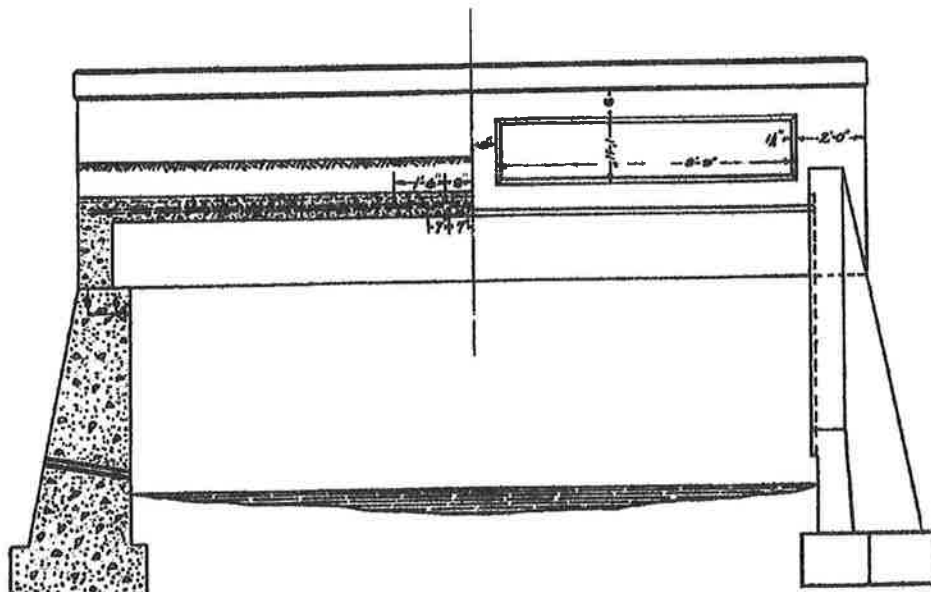


BRIDGE BASICS

A Guide to Common Bridge Types



HALF SECTION

*HALF ELEVATION
DOWNSTREAM SIDE*

2005

LICHTENSTEIN CONSULTING ENGINEERS

Suite 818

One Oxford Valley

Langhorne, Pennsylvania 19047

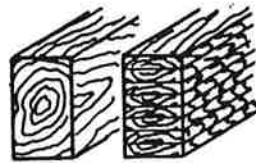
(215) 752-2206

BASIC MEMBER SHAPES

TIMBER



PLANKS



BEAMS

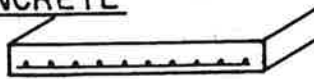


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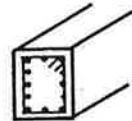


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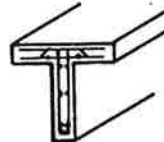
CONCRETE



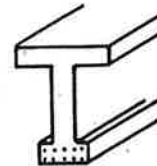
SLAB



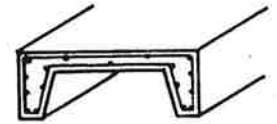
RECTANGULAR BEAM



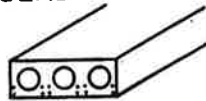
T-BEAM



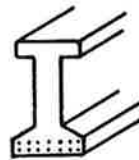
PS BULB TEE BEAM



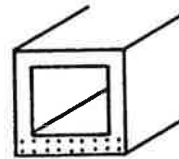
CHANNEL BEAM



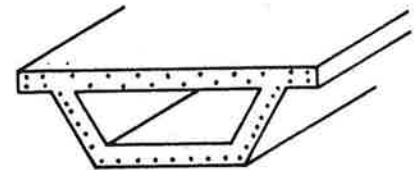
PS VOIDED BEAM



PS I BEAM

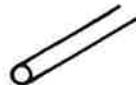


PS BOX BEAM

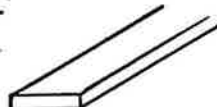


PS BOX GIRDER

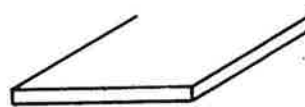
ROLLED STEEL



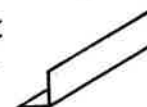
RODS



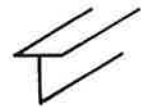
BAR



PLATE



ANGLE



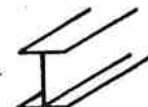
TEE



CHANNEL



S-BEAM

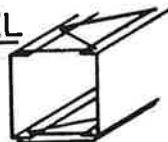
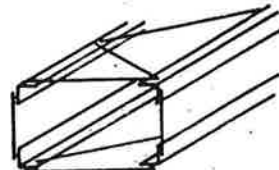


WF BEAM

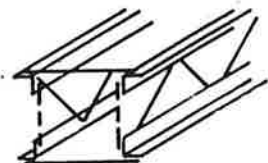
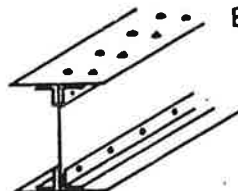


H-PILE

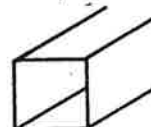
FABRICATED STEEL



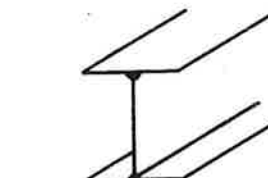
BOX SHAPES



RIVETED GIRDER



WELDED BOXES



WELDED GIRDER

BRIDGE BASICS

Purpose

The purpose of this guide is to explain the most common pre-1960 highway bridge types and how to describe them.

Since bridges are an integral component of highways and byways, they are ubiquitous features of the built environment. Most bridges are common solutions to typical engineering problems, and those bridges constructed by the state highway department after about 1920 are based on standard designs, like T beam or slab, and standard bridge components, like mass-gravity concrete abutments or two-rail high railings, that were used over and over again.

And, like building styles with their vocabulary of similar features, bridge types too have common characteristics and terminology for identification and description of the requisite members. Knowing the characteristics and terminology facilitates understanding of how bridges work, how to identify important components, and how to accurately convey that information. This understanding also fosters a fair and balanced assessment of historical significance.

Bridges are engineered structures designed to efficiently and economically carry loads across features, and with the exception of the railings that are a safety component (not a load-carrying component), all bridge members are needed in order for the particular type to work. Thus, unlike buildings or historic districts that have some features that are more important to historical significance than others and can thus be called "character defining," bridges do not have character-defining features since ALL of their components are equally important to the function of carrying loads.

Summary of How Bridges Work

☞ All bridges, regardless of specific type and design, are one of three basic categories: beam, arch, or cable supported (Figure 1). Most standard-design bridges are of the beam category, including trusses (really a deep beam with an open middle section known as a web), girder-floorbeams, and slabs.

☞ The engineering principle underlying how a particular bridge type works is the same regardless of its material. All longitudinal (parallel to the roadway) beam bridges, like stringers, slabs, girder-floorbeams, or T beams, rely on the bending strength of the material to resist loads, no matter whether the beams were fabricated with wrought iron, steel,

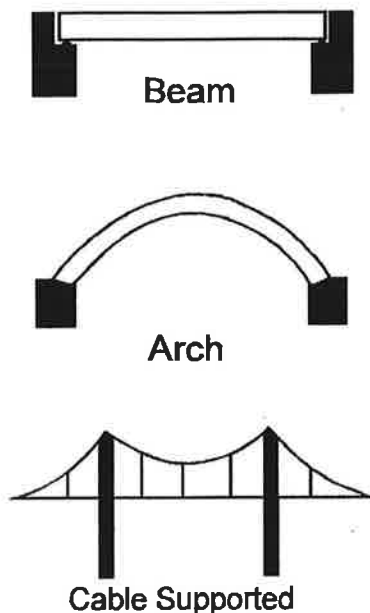


Figure 1.
Three basic bridge
categories.

reinforced concrete, or prestressed concrete. The depth of the beam, including trusses, is generally equated with span length, and the thickness of members is generally equated with stiffness/strength or load-carrying capacity.

The same is true for arch bridges. Whether built of stone, brick, steel, or reinforced concrete, all arch bridges transmit their loads diagonally via the arch ring to the abutments where they are resisted by an equal force. Cable-supported suspension and cable-stayed bridges are the reverse of the arch where the cables generally put tension on their supports.

☞ Bridges are classified by their broad type, e.g., thru truss, pony truss, stringer, slab, girder-floorbeam, etc. Such labeling immediately implies how the bridge works. Further description, like a truss pattern (e.g., Pratt or Warren) or the distinction between simple and continuous support, is the design. The adjective (design) modifies the noun (type), as in a Warren pony truss bridge or a continuous stringer bridge. Material is also an adjective used to describe bridges, as in a prestressed concrete I-beam bridge. Without identifying the type, design (if any), and material, the description of the bridge is not as accurate and complete as it should be.

Some multi-span bridges are composed of more than one bridge type/design. Bridges are classified by the main span, but the type/design and materials of all spans should be included in the description, like the five-span bridge is composed of a 150'-long steel Pratt thru truss main span and two, 45'-long steel stringer approach spans on each side. A viaduct is a term commonly used to refer to a long bridge that crosses several features, like city streets and a water feature or a railroad.

☞ Materials used in bridge construction have different properties. Sometimes the presence of a material can make a bridge historic, like wrought-iron, rolled I-beams or an early use of prestressed concrete. So can the early use of a technologically significant reinforcing system in concrete. Since bridges are typed by the material of the main span, not the material of the spandrel walls or the substructure units, it is important to properly identify material. This can be done by looking at the underside of the bridge for clues, like exposed reinforcing bars in the concrete, evidence of concrete encasement on rolled steel beams, how a metal

beam is weathering, the cold joints between precast units, or the difference between a stone veneer and a true stone arch. The distinctions, particularly among the various cementitious materials and encasements, can be very significant when describing a bridge and assessing its historical significance.

Plain concrete is a great material in compression, but it does not accommodate tension forces well. Because of this, reinforcement was added starting almost as soon as the material was first applied to bridges about 1890. Unreinforced (monolithic) concrete bridges are rare, so most are accurately described as being of reinforced concrete, even when the reinforcing system is not known due to lack of plans or outward physical evidence of reinforcing.

Steel began replacing iron in bridge construction in the 1890s and most 20th century bridges are steel. Steel rusts by delaminating while wrought iron rusts slowly with pock mark-like loss of material.

☞ All bridge types have span lengths suited to their type, design, and material, and the span length and load-carrying capacity largely controls the selection of one bridge type, design, and material over another. At some point, based on site conditions, the price of materials and labor, or other constraining factors, a particular bridge type becomes more cost effective and structurally efficient. For instance, wood stringers are efficient for span lengths up to about 20'. After that the beams become so deep that the waterway is restricted and the cost of the material is not economical in comparison to other bridge types such as a precast or cast-in-place, reinforced-concrete slab span that is efficient up to about 35' in length. Beyond that, the reinforced-concrete T beam is more efficient. The same principle underlies the choice between metal thru and pony truss bridges with pony trusses used for spans lengths generally between 60' and 100'. Thru trusses, with their deeper webs, are used for spans greater than 100' with the limit being about 350' for a simply supported truss span.

A culvert is either a bridge with a clear span of less than 20' long and/or a structure, particularly arches and frames, with no headwalls or spandrel walls and the roadway carried above on earth fill (no railings). Culverts embody the same engineering principals as bridges, only shorter.

☞ Engineers are not architects, and only in rare instances do aesthetic considerations underlie bridge design. All features, from substructure material to the design of the railings/barriers, are predicated on a variety of engineering principles, theories, and empirical evaluations available at the time the bridge and associated roadway were constructed, including safety and long-term maintenance. The exceptions, of course, are bridges in important, usually urban and park settings, or that were built in association with manipulated landscapes.

Basic Bridge Terminology

☞ Bridges are composed of three major components; **deck**, **superstructure**, and **substructure** (Figure 2).

The **deck** is the member to which **live load** (temporary, short-term loads like a vehicle passing over the bridge or wind or rain) is directly applied. **Dead load** is the permanent load acting on the structure, like the weight of the materials to construct the bridge, including the deck/wearing surface, superstructure, and railings.

The **superstructure** is the member that receives and supports traffic loads and in turn transfers those loads to the substructure. The superstructure is above the substructure, and it is how the bridge is identified, like a truss or stringer or slab.

The **substructure** supports superstructure and transfers loads from it to the ground or bedrock. Substructures

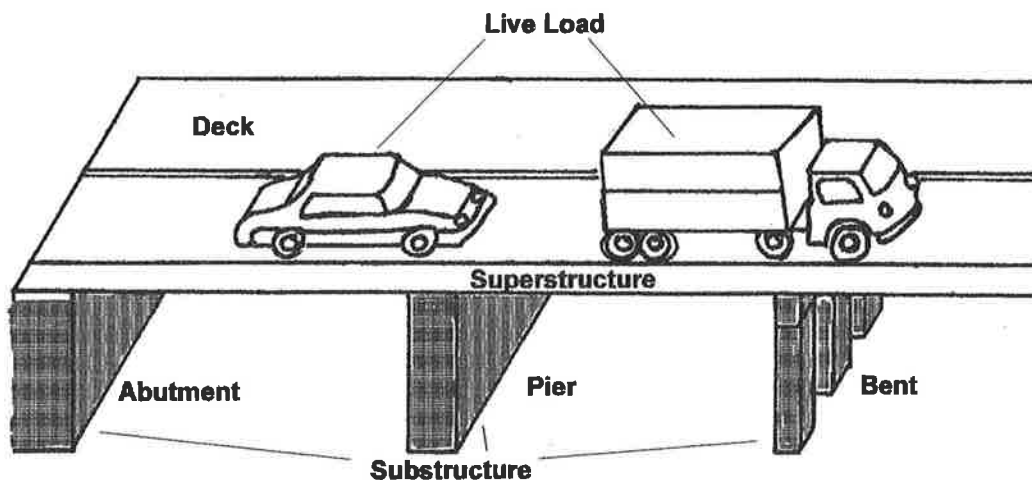


Figure 2.

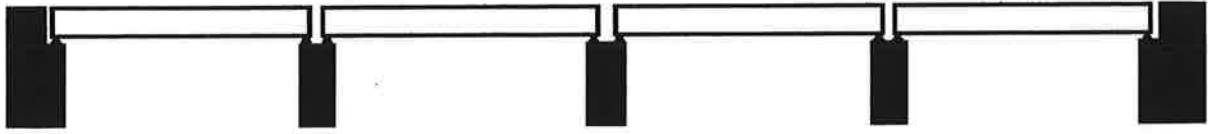
units are **abutments** (supporting the ends of the bridge superstructure, and retaining/supporting the embankment of the approach roadway), **piers** (solid supports) or **bents** (two or more columns connected at their topmost ends by a cap beam).

☞ It is not uncommon to have a superstructure and substructure with different dates of construction because stone and concrete substructures are frequently reused, either wholly or as part of a rebuilt, widened structure.

For accuracy and consistency, the date of construction of the superstructure is usually taken as the ruling date. This is because the superstructure is the dominant feature of any bridge, and there needs to be consistency between the date and the superstructure type. For instance, a prestressed concrete box beam bridge with a date of 1938 is not plausible/credible because the bridge type was not developed until 1951. The substructure units may date to 1938, but the superstructure is much later and most likely less than 50 years of age.

☞ Bridges are identified by the number of spans they contain. A **span** is the distance between two supports holding up the superstructure (measured as clear span). A span can be **simple** where it rests on two supports, one at each end, and the load does not affect the stresses in any adjoining spans. Or, it can be **continuous**, where the span extends without joints over more than two substructure units, and which then distributes the load over several spans and supports. Continuous designs have economic benefits, and in long continuous design spans, the beams are deepest over the supports, where stresses are the greatest. The length of the beam or the section of a deck that extends beyond or overhangs a support is **cantilevered** (Figure 3).

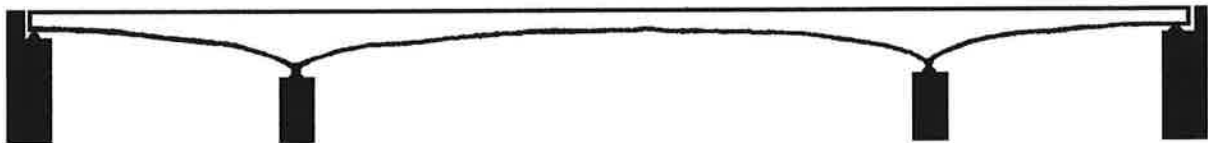
☞ Most metal bridges are built with **rolled shapes** (I beams, H sections, angles, channels, plates, etc.), which are formed at mills by passing hot metal bars between heavy metal rollers to create the shapes. Shapes and sizes of beams not available by rolling are usually called **built-up members** because they are composed of plates, channels, and angles united by riveting, bolting, or welding (Figure 4). Most built-up beams were riveted together prior to 1950, but beams fabricated by welding or using high-strength bolts became increasingly common during the 1950s because of



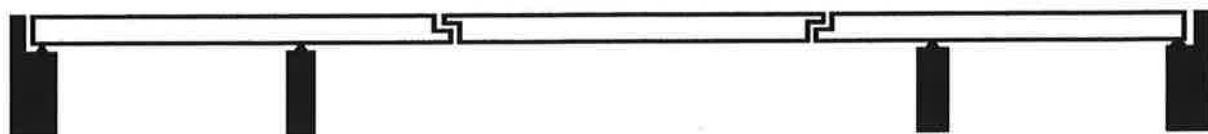
Simple spans - beams have joints between the spans



Continuous spans - beam does not have joints over the piers



Continuous spans with haunched (variable depth) beam



Cantilevered beams with a suspended span (center)

Figure 3.

technological improvements. Truss and girder-floorbeam bridges typically have built-up members (verticals, diagonals, end posts, girders) while stringer bridges are rolled beams.

Three other common terms are **beam**, **stringer**, and **girder**. A beam is any linear structural member that is designed to span from one support to another. A stringer is generally any longitudinal beam directly supporting a deck. Girder is often used imprecisely to describe any large beam, especially if built-up. The term is more precise when used to refer to the main longitudinal members between the substructure supports of the girder-floorbeam bridge type.

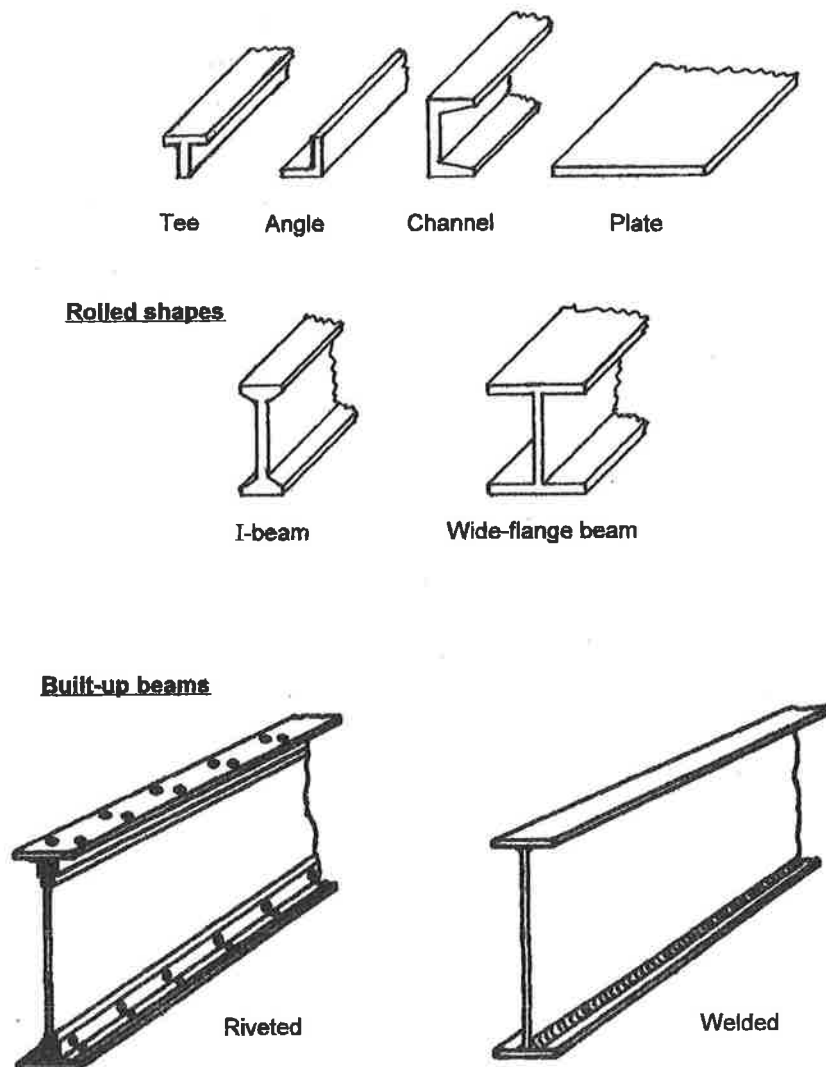


Figure 4.

COMMON BRIDGE TYPES

Stringer Bridges

Stringer bridges consist of a series of parallel, longitudinal beams supporting the deck (Figures 5, 6). A discrete deck is supported on the tops of the beams. Diaphragms (solid or X-bracing) are often placed between the longitudinal beams to provide lateral stability (keep the beams upright). Stringer bridges can be of wood, rolled steel I-shaped or wide-flange beams, built-up steel beams (composed of plate and angle sections riveted together to make an I-shaped section), or prestressed concrete beams.

Early rolled beam bridges were sometimes concrete encased (Figure 7). It is important to distinguish an encased stringer, which is not common, from a T beam, which is common. Look at the underside of the bridge for signs of beam flange in areas of concrete deterioration.

Stringer bridges can be simply supported or can be continuous. Abutments and piers/bents are typically concrete or timber pile. Rolled steel beam span lengths do

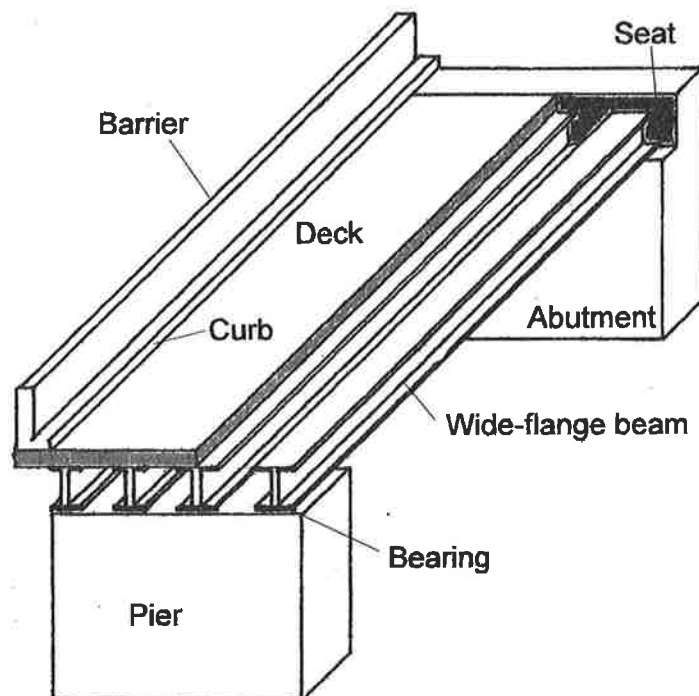


Figure 5. Steel stringer bridge.

not generally exceed 60' with 25'- to 50'-long beams being the most common range. Wood stringers are generally 20' long or less. Prestressed concrete I beams can be up to 100' long and quite deep. They are characterized by their distinctive profile with deep, bulbous flanges and thin webs.

Since stringer bridges of all designs and materials are common, knowing material and design (simple or continuous) is important. This entails walking down the embankment to look at the underside of the superstructure and looking at the bridge in elevation. Again, it is important that the date of construction be the year that the present beams were placed, not the date of the substructure. Wood bridges, in particular, are characterized by a high degree of in kind replacement material placed as part of routine maintenance.

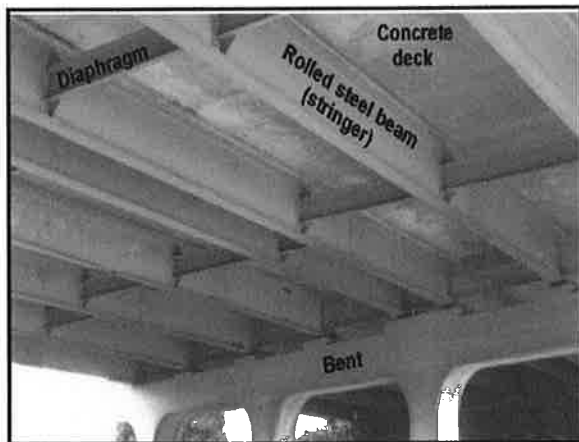


Figure 6. Underneath view of a typical steel stringer bridge.



Figure 7. Underneath view of an encased steel stringer bridge. Cracking and spalling of the concrete encasement has begun to expose the beams.

Girder-Floorbeam Bridges

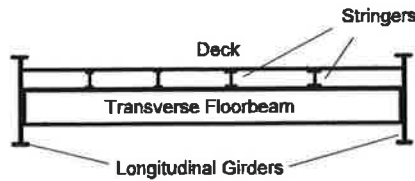


Figure 8. Section of girder-floorbeam bridge

Girder-floorbeam bridges consist of two or more longitudinal beams (i.e., girders) with transverse floorbeams (Figures 8, 9). They are called transverse because they are perpendicular to the longitudinal member and the roadway. The floorbeams are part of the flooring system that support any stringers and the deck, and they transfer live loads to the main girders. The girders are generally built up of steel plates and angles (plate girders), and are deeper than most rolled beams. The transverse floorbeams can be rolled section or built up like the girders. Girder-floorbeam bridges were favored by the railroads as they are strong, economical, and efficient. They are common for span lengths between 35' and 100' for simply supported spans, and there is very little variation in their design. Ones fabricated in the 1890s are just like those built in the 1930s. Starting in the 1930s, continuous design girder-floorbeam bridges were used for spans between 100' and 150' long.

The roadway is located either thru (thru girder) or on top of the longitudinal girders (deck girder). In the thru girder, the floorbeams are in line with the bottom flanges while the deck girder has the floorbeams near or on top of the top flanges. Other than the placement of the roadway, there is no technological difference between the two designs. To tell the difference between a stringer and a deck girder-floorbeam bridge, the underside of the superstructure needs to be examined. The presence of the transverse floorbeams is what distinguishes girder-floorbeam bridges from stringer bridges.

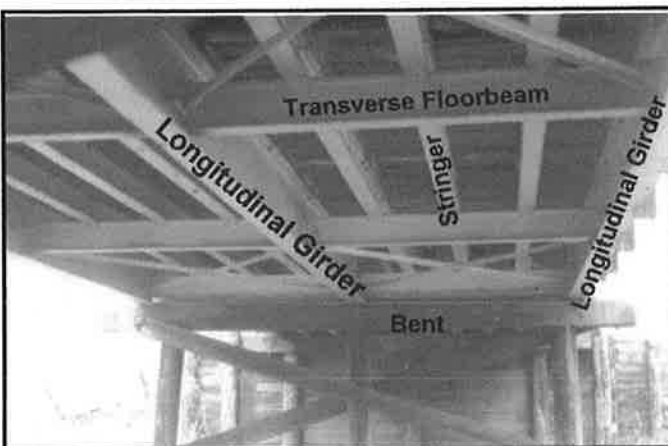


Figure 9. Underneath view of girder-floorbeam bridge.

T Beam Bridges

T beam bridges are cast-in-place, reinforced concrete beams with integral, monolithic deck sections (Figures 10, 11). There is a wearing surface applied over the integral deck. T beams are nearly always supported on concrete substructure units, and the bridge type is used for spans between 25' to 60'. Some T beams have shear details (haunches) at the ends. The spans can either be simply supported or continuous, but continuous design T beam bridges are not common. The basic technology of the T beam bridge did not change through the 20th century, and they date from ca. 1915 through the 1950s. Most bridges built after the mid 1920s have four or more beams.

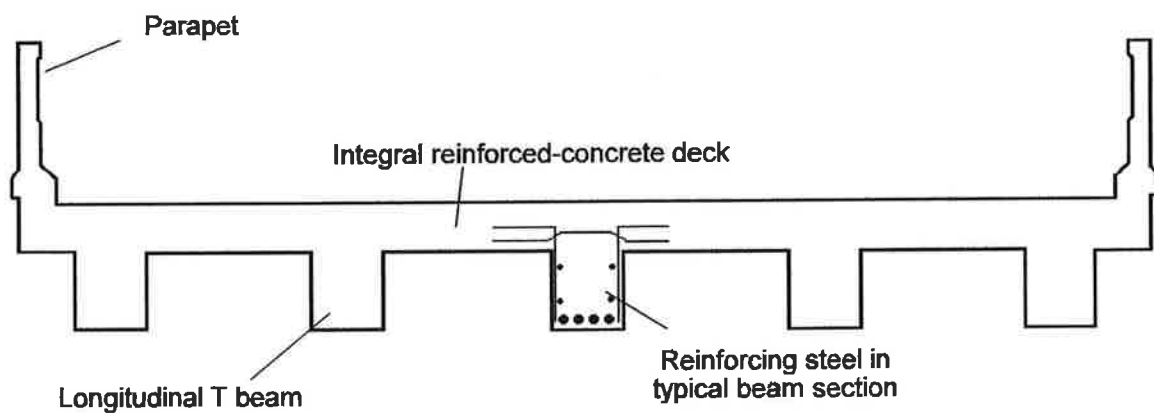


Figure 10. Section of T beam bridge.

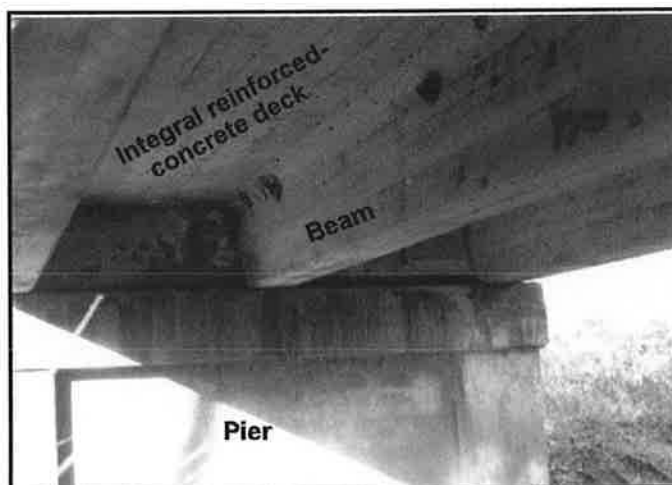


Figure 11. Undereath view of T beam bridge.

Slab Bridges

A slab bridge can be either cast-in-place or precast. The cast-in-place, reinforced concrete slab bridge has a uniformly thick slab with the reinforcing steel concentrated in the lower portion and ends where the tensile and shear forces are the greatest (Figure 12). The type is used only for short spans because it is not as economical (uses more material) as T beams for lengths over 30'. It is usually simply supported and has a concrete substructure (Figure 13).

After 1946, a precast reinforced concrete slab bridge composed of 10'-long spans with the 5'-wide panels tied into a unit by transverse threaded bolts was developed by the state engineers for use on secondary roads. By the early 1950s, the state highway department had such success with the 10'-long spans that it also adopted a precast slab with 14'-long spans. The panels were cast with integral curbs in the fascia units. The precast slab bridge was set on timber pile and reinforced concrete cap beam bents.

Differentiating between cast-in-place and precast slab bridges is important. The precast slab bridges are identified by the 5'-spaced grooves or cold joints visible on the underside. (Figure 14)

Laminated wood slab superstructures (either glued or nailed) came into common use during the last quarter of the 20th century. If a bridge has a laminated wood superstructure or deck panels, it is likely less than 50 years old, although a very few examples from the mid 1930s to 1950s are known in other states (Georgia, Delaware).

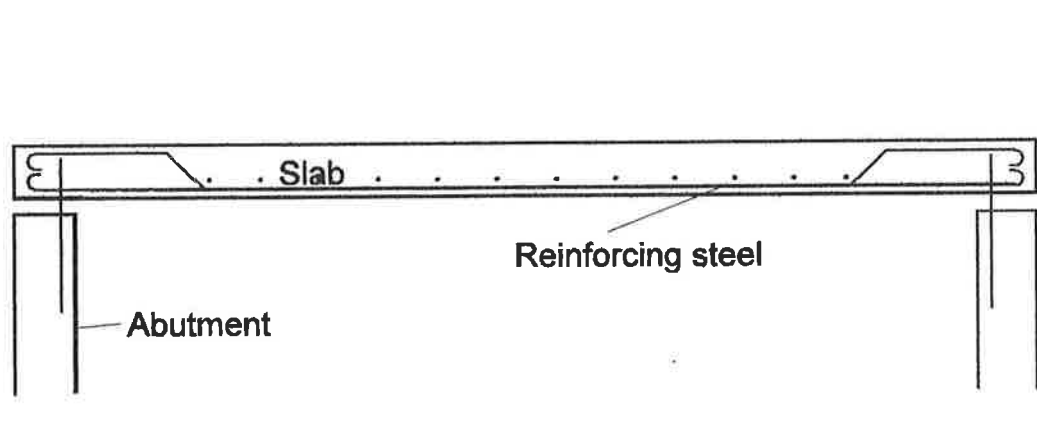


Figure 12. Longitudinal section of slab bridge.



Figure 13. Cast-in-place, reinforced-concrete slab bridge.

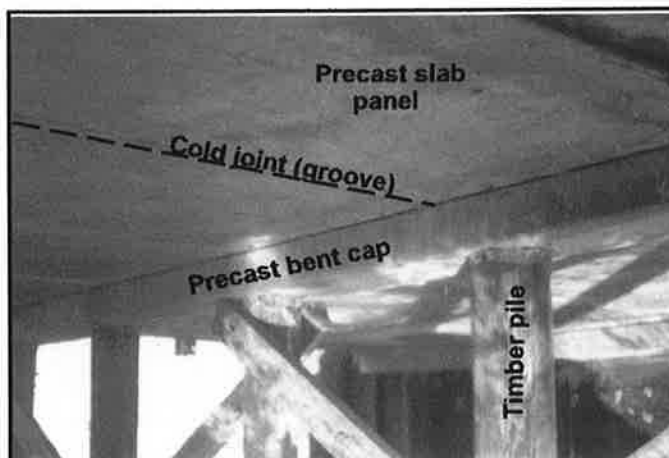


Figure 14. Underneath view of precast, reinforced-concrete slab bridge.

Channel Beam Bridges

A channel beam is a precast unit that is C-shaped (also known as inverted U-shape) in cross section (Figures 15, 16). The beams are 20' to 30' in length and can be either reinforced concrete or prestressed concrete (after 1956). The individual beams are locked into a unit by grouted keyways and lag bolts through the beam toes. There is no visual difference between reinforced concrete and prestressed concrete channel beams, so plan sheets need to be consulted to accurately determine the material.

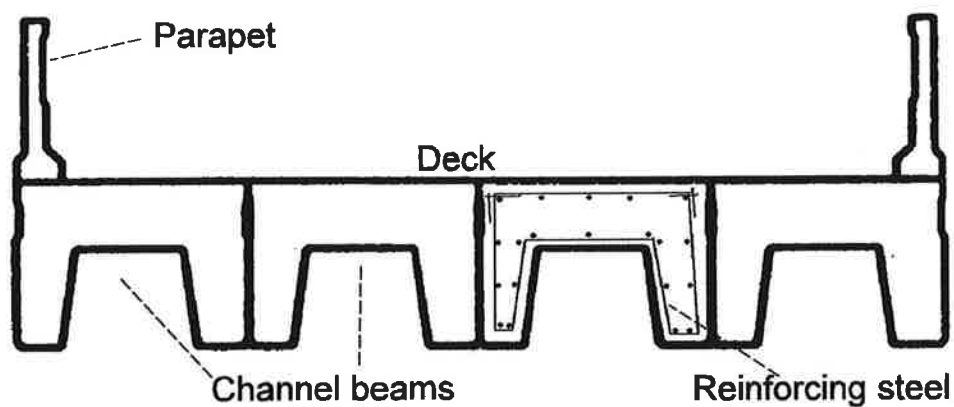


Figure 15. Transverse section of reinforced-concrete channel beam bridge.



Figure 16. Underneath view of channel beam bridge.

Reinforced-Concrete Arch Bridges

Regardless of the shape (semicircular, elliptical, segmental, etc.), the engineering principle behind an arch is the same. Loads are transferred to the ground through the arch ring, which is in compression, and the vertical forces at the base of the arch ring have to be balanced by equal reactions at the abutments. Since concrete accommodates compressive forces well, but not tensile forces, nearly all arch bridges are constructed of reinforced concrete with reinforcing steel in the tension zone of the arch ring. In a closed-spandrel arch, the spandrel walls hold back the stone rubble and earth fill placed over the arch ring to support the deck. In an open-spandrel arch, spandrel columns supported the deck. Parapets (solid railings) or railings/balustrades are usually concrete or reinforced concrete and are tied to the spandrel walls (Figure 17).

Some reinforced concrete arch bridges are finished with a stone veneer on the spandrel walls and parapets, but the presence of such detailing does not change the fact that the bridge is a reinforced concrete arch, not a stone arch. Looking at the intrados (underside of the arch ring) will reveal whether the arch is truly a stone arch or a reinforced concrete arch.

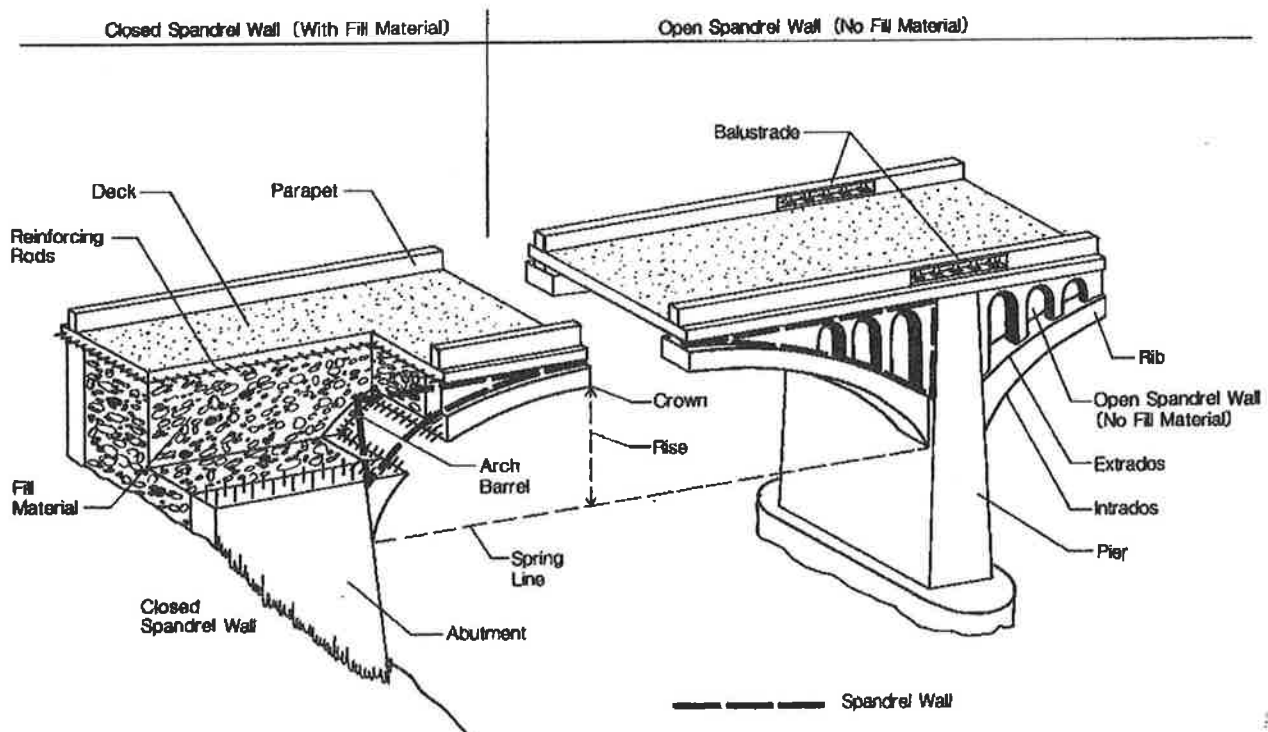


Figure 17. Reinforced-concrete arch bridge terminology.
Source: PennDOT, Historic Highway Bridges of Pennsylvania, 1986.

Rigid Frame Bridges

A rigid frame bridge is one where the legs (akin to substructure) and the vertical (akin to superstructure) are integral (monolithic) and continuous from footing to footing (Figures 18, 19). Most were built of reinforced concrete, but they can also be steel. The intrinsic form of a rigid frame is that of a shallow arch because of mass and reinforcing placed at the transition between the legs and the vertical where the stresses are greatest and most complex. The bridge type was used between the mid 1920s and about 1950 in settings where aesthetic bridges were desired because rigid frame bridges lend themselves to architectural embellishing.

The concept of the reinforced concrete rigid frame was initially applied to low rise, box culverts starting in the 1910s. There is no reinforcing at the corners, so they have a trabeated appearance. They can have an invert slab (bottom) or not, and are distinguished from slab bridges by the absence of joints between the abutments and slab. Culverts (structures with a less than 20' long opening, known as the clear span) are identified by the number of cells rather than spans.

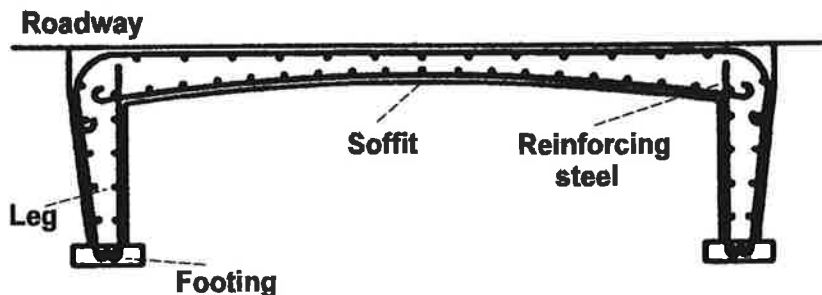


Figure 18. Longitudinal cross-section of reinforced-concrete rigid frame bridge.



Figure 19. Rigid frame bridge.

Stone/Brick Arch Bridges

An arch is particularly well suited for the compressive strength inherent in natural rock, and the stone arch was the only technology available for substantial bridges during most of the 19th century in regions where stone was readily available. It was favored by the railroads well into the 20th century because of its relative maintenance-free permanence. While the arch ring itself is usually composed of dressed stone voussoirs or ringstones with or without a keystone, the spandrel walls and parapets can be a variety of stone bonding patterns from ashlar to random ashlar and random rubble (Figure 20). The terminology describing the bonding pattern is the same as for buildings and other structures like walls. Other than bonding patterns, stone-arch bridge terminology is similar to that for reinforced-concrete arch bridges (Figure 21).

The engineering principle behind the stone arch is the same as all other arch bridge types; loads are transferred to the ground through the arch ring, which is in compression, and the vertical forces at the base of the arch ring have to be balanced by equal reactions at the abutments. Stone arch bridges were usually laid up with mortared joints to lock the individual stones into a compressive unit, but some were dry laid with no mortar between the stones. Careful inspection and review of any records is needed to determine if stone bridges with open joints, which could have weathered and thus lost their mortar, were in fact constructed as dry laid.

In areas where stone is not plentiful, arch bridges could be constructed of brick. Antebellum examples are rare, but the increased availability and quality of American-made Portland cement after 1880 resulted in brick arches being constructed from then through the first world war. Brick arch bridges can be finished with stone spandrel walls and parapets.

Note that all arch bridges are typed by the material of the arch ring, not the spandrel walls and parapets. Inspection of the arch intrados will be required to determine the correct material.



ashlar



random ashlar



rubble

Figure 20. Stone bonding patterns

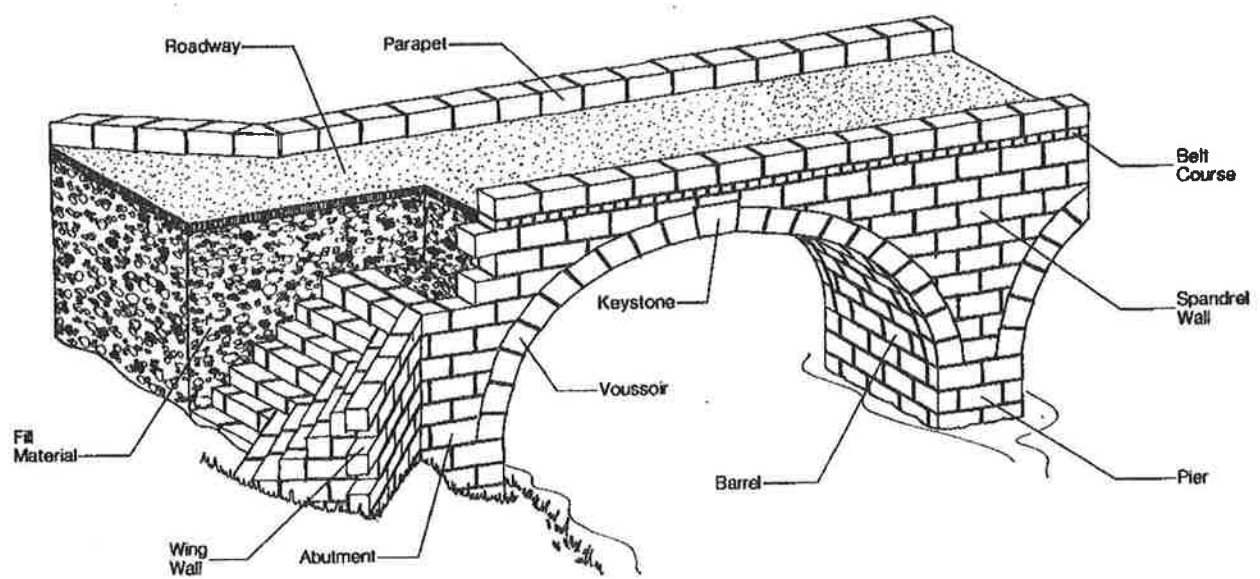


Figure 21. Stone-arch bridge terminology.
Source: PennDOT, Historic Highway Bridges of Pennsylvania, 1986.

Truss Bridges

There are three types of trusses (thru, pony, and deck) and a variety of designs based on the arrangement of the many small pieces (members) that make up the series of triangular shapes that transfer live loads back to the abutments. A **thru truss** is where the roadway passes between the truss lines and there is overhead bracing. Thru trusses are deeper and are used for span lengths greater than about 100'. The roadway also passes through the truss lines on a **pony truss**, but there is no overhead bracing. The pony truss is used for span lengths between 45' and 100'. The superstructure is above the roadway for both the thru and pony truss bridge. A **deck truss** has the superstructure below the roadway, and the flooring system is at the level of the upper chords, not the lower chords (Figure 22). How the component members (chords, verticals, diagonals, end posts) are arranged defines its design, like Pratt, Warren, Parker, etc. It is important to know the type/design of all truss bridge and how the members are connected (Figure 23).

Many of the earliest extant truss bridges are pin connected (Figure 24). This means that the prefabricated members were connected together in the field at panel points by using pins (cylinders with threaded ends secured with nuts) passing through punched holes, pin plates or eyes. Although pin-connected truss bridges continued to be built into the 1920s in some regions, they had generally been eclipsed by riveted field connections starting in the 1900s (Figure 25). On rivet-connected truss bridges, members are connected to gusset plates at the panel points. Some light pony truss bridges have bolted field connections. It is important to identify the method of field connection.

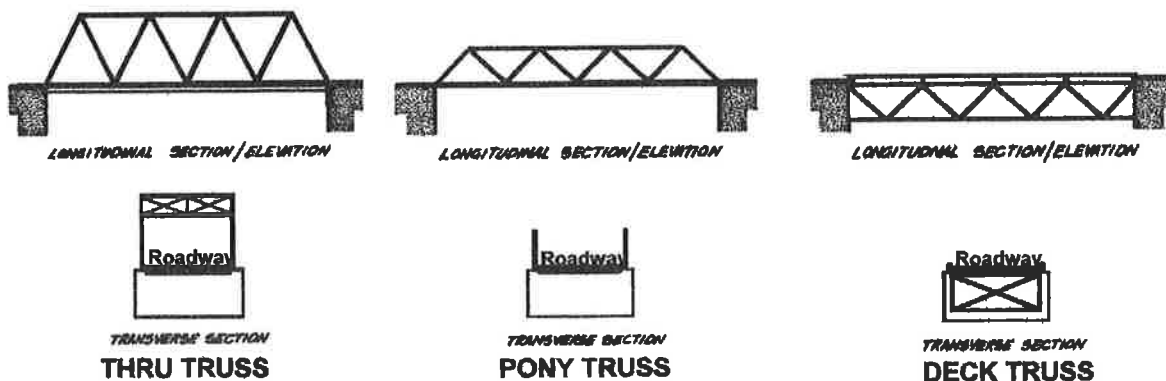


Figure 22. Truss types. Adapted from, "Bridge Truss Types," AASLH Technical Leaflet 95, 1977.

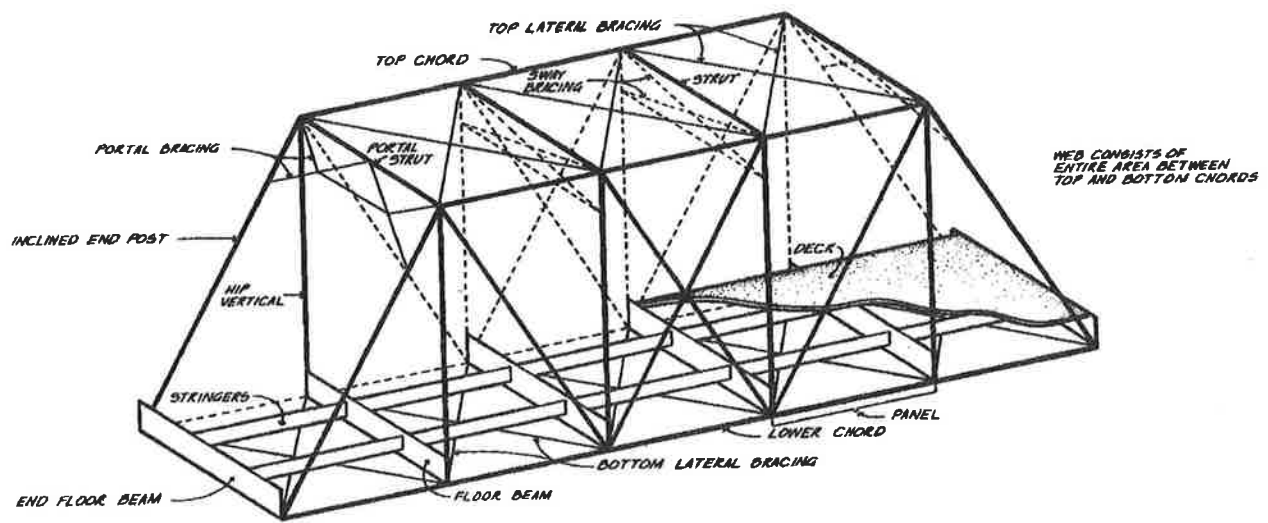


Figure 23. Truss bridge terminology.

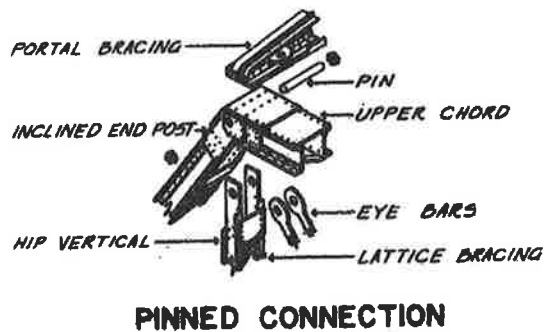


Figure 24.

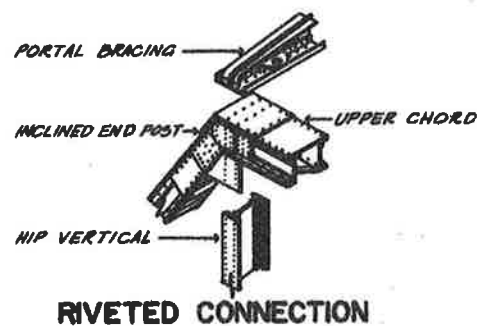


Figure 25.

Truss drawings adapted from "Bridge Truss Types,"
AASLH Technical Leaflet 95, 1977.