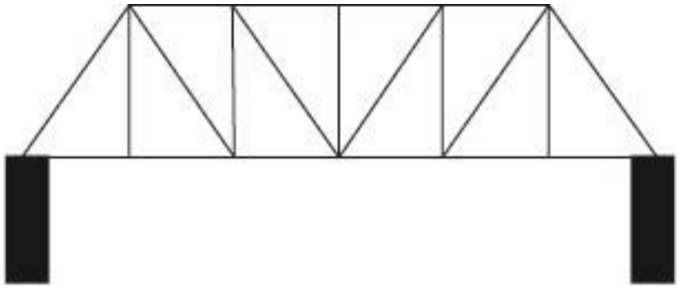


Figure 3.23 Schematic of Steel Truss

Types of structural members in a truss bridge (i.e., primary members) are listed below and are shown in Figure 3.24.

Chords: The upper and lower longitudinal members that extend the full length of a triangular section are called chords. For a simple span, the bottom chord will always be in tension, while the top chord and end posts will always be in compression. The bottom and top chords are primary structural members. Failure of either chord will make the truss unsafe.

Diagonals: The diagonal members connect successive top and bottom chords and resist either tension or compression depending on the truss configuration.

*Vertical*s: Vertical web members connect the top and bottom chords and resist tension or compression stresses depending on the truss configuration. Most vertical members are primary structural members.

Floor Beams: Floor beams span between the trusses at panel points and carry loads from floor stringers and the deck system to the trusses.

Stringers: Stringers span between floor beams and provide primary support for the deck system. The deck loading is transferred through the stringers to the floor beams and then to the truss.

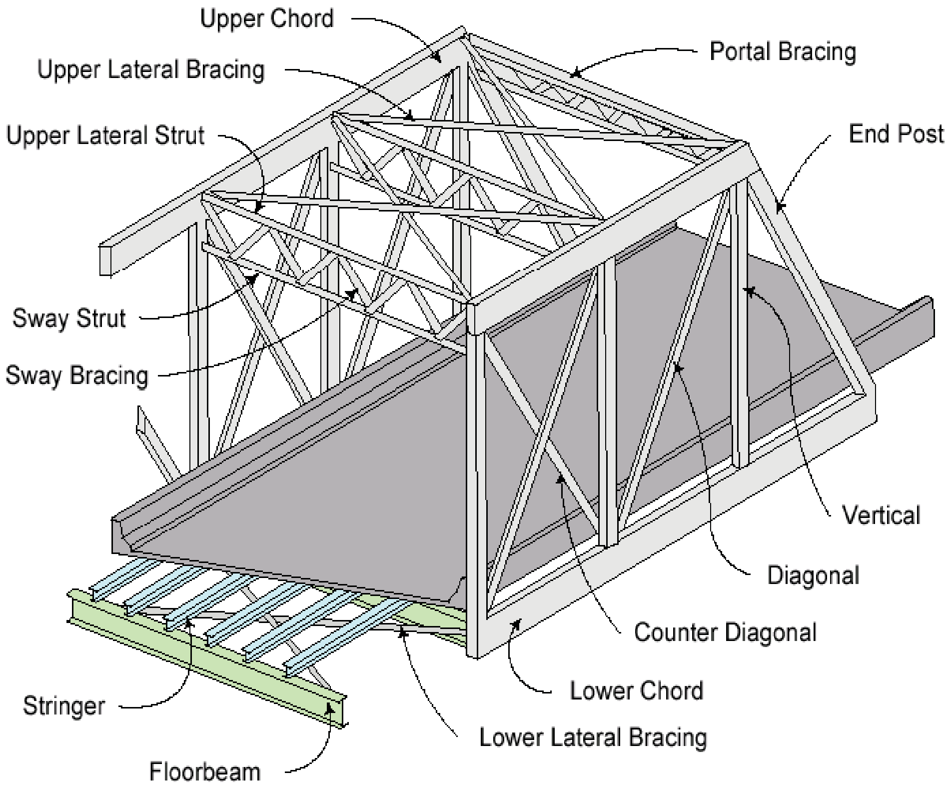
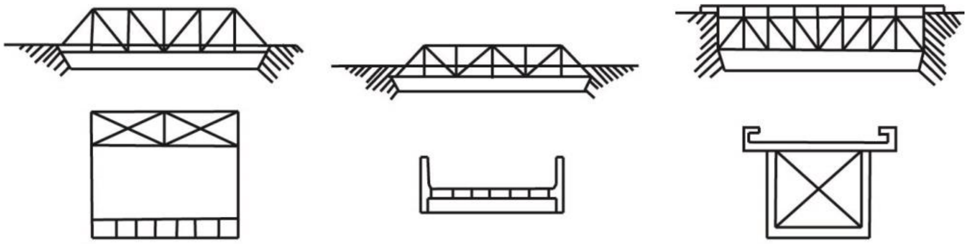


Figure 3.24 Truss Components (Courtesy of ODOT)

There are three types of timber trusses including through trusses, pony trusses, and deck trusses, with many variants in the arrangement of the structural members. Figure 3.25 shows the typical timber truss shapes.



Through Truss

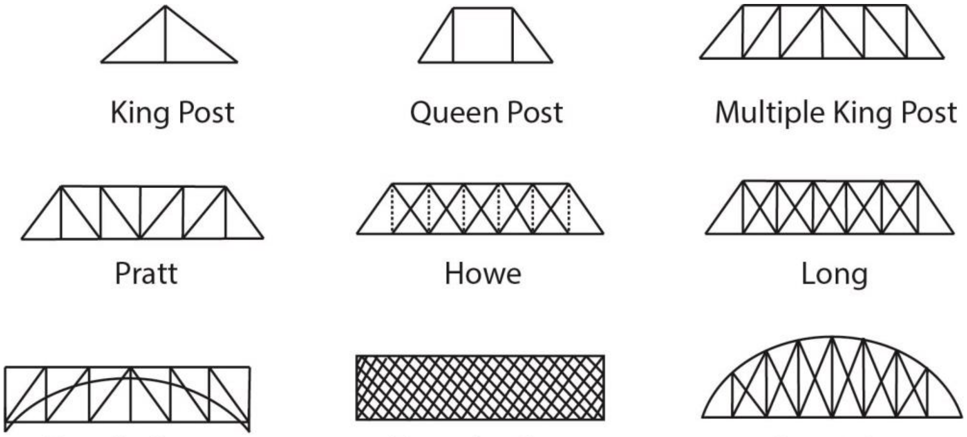
Pony Truss

Deck Truss

Figure 3.25 Typical Types of Timber Trusses

The bowstring truss (shown in Figure 3.26) was historically constructed with lumber top chords, and later with steel. But with the advent of glulam beams, the top chords have sometimes been replaced by glulam beams which are much easier to curve in the shop into either one-piece or two-pieces per arch.

In a pony truss, the deck is located in-between the top and bottom chord such that there are no top chord cross-braces. Many through trusses look similar to deck trusses that have been vertically flipped. Covered bridges often used Howe, town lattice, queen post, king post, or burr arch trusses for the superstructure.



King Post

Queen Post

Multiple King Post

Pratt

Howe

Long

Burr Arch

Town Lattice

Bowstring

Figure 3.26 Typical Types of Through Trusses

Floor Beam – Stringer System

Stringers span longitudinally between floor beams and transmit loads from the deck to the floor beams. The floor beams span between trusses and transfer loads from the stringers to the trusses, shown in Figure 3.24. Floor beams can also span between longitudinal girders. Floor beams can be used without stringers. In this application the deck spans longitudinally between the floor beams.

Stringers

The term stringers is usually associated with a floor beam system, but sometimes the term is used to describe what has been defined in this manual as beams/girders.

Stiffeners, Bracings, Gusset Plates, and Connection Plates

The individual members of beam and girder structures are tied together with diaphragms and cross frames; trusses are tied together with portals, cross frames, and sway bracing. Diaphragms and cross frames stabilize the beams and trusses and distribute loads among them. A diaphragm is usually a solid web member, either of a rolled or built up shape. An example of a diaphragm is shown in Figure 3.27. A cross frame is a truss, panel, or frame.

Figure 3.27 Diaphragm (K-bracing)

Bearings

Bearings transmit loads from the superstructure to the substructure and, as needed, allow movement due to expansion, contraction, and rotation. Typical of bridge bearings include fixed, rocker, roller, sliding plate, elastomeric, pot, and disc.

A bridge bearing has four basic elements (see Figure 3.28):

1. Sole plate
2. Bearing device
3. Masonry plate
4. Anchor bolts

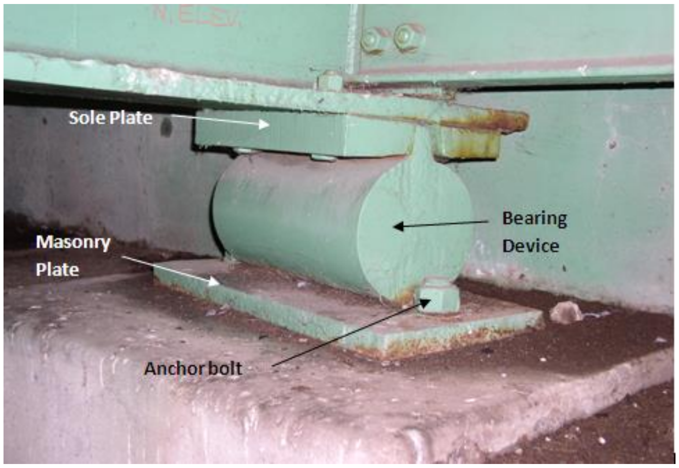


Figure 3.28 Four Basic Elements of a Steel Roller Bearing

Steel roller bearings, shown in Figure 3.28, can need substantial maintenance. In the figure, dirt and debris are observed where the round bearing device comes in contact with the masonry plate. Since the bearing must roll on the masonry plate to allow the bridge to move, dirt and debris may prevent the motion. If that happens the bearing is referred to as "frozen". If a bearing cannot move, something else must give and that can, for example, create cracks in concrete members. New maintenance-free bearings no longer rely on steel, but on elastomer materials. An example of an elastomeric bearing is shown in Figure 3.29.

Figure 3.29 Elastomeric Bearing

3.1.4 Substructure

3.1.4.1 Abutments

Abutments provide support for the ends of the superstructure and retain the roadway approach embankment. Abutments may be founded on spread footings, piles, or drilled shafts.

Basic types of abutments, shown schematically in Figure 3.30, 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 3.31 and Figure 3.34).
- 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. New construction often uses this type of abutment (see Figure 3.32).
- 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 made of rock.
- 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 3.33).
- Semi-integral abutment - similar to integral abutments, however, the superstructure and the top of the abutment act as one unit, but the bottom portion act independently of the superstructure. This is achieved by a joint between the top and bottom portions

of the abutment which will allow for un-restrained rotation and thermal movement (see Figure 3.31).

- Mechanically Stabilized Earth (MSE) abutment (see Figure 3.34 and Figure 3.35).

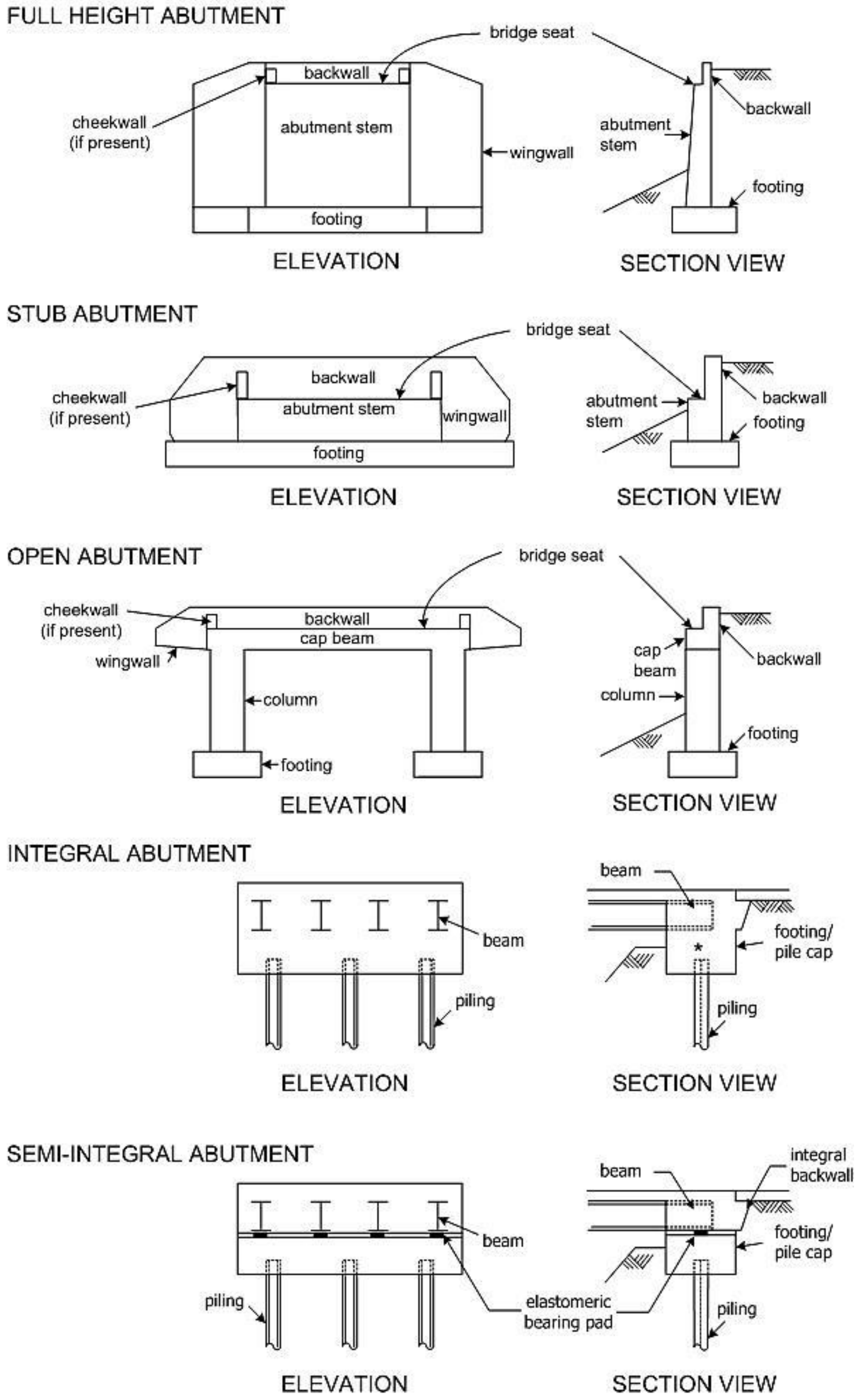


Figure 3.30 Schematics of Several Abutment Types

Figure 3.31 Abutment Supporting Superstructure End

Figure 3.32 Example of a Shorter Abutment

Figure 3.33 Example of an Integral Abutment

Figure 3.34 Abutment Utilizing Mechanically Stabilized Embankments (MSE)

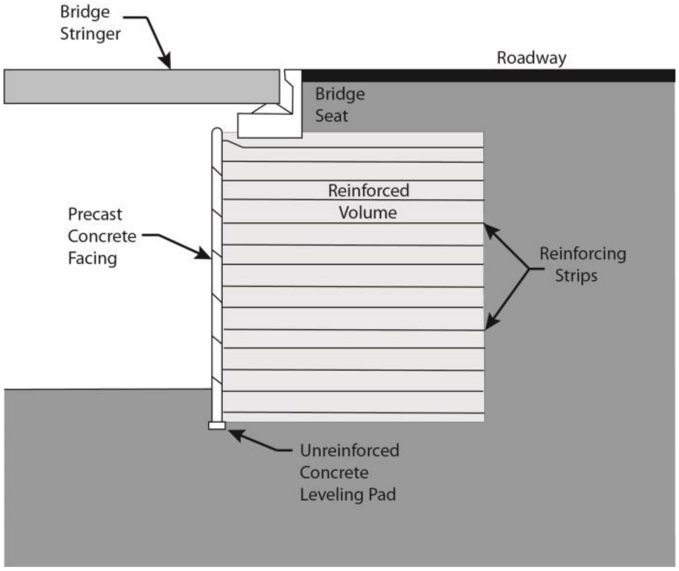


Figure 3.35 Concept of MSE Abutment

3.1.4.2 Wingwalls

Wingwalls are the retaining wall extension of an abutment. Their purpose is to retain side slope material of an approach roadway embankment. An example of a wingwall is shown in Figure 3.36.

Figure 3.36 Example of a Wingwall

3.1.4.3 Piers

Bridge piers, shown in Figure 3.37, transmit the load of the superstructure to the foundation material and provide an intermediate support between abutments.

Figure 3.37 Piers Support the Superstructure

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. There are several basic types of piers:

- Solid shaft pier (see Figure 3.38 and Figure 3.39)
- Column pier (see Figure 3.40)
- Column pier with web wall
- Cantilever or hammerhead pier (see Figure 3.41)
- Column bent
- Pile bent (see Figure 3.42)

Figure 3.38 Solid Shaft Pier

Figure 3.39 Solid Shaft Pier

Figure 3.40 Column Pier

Figure 3.41 Hammerhead Pier

3.1.4.4 Caps

Caps are the topmost portion of a pier or a pile bent. Their purpose is to (1) distribute the loads to the columns or piles and (2) to hold columns or piles in their proper relative positions. Caps are usually horizontal members and can be made of concrete, steel or timber. An example of a concrete cap is shown in Figure 3.42. See sections on "Piers" and "Piles" in this chapter for more information and photos.


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Figure 3.42 Concrete Cap as Part of Pile Bent Structure

3.1.4.5 Piles

Piles are shaft-like members that carry load to the underlying rock or soil strata. A lead-on pile driver holds the pile-in-place and also guides the piles into the ground at the proper angle, as shown in Figure 3.43.

Figure 3.43 Lead-on Pile Driver

When to Call the Engineer

An engineer should be consulted when piles normally driven into the ground become exposed by scour or erosion, since the piles can become unstable.

Most piles are buried, so not visible. However, a pile bent is a row of driven or placed piles extending above the ground surface supporting a pile cap, as shown in Figure 3.44.

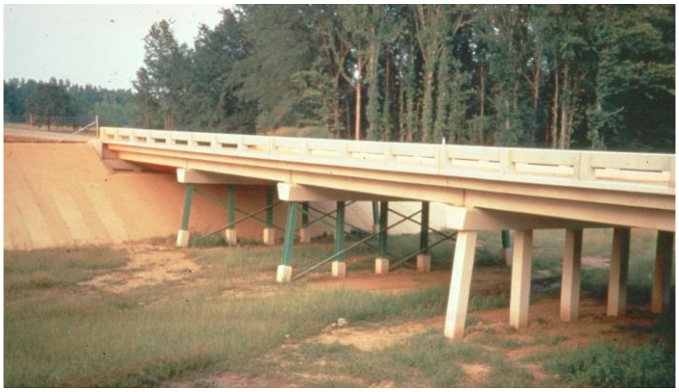

Figure 3.44 Example of Pile Bents

Types of piles include:

- Steel H-piles
- Steel pipe piles (sometimes filled with concrete)
- Timber piles
- Prestressed concrete piles
- Reinforced concrete cast in place into pre-drilled holes (also called drilled shafts)

3.1.4.6 Columns

A column is a general term applying to a vertical member having, in general, a considerable length in comparison with its transverse dimensions. A column transfers load from the superstructure into the ground. The term column and pier are sometimes used together to describe the element, see section on “Piers” for more information.

3.1.4.7 Footings

Footings are the enlarged, lower portion of a substructure that distribute the structure load either to the earth or to supporting piles. A common footing is the concrete slab.

3.1.5 Structures Located in the Channel

Rivers are dynamic systems. During floods, significant changes can occur in a short period of time. There are several ways in which channels can change and thereby jeopardize the stability and safety of bridges. For this reason, structures are built in the channel to control this potentially dynamic system. On the other hand, structures are also placed in the channel to protect the bridge, usually the substructure. Both of these structure types are described in greater detail below.

3.1.5.1 Fender Systems

Fender systems are structures that act as a buffer to protect bridge piers exposed to collision by floating debris and water-borne traffic. Fenders are called ice guards in regions with ice floes. A fender pier is a pier-like structure which performs the same service as a fender but is generally more substantially built. An example is shown in Figure 3.45.

Figure 3.45 A Bridge Fender System

3.1.5.2 Dolphins

Dolphins are a group of piles driven close together or a caisson placed to protect portions of a bridge exposed to possible damage by collision with river or marine traffic. Examples are shown in Figure 3.46.

Figure 3.46 Examples of Dolphins. Timber Dolphin (left) and Steel Pipe Pile Dolphin with Concrete Cap (right).

3.1.5.3 Slope Protection

Slope protection is a surfacing of stone, concrete or other material deposited on a sloped surface to prevent its disintegration by rain, wind or other erosive action; also known as slope pavement. Slope protection can consist of the placement of geotextiles, wire mesh, riprap, paving, revetment, plantings or other materials on channel embankment. The purpose is to protect the slope from erosion, slipping or caving or to withstand external hydraulic pressure.

Figure 3.47 is an example of slope protection using a gabion basket. A gabion basket is a wire mesh filled with rocks. Gabions can be stacked. A common type of slope protection for bridges is installation of riprap, or large stones, placed along the slope. Figure 3.48 is a photo showing riprap protecting a bridge abutment.

Figure 3.47 An Example of a Gabion Basket Serving as Slope Protection

Figure 3.48 Riprap Used for Slope Protection

In addition to gabions and riprap, there are other ways to protect a channel. Some include poured concrete, articulated blocks, and vegetation. These protection methods are covered in greater detail in Chapter 15.

3.1.5.4 Spurs and Dikes

Spurs and dikes are used to prevent scour or redirect water away from bridges. A spur is a projecting jetty-like construction placed adjacent to an abutment or embankment. A dike is an earthen embankment constructed to retain or redirect water. When used at a bridge, the dike prevents stream erosion and localized scour. As a result, the stream current is directed such that debris does not accumulate.

3.2 Bridge Types and Design Details

3.2.1 Multi-Girder System Bridge A multi-girder bridge is a popular type of bridge. The girders, as described in Section 3.1, can be concrete, steel or timber. Examples of timber and concrete multi-girder bridges are presented in Figure 3.49 and Figure 3.50. An attractive feature of the multi-girder system is that there is redundancy; if one girder cannot hold its load there are others that can share the load. The disadvantage is that span lengths are limited, and they have more bearings to maintain than a two girder or truss bridge.

Figure 3.49 Timber Multi-Girder Bridge

Figure 3.50 Prestressed Concrete Multi-Girder Bridge

3.2.2 Girder and Floorbeam Bridge

A girder and floorbeam bridge is rarely used in new construction since there is no redundancy. If a girder failure is imagined in the example 2-girder system bridge shown in Figure 3.51, the entire bridge could collapse. This is in contrast to the multi-girder bridge that has redundancy; failure of one girder does not cause immediate failure of the bridge. The advantage of this type of bridge is that there are fewer bearings to maintain compared with a multi-girder bridge.

Figure 3.51 2-Girder Steel Bridge

3.2.3 Thru-girder (Concrete and Steel)

A thru-girder bridge consists of two girders on the outer edges of the roadway. The bridge deck is supported by floor beams that span between these two girders. These types of bridges are most commonly used for railroads since very heavy loadings can be supported. They are also used in locations where distance between the top of the roadway and bottom of the structure is restricted. However, similar to the 2-girder bridge, this system lacks redundancy. Thru girders are also exposed to possible vehicle impacts, as well as exposure to precipitation and de-icing chemicals in colder climates. Figure shows a thru-girder bridge.

Figure 3.52 Thru-girder Bridge

3.2.4 Slabs

In bridges, loads from the slab are transmitted vertically to the substructure without the use of girders or beams. As a result, slab bridges are used for short span bridges, typically less than 30 feet. The entire superstructure of a concrete slab bridge can be constructed in one pour. Similarly, the timber planks become the entire superstructure for a timber slab bridge. The advantage of slab bridges is that they are relatively simple to construct, but they are limited in the distance they can economically span.

3.2.5 FRP Decks and Superstructures

Fiber Reinforced Polymer (FRP) materials have been used in bridge construction for more than 25 years, mostly for demonstration and research projects. However, they are becoming more widely accepted as a substitute to concrete, timber, and steel. FRP materials are very strong, much stronger than concrete on a strength to weight basis, and do not rust like steel or decay like timber. FRP materials have been successfully used in deck replacements where a lighter weight deck was needed, in pedestrian bridges and bridges in remote locations where transporting large girders could be a problem. FRP is used for various repairs and for strengthening of bridges.

3.2.6 Rigid Frames

Rigid superstructures are characterized by rigid (moment) connections between the horizontal girder and the legs. Legs are the rigid vertical supports with moment connections to the other portions of the superstructure. 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 floor beams and longitudinal stringers to support the deck. The advantages of rigid frame bridges are reduced structure depth at midspan and reduced space requirements for approaches/abutments. The disadvantages include that they are less tolerant of settlement than other types of bridges. An example of a bridge with a rigid frame is shown in Figure 3.53.

Figure 3.53 Example of a Rigid Frame Bridge

3.2.7 Trusses

There are a great variety of truss systems in existence, since engineers from the beginning of modern bridge building have sought the perfect weight-to-load carrying proportions. In general, truss nomenclature is usually related to the manner in which the truss provides support relative to the deck. For a deck truss bridge (see Figure 3.54) the truss supports the bridge deck from underneath. For a through truss bridge, the truss support is provided from above the bridge deck (see Figure 3.55). Trusses have the advantage of spans up to 1300 feet, but they also have the disadvantage of non-redundancy. Many trusses also have connections that are prone to trapping moisture and debris.

Figure 3.54 Deck Truss Bridge

Figure 3.55 Through Truss Bridge

3.2.8 Arches

Similar to truss bridges, arch bridges have been around a long time, and the nomenclature is similar. Arch bridges are still constructed today for spans up to 1800 feet. The arch handles large compressive forces and the vertical components can be either in tension or compression depending on the arch type. A deck arch bridge has vertical spandrels, as shown in Figure 3.56, that carry loads from the deck to the arch. A through arch bridge uses tension members, e.g., steel cables, to support the roadway deck. Arches have the advantage of being able to span longer distances, but have the disadvantage of being redundant.

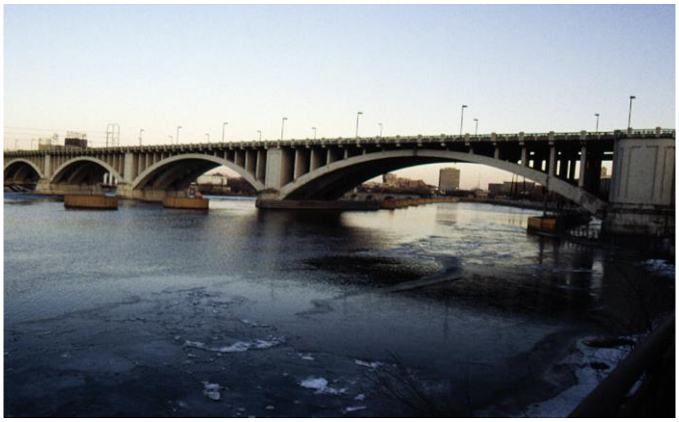

Figure 3.56 Deck Arch Bridge

Glulam suspension arches have allowed timber to enter into the suspension market as an alternative to steel arches. Arches made of glulam can span crossings up to 200 feet, and can be parabolic or segmental circular in shape. There are two main types: two-hinge arches hinged only at the abutments and three-hinge arches, where the third hinge is located at the top of the arch at midspan. Roadways can be connected by glulam posts or steel cables to the arch.

An example of a three-hinge glulam suspension arch bridge is shown in Figure 3.57. Notice the third hinge is a steel pin at mid-span on the arch. Glulam floorbeams support the paved two-lane road above, with the sidewalk supported by cantilevering the glulam floorbeams on the arch.

Figure 3.57 Glulam Suspension Arch Bridge

Glulam deck arches had their start in Oregon in the 1940’s but have since grown to be used throughout the country. Glulam deck arches offer an alternative to steel deck arches, especially in regions where timber is plentiful and glulam production is nearby. Often these appear as trestle-like timber frames above the arch as the bottom chord, providing tall clear spans over highways and deep waterways. Keystone Wye Interchange Bridge in South Dakota is a well-known example of a glulam deck arch bridge, as shown in Figure 3.58. In general, glulam deck arch bridges have been used to span deep valleys. Similar to glulam suspension arches, glulam deck arch bridges can be two-hinged or three-hinged.

Figure 3.58 Glulam Deck Arch Bridge

3.2.9 Culverts and Pipes (Concrete and Metal)

3.2.9.1 Introduction

Culverts are small bridges that are constructed entirely below and independent of the roadway surface. Culverts do not have a deck, superstructure, or substructure. A culvert is usually a hydraulic structure, and its main purpose is to transport water flow efficiently, but can also be used for pedestrian, vehicle, or animal underpasses. An example of a culvert is shown in Figure 3.59.

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

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

A culvert takes advantage of submergence to increase water carrying capacity.

Figure 3.59 Culvert Structure

3.2.9.2 Headwalls

Headwalls are used to retain the fill, resist scour, and improve the hydraulic capacity of the culvert. Headwalls are usually reinforced concrete, as shown in Figure 3.60, but can be constructed of timber or masonry. Metal headwalls are often found on metal box culverts.

Figure 3.60 Reinforced Concrete Culvert Headwall and Wingwalls

The common types of headwalls are:

- Projecting: The barrel simply extends beyond the embankment (see Figure 3.61). No additional support is used.
- Mitered: The end of the culvert is cut to match the slope of the embankment. This is used when the embankment has slope paving (see Figure 3.62).
- Skewed: Culverts, which are not perpendicular to the roadway, may have their ends cut parallel to the roadway (see Figure 3.63).
- Pipe end section: A section of pipe is added to the ends of the culvert barrel. These are used on smaller culverts.

Figure 3.61 Culvert End Projection

Figure 3.62 Culvert Mitered End

Figure 3.63 Culvert Skewed End

3.2.9.3 Wingwalls

Wingwalls and headwalls support the embankment around the openings of the culvert, as shown in Figure 3.64. This is the same function that an abutment wingwall provides for a bridge.

Figure 3.64 Cast-In-Place Concrete Headwall and Wingwall

Culverts can be rigid, flexible, or something in between. All culvert types carry some loads by soil arching when the fill depth is sufficient. When there is no fill or the fill is shallow, rigid culverts independently support all loads. An example of a rigid culvert is shown in Figure 3.65.

Figure 3.65 Rigid Culvert

Flexible culverts require lateral earth pressure to help maintain their shape and soil arching to carry loads. An example of flexible culverts is shown in Figure 3.66. The loads are distributed through the flexible culvert and backfill. Backfill is critical to the performance of a flexible culvert.

Figure 3.66 Flexible Culverts

3.2.9.3 Box Culvert

One type of rigid culvert is the concrete box culvert as shown in Figure 3.67. Box culverts are used in a variety of circumstances for both small and large channel openings and are easily adaptable to a wide range of site conditions, including sites that require low profile structures. In situations where the required size of the opening is very large, a multi-cell box culvert can be used, as shown in Figure 3.68. A box culvert may have multiple barrels, but it is still a single structure. The internal walls support the top slab.

Figure 3.67 Concrete Box Culvert

Figure 3.68 Multicell Concrete Box Culvert

Concrete box culverts can be cast-in-place or precast. Precast concrete box culverts are generally preferred for speed of onsite construction. For situations with complex site geometries or other special applications, cast-in-place concrete box culverts may be the preferred choice.

3.2.9.4 Barrel/Pipe

Concrete Pipe Culverts are precast. Precast concrete pipe culverts are manufactured in three standard shapes:

- Circular
- Horizontal elliptical
- Vertical elliptical

Circular pipe culverts are very common. In situations where the required size of the opening is very large, two or more concrete pipe culverts may be used, as shown in Figure 3.69.

Figure 3.69 Twin Concrete Pipe Culvert

Elliptical shapes are used in situations where horizontal or vertical clearance is limited. The oblong shape allows the pipe to fit where a circular pipe would not, but still allows for the necessary size opening. Elliptical shaped pipe culverts may also be used when a wider section is desirable for low flow levels.

3.2.10 Cable Supported Bridges

Types of cable supported bridges include suspension, cable stayed, and tied arch.

A suspension bridge uses cables to suspend the roadway deck and, in simple terms, acts like an old fashioned clothes line, as shown in Figure 3.70. A drawback of a suspension bridge is the need to anchor the clothes line, which is costly. Another type of suspension bridge uses a "self-anchored" approach where the cables are anchored to the ends of the deck, making the deck not only a riding surface but also a larger compression element.

A suspension bridge has a deck which is supported by vertical suspender cables that are, in turn, supported by main suspension cables. The suspension cables are supported by saddles atop the towers and are anchored at their ends.

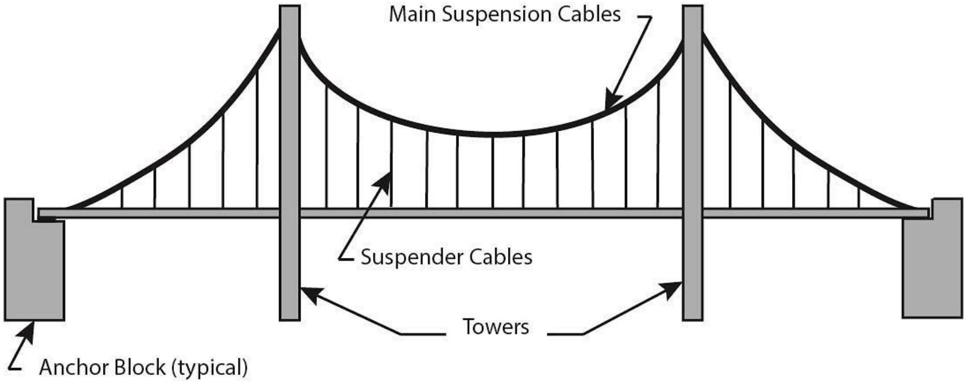

Figure 3.70 Main Elements of a Cable- Supported Suspension Bridge

An example of a cable-supported suspension bridge is shown in Figure 3.71.

Figure 3.71 Cable-Supported Bridge: Suspension Cables and Suspenders

In cable stay bridges, the superstructure is supported by cables or stays that are anchored to towers or pylons located at the main piers. The two major types of cable stay bridges are fan and harp (i.e., parallel), as shown by the schematic Figure 3.72.

Figure 3.72 Types of Cable Stay Bridges. Fan (left). Harp (right).

An example of a cable stay bridge is shown in Figure 3.73.

Figure 3.73 Cable-Supported Bridge: Cable Stayed

The tied arch bridge is one where the reactive horizontal forces acting on the arch ribs are supplied by a tension tie at deck level of a through or half-through arch (see Figure 3.74).

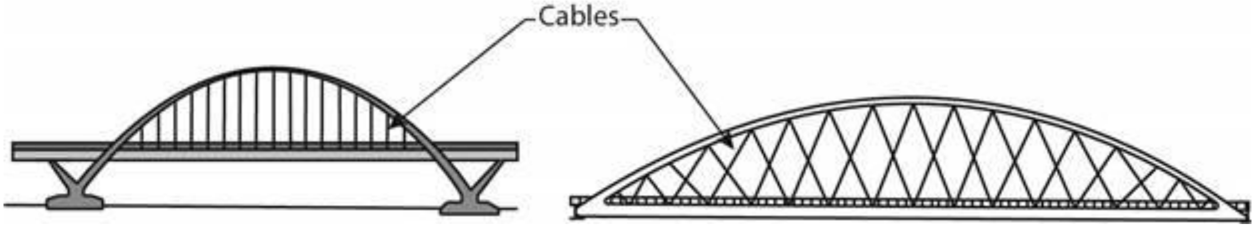

Figure 3.74 Steel Arch with Vertical (left) and Diagonal (right) Hangers

Steel cables are tension members and are used in suspension, some tied-arch, and cable-stayed bridges. Examples of different types of cable cross-sections are shown in Figure 3.75. They are used as the main cables and hangers of this bridge type. The advantage of cable supported bridges is their ability to be used for the longest spans, up to 6500' for suspension bridges and 3600' for cable stayed. The disadvantage is a relatively light and flexible deck which can be subject to vibration in high winds if not stiffened or shaped to be aerodynamically stable.

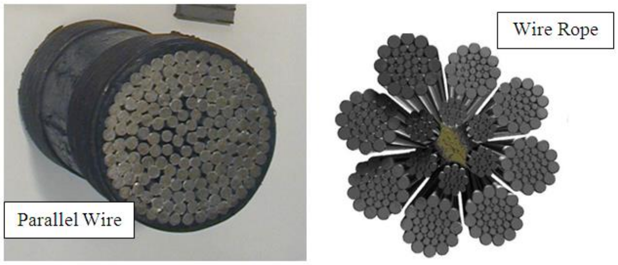

Figure 3.75 Examples of Cable Cross-Sections

3.2.12 Ancillary Structures

Ancillary structures are secondary structures on the highway system, meaning secondary to bridges. Bridges are the main focus of highway structure inspection, maintenance and repair, but recent failures of secondary structures have gotten the attention of the FHWA. Large overhead sign structures have failed and collapsed to the roadway injuring and killing motorists, as have high mast lights, luminaires and retaining walls. Ancillary structures include:

- Structures that support signs
- High mast lighting
- Retaining walls
- Sound walls
- Traffic Signals
- Utilities

Chapter 19 of this manual covers ancillary structures such as bridge mounted signs and utilities.

Figure 3.76 Failed Ancillary Sign Structure

3.3 Chapter 3 Reference List

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