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Section 8
Inspection and Evaluation of Common Steel Superstructures

Topic 8.6 Steel Trusses

8.6.1 Introduction

Metal truss bridges have been built since the early 1800's. They can be thought of as a deep girder with the web cut out. They are also the only bridge structure made up of triangles. The original metal trusses were made of wrought iron, then cast iron, then steel. When trusses were first being built of metal, material costs were very high and labor costs were low. Because trusses were made up of many short pieces, it was cost effective to build the members in the shop and assemble them at the site. Today the higher costs of labor and the lower costs of material have limited the use of trusses to major river crossings.

8.6.2 Design Characteristics

The superstructure of a truss bridge usually consists of two parallel trusses (see Figure 8.6.2). The trusses are the main load-carrying members on the bridge. There are three types of trusses, grouped according to their position relative to the bridge deck (see Figure 8.6.2).

Figure 8.6.1 Single Span Truss

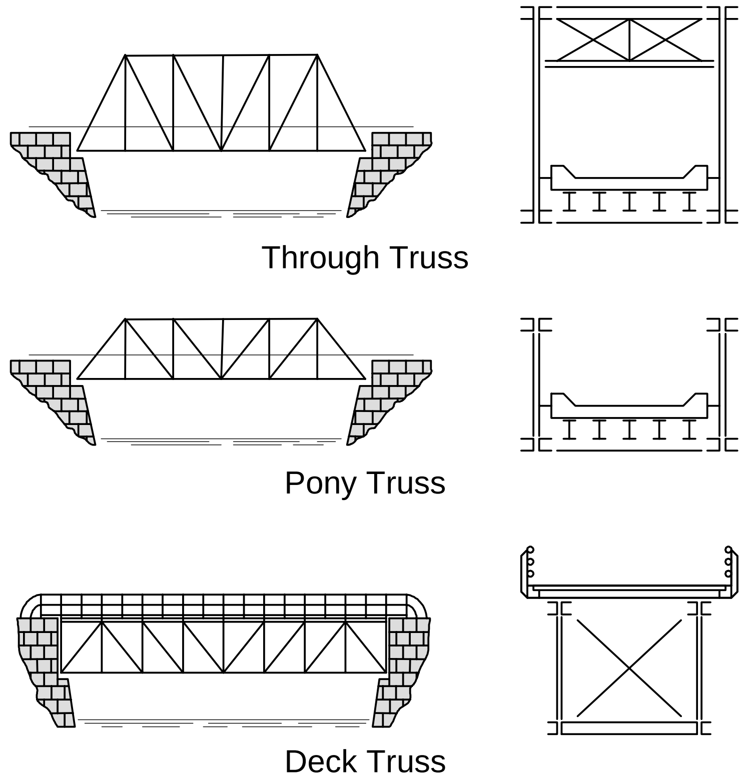

Figure 8.6.2 Through-Pony-Deck Truss Comparisons

Through Truss

On a through truss, the roadway is placed between the main members (see Figure 8.6.3). Through trusses are constructed when underclearance is limited.

Figure 8.6.3 Through Truss

Pony Truss

A pony or "half-through" truss (see Figure 8.6.4) has no overhead bracing members connecting the two trusses. The vertical height of the pony truss is much less than the height of a through truss. Today, pony trusses are seldom built, having been replaced by the multi-beam bridge.

Figure 8.6.4 Pony Truss

Deck Truss

On a deck truss (see Figure 8.6.5), the roadway is placed on top of the main members. Deck trusses have unlimited horizontal clearances and can readily be widened. For these reasons, they are preferred over through trusses when under-clearance is not a concern.

Figure 8.6.5 Deck Truss

Other Truss Applications

Trusses are generally considered to be main members. However, they are also used as floor systems in arches and as stiffening trusses in suspension bridges and arch bridges (see Figures 8.6.6 and 8.6.7). Trusses are also commonly used for movable bridge spans because they are lightweight and have higher overall stiffness (see Figure 8.6.8). Even towers are sometimes braced with web members, as a truss.

Figure 8.6.6 Suspension Bridge with Stiffening Truss

Figure 8.6.7 Arch Bridge with Stiffening Truss

Figure 8.6.8 Vertical Lift Bridge

Design Geometry

Bridge engineers have used a variety of arrangements in the design of trusses. Many of the designs were patented by and named after their inventor. One characteristic that all bridge trusses have in common is that the arrangement of the truss members forms triangles (see Figure 8.6.9).

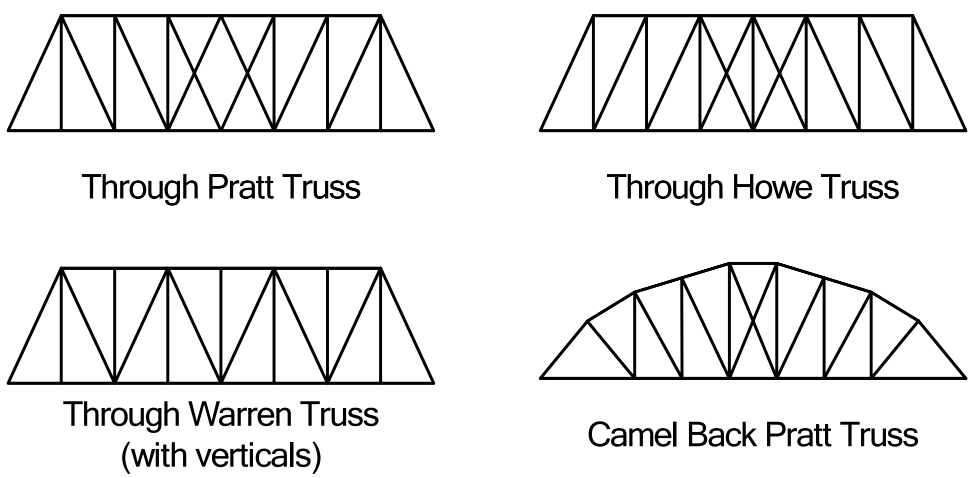

Figure 8.6.9 Various Truss Designs

Trusses have been constructed for short to very long spans, using simple, multiple and continuous designs (see Figure 8.6.10 to Figure 8.6.14). Cantilevered trusses often incorporate a "suspended" or "drop-in" span between two cantilever spans (see Figures 8.6.15, 8.6.16 and 8.6.17). The suspended span behaves as a simple span and is connected to cantilevered spans with pins or pin and hanger connections. The back span on a cantilever truss is called the anchor span.

Figure 8.6.10 Single Span Pony Truss

Figure 8.6.11 Single Span Through Truss

Figure 8.6.12 Multiple Span Pony Truss

Figure 8.6.13 Multiple Span Through Truss

Figure 8.6.14 Continuous Through Truss

Figure 8.6.15 Cantilever Through Truss

Figure 8.6.16 Cantilever Deck Truss

Figure 8.6.17 Cantilever Through Truss

As stated earlier, a truss can be thought of as a very deep girder with portions of the web cut out. Truss members are divided into three groups: (see Figure 8.6.18)

- Top or upper chord members
- Bottom or lower chord members
- Web members (diagonals and verticals)

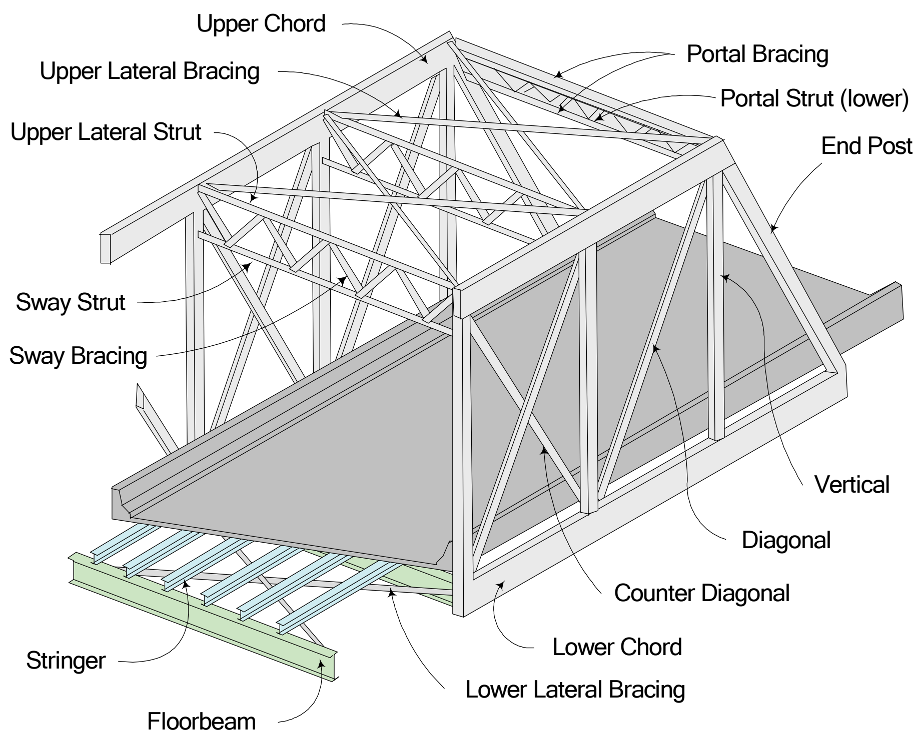

Figure 8.6.18 Truss Members and Elements

Truss members are fabricated from eyebars, rolled shapes, and built-up members (see Figure 8.6.19). Built-up sections are desirable for members that carry compression because they can be configured to resist buckling (see Figure 8.6.20). Structural tubing and fabricated box sections are popular for modern trusses because they provide a "clean" look and are easier to maintain.

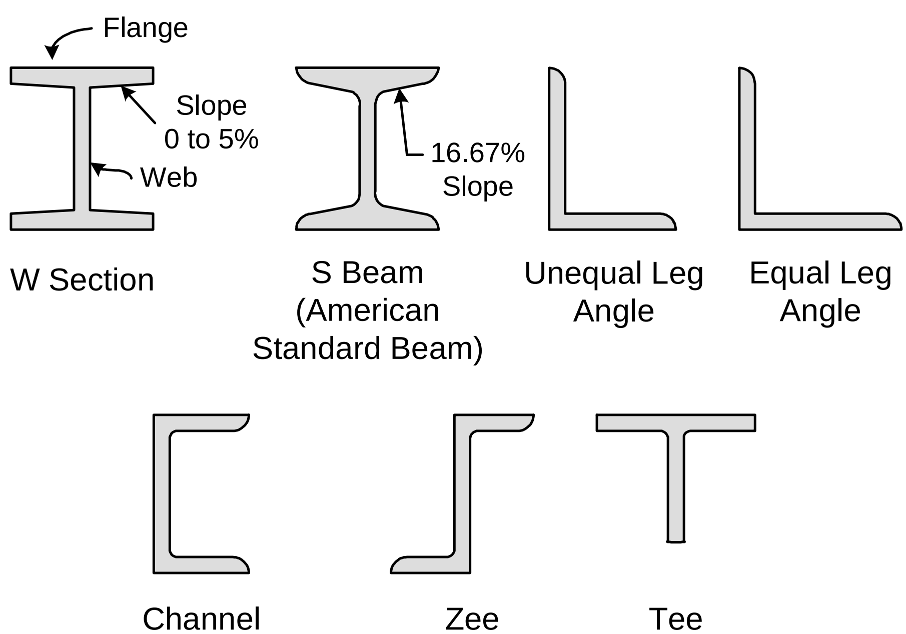

Figure 8.6.19 Rolled Steel Shapes

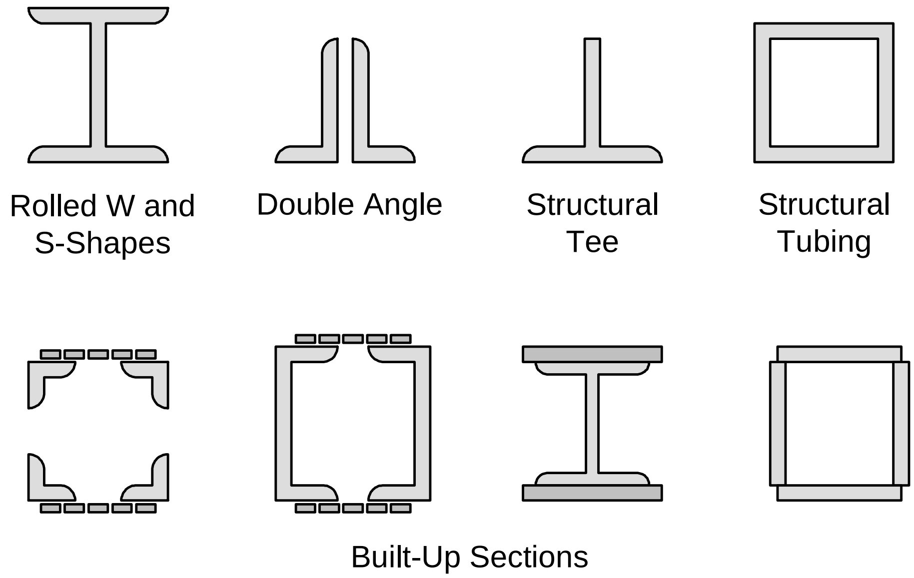

Figure 8.6.20 Typical Compression Members

Chord Members

Trusses, like beams and girders, support their loads by resisting bending. As the truss bends, the chord members behave like flanges of a beam and carry axial tension or compression forces (see Figure 8.6.21). On a simple span truss, the bottom chord is always in tension, while the top chord is always in compression. The diagonally sloped end post is a chord member. Top chords are also known as upper chords (U), and bottom chords are referred to as lower chords (L) (see Figure 8.6.22).

As truss bridge spans increase, cantilever and continuous designs are used, creating negative moment regions. Therefore, over an intermediate support, the top chord of a truss, like the top flange on a girder, is in tension (see Figure 8.6.21). The negative moment regions produce very large moments. It is common to find varying depth trusses on large complex structures, with the greatest depth at the supports where the moments are the largest (see Figure 8.6.23).

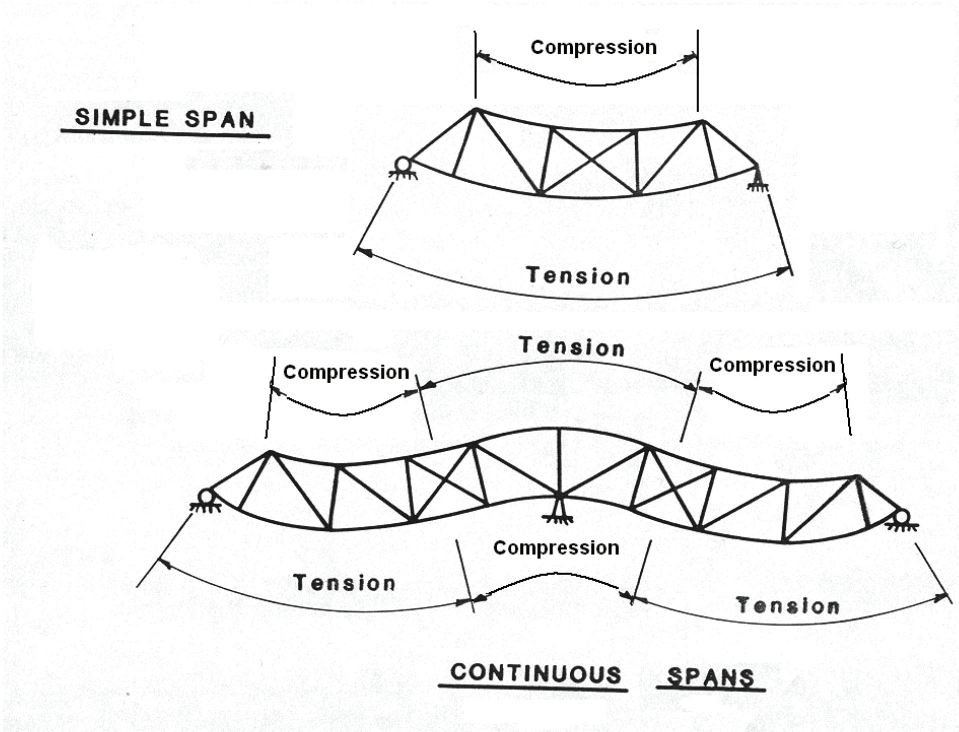

Figure 8.6.21 Axial Loads in Chord Members

Figure 8.6.22 Single Span Through Truss – General Elevation View

Figure 8.6.23 Continuous Through Truss

Web Members

The web members are typically connected to the top chord at one end and to the bottom chord at the other end. All trusses will have diagonal web members, and most trusses will also have vertical web members. Depending on the truss design, a web member may be in axial tension or compression, or may be subjected to force reversal and carry either type of stress for different loading conditions.

Diagonals

For simple spans, an easy method to determine when a truss diagonal is in tension or compression is to use the "imaginary cable - imaginary arch" rule (see Figure 8.6.24). Diagonals that are symmetrical about midspan and point upward toward midspan, like an arch, are in compression. Diagonals that are symmetrical about midspan and point downward toward midspan, like a cable, are in tension. This rule applies only to simple span trusses.

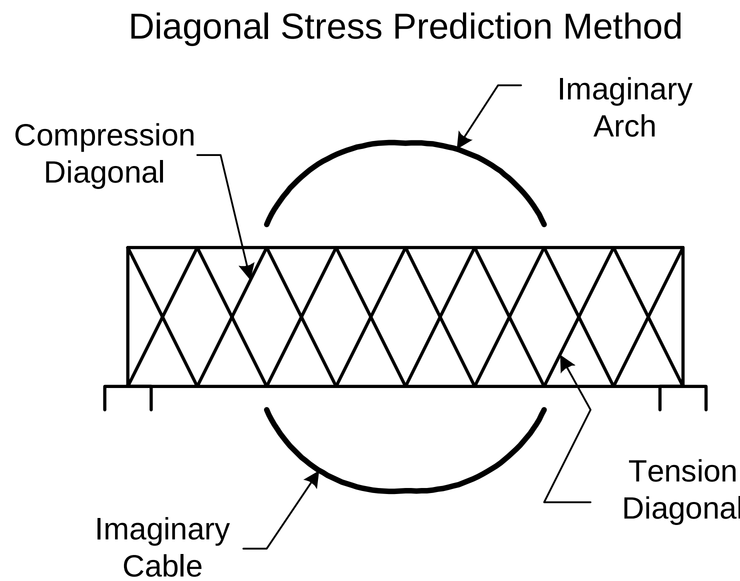

Figure 8.6.24 "Imaginary Cable – Imaginary Arch"

On older simple span trusses, the section of the member can be used to determine which members are in tension and which are in compression. The design of a 7.6 m (25-foot) tension member, subjected to a load, will require a much smaller member (cross section) than a 7.6 m (25-foot) compression member subjected to the same magnitude. On older pin-connected trusses, compression members are always the larger built-up members as compared to the tension members, which were often eyebar members. The Pratt truss, with all its diagonals in tension, quickly replaced the Howe truss, whose diagonals are in compression. The Pratt truss is lighter and therefore easier and less expensive to erect.

For trusses, counters are tension-resisting diagonals installed in the same panel in which the force reversal occurs. They are oriented opposite from each other, creating an "X" pattern. Counters are stressed only under live loads. On older bridges on which counters are bar shaped, they should be capable of being moved by hand during an inspection. Counters are found on many older trusses but rarely on newer trusses.

With more complex truss designs (continuous and cantilever), the diagonal web members must be capable of withstanding both tension and compression. This is known as force reversal, and it is one of the reasons that, on many modern truss bridges, the appearance of the tension and compression diagonals is almost identical.

As trusses become longer and, more importantly, as live loads become larger, the forces in some diagonals on a bridge continually change from tension to compression and back again. This situation occurs near the inflection points of continuous trusses. The inflection points in a continuous truss are similar to a continuous girder. The inflection points are located at the transition between positive and negative moments. Adjacent to the inflection joints, an unsymmetrical live load can cause large enough forces to overcome the symmetric dead load forces in the diagonals.

See Figure 8.6.18 of a sample truss schematic showing diagonals in a simply supported truss.

Verticals

There is also an easy method to determine when a vertical member is in tension or compression for a simply supported truss. Verticals that have one diagonal at each end are opposite to the force of the diagonals (see Figure 8.6.25). Verticals that have two diagonals at the same end are similar to the force in the diagonal closest to midspan (see Figure 8.6.26). Verticals that have counters on both ends are in compression (see Figure 8.6.27).

A vertical compression member is commonly called a post or column, while a vertical tension member is sometimes called a hanger.

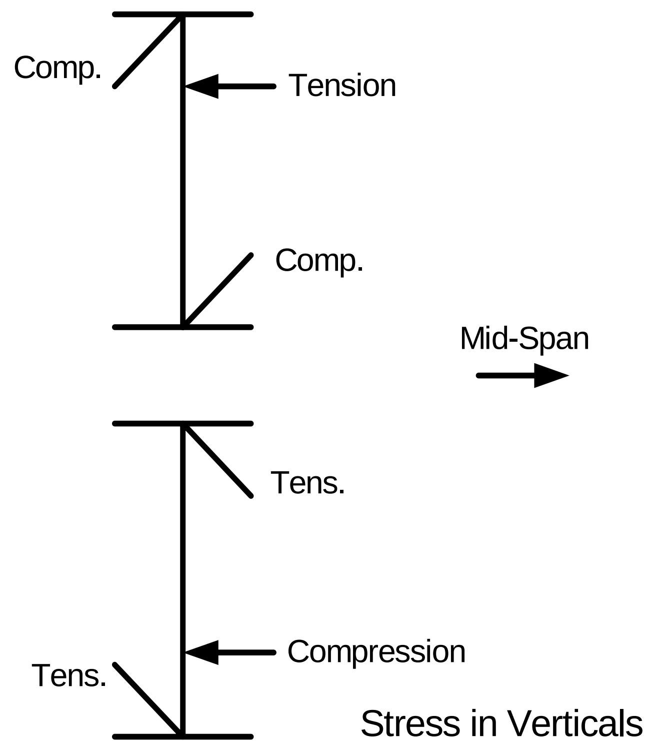

Figure 8.6.25 Vertical Member Stress Prediction Method

See Figure 8.6.18 of a sample truss schematic showing verticals in a simply supported truss.

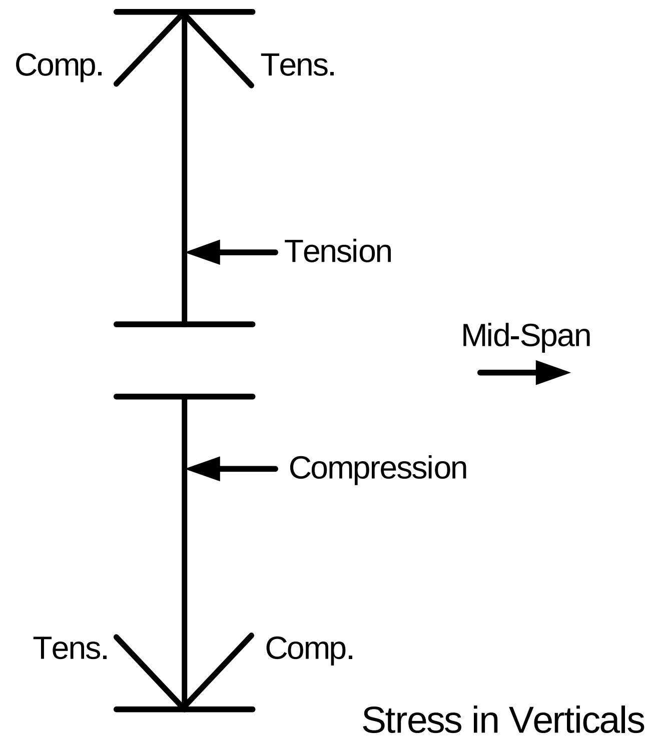

Figure 8.6.26 Vertical Member Stress Prediction Method

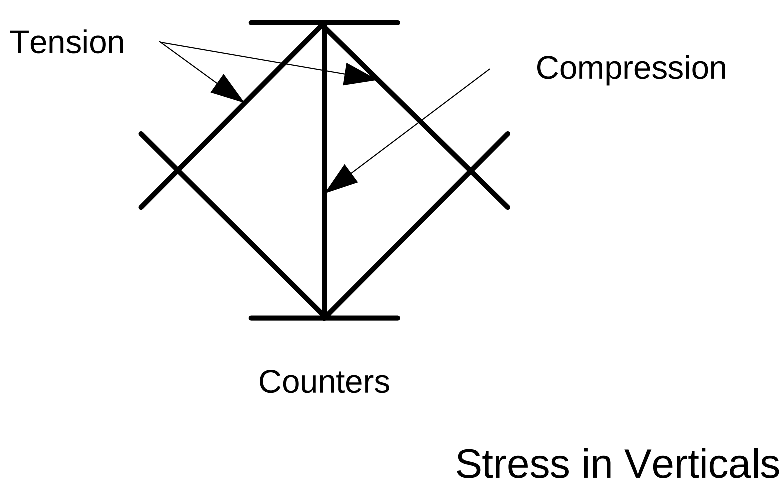

Figure 8.6.27 Vertical Member Stress Prediction Method

Panel Points and Panels

A panel point is the location where the truss members are connected together. Modern truss bridges are generally designed so that all members have approximately the same depth, thereby minimizing the need for shims and filler plates at the connections. This is often accomplished by varying the plate thicknesses of built-up members or using several grades of steel to meet varying stress conditions.

The connections are typically made using gusset plates and are made by riveting, bolting, welding or a combination of these methods. Connections using both rivets and bolts were popular on bridges constructed in the late 1950's and early 1960's, as high strength bolts began to replace rivets. Rivets were used during shop fabrication while bolts were used to complete the connection in the field (see Figure 8.6.28). Old trusses used pins at panel point connections (see Figure 8.6.29). Truss members may also be spliced, sometimes at locations other than the panel points.

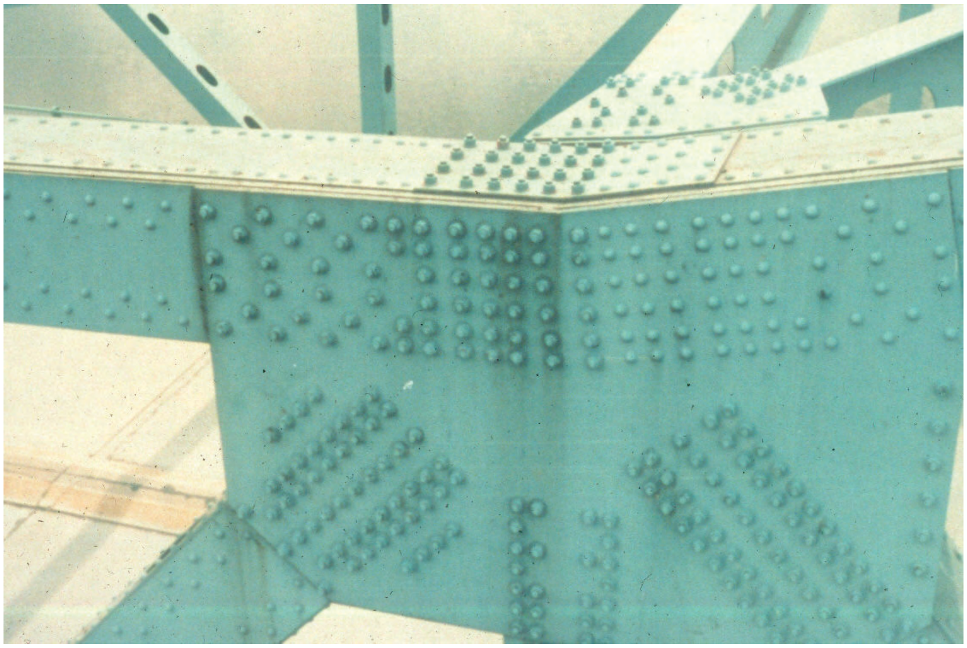

Figure 8.6.28 Truss Panel Point using Shop Rivets and Field Bolts

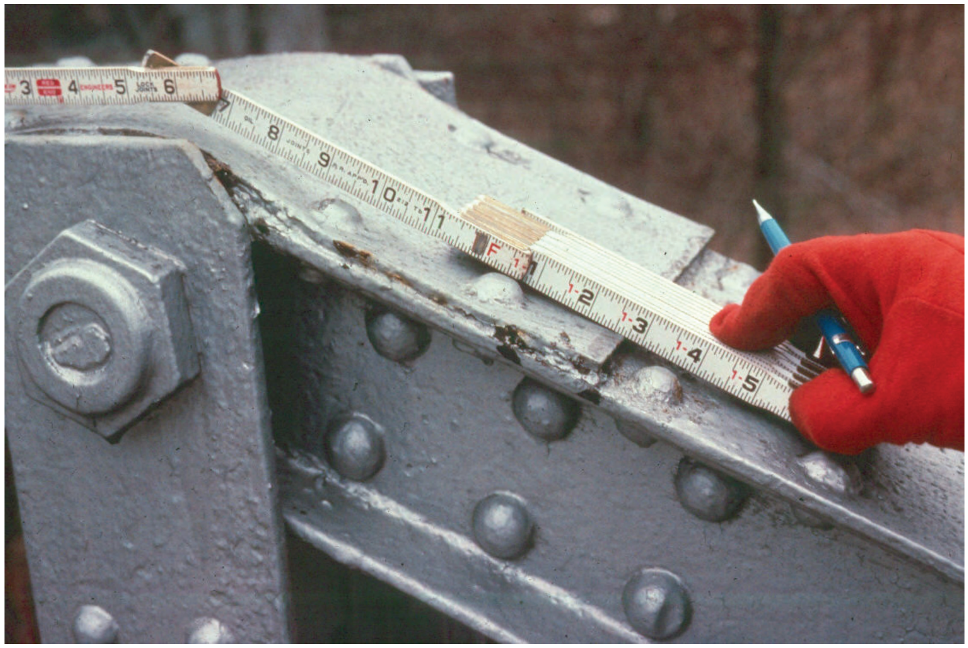

Figure 8.6.29 Pin Connected Truss

Either the letter U, for upper chord, or the letter L, for lower chord, or the letter M, for middle chord designates a panel point. Additionally, the panel points are numbered from bearing to bearing, beginning with 0 (zero). Most trusses begin with panel point L_0. Some deck trusses may begin with U_0. Upper and lower panel points of the same number are always in a vertical line with each other (e.g., U_7 is directly above L_7) (see Figures 8.6.30 and 8.6.31).

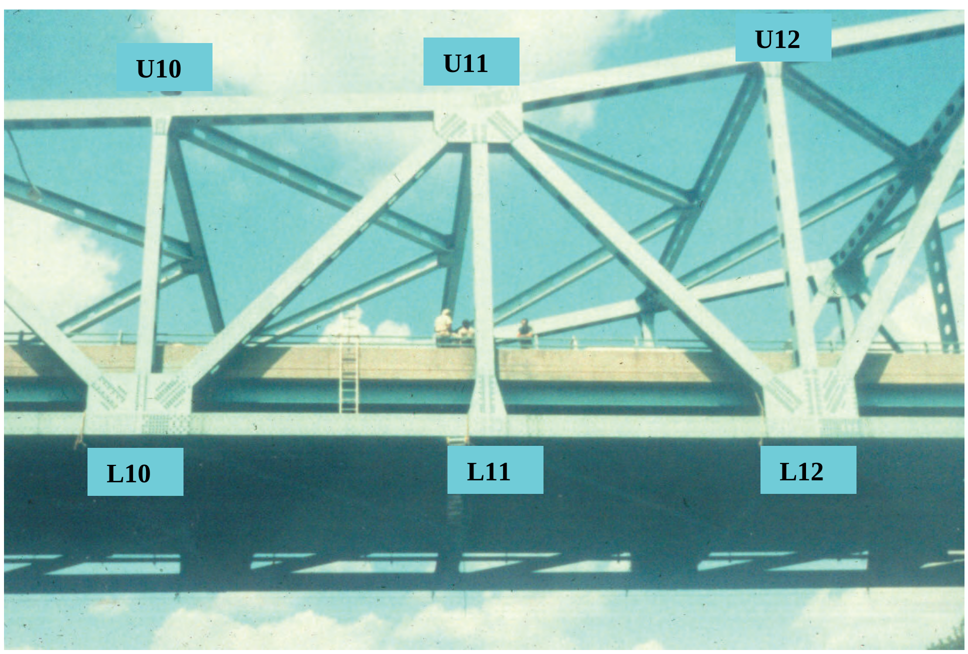

Figure 8.6.30 Truss Panel Point Numbering System

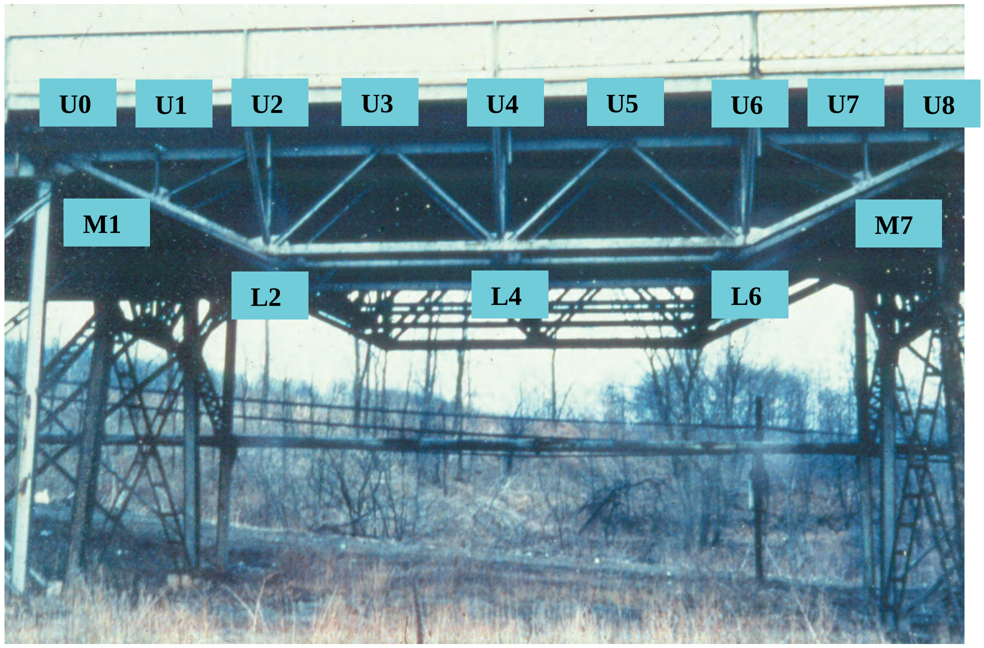

Figure 8.6.31 Deck Truss

A panel is the space, or distance, between panel points. Truss panels are typically 6 to 7.5m (20 to 25 feet) long and range 5 to 10 m (16 to 32 feet) deep. The panel length is a design compromise between cost and weight, with the longer panels requiring heavier floor systems.

As truss spans became longer, they also had to become deeper, increasing the distance between the upper and lower chords. They also required longer panels. As the panels became longer, the diagonals became even longer and the slope became flatter. The optimum angle between the diagonal and the horizontal is 45° to 55°.

To obtain a lighter floor system, designers subdivided the panel. The midpoint of each diagonal was braced with a downwardly inclined sub-diagonal in the opposite direction and with a sub-vertical down to the lower chord. Subpanel points are designated with the letter M. Sometimes, the "half" number of the adjoining panels is used for these diagonal midpoints (e.g., $M_{7\ 1/2}$). The method of subdividing the truss created a secondary truss system within the main truss to support additional floorbeams. Baltimore and Pennsylvania trusses, patented in the 1870’s, use this method. The K truss, a more recent design, accomplishes the same purpose (see Figure 8.6.32).

Figure 8.6.32 A Pennsylvania Truss, a Subdivided Pratt Truss with a Camel Back Top Chord

Floor System Arrangement

Most trusses have a floor system arrangement consisting of stringers and floorbeams similar to the two girder systems (see Figure 8.6.33). Floor systems support the deck and are supported by the trusses. Floor systems (floorbeams and stringers) are subjected to bending, shear and out-of-plane bending stresses. Trusses have floorbeams at each panel and sub panel point along the truss. Floorbeams should be designated by their panel point number. Some floor systems only contain floorbeams and no stringers (see Figure 8.6.34).

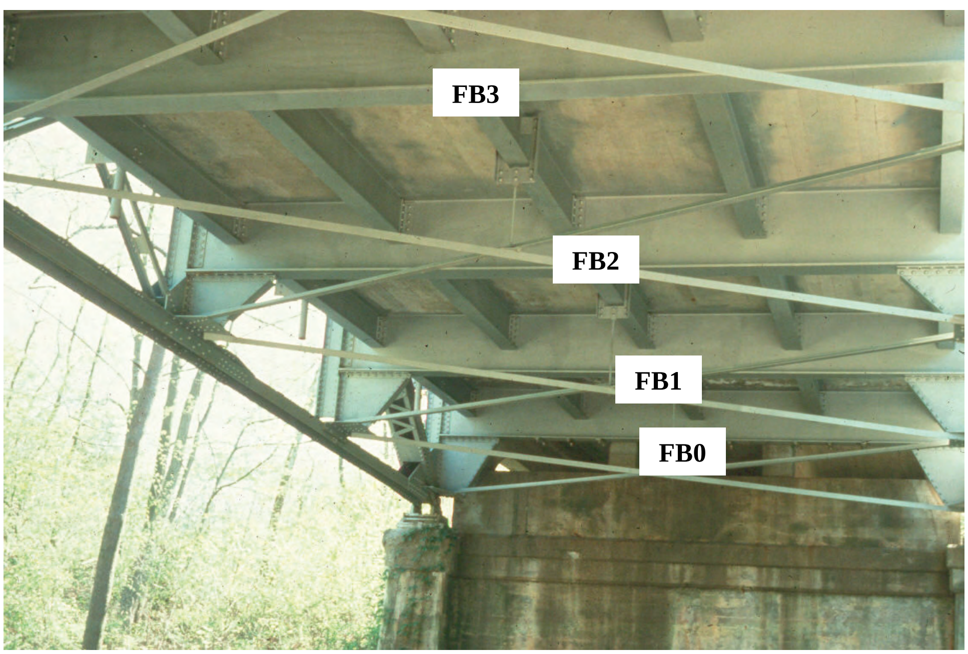

Figure 8.6.33 Floorbeam Stringer Floor System

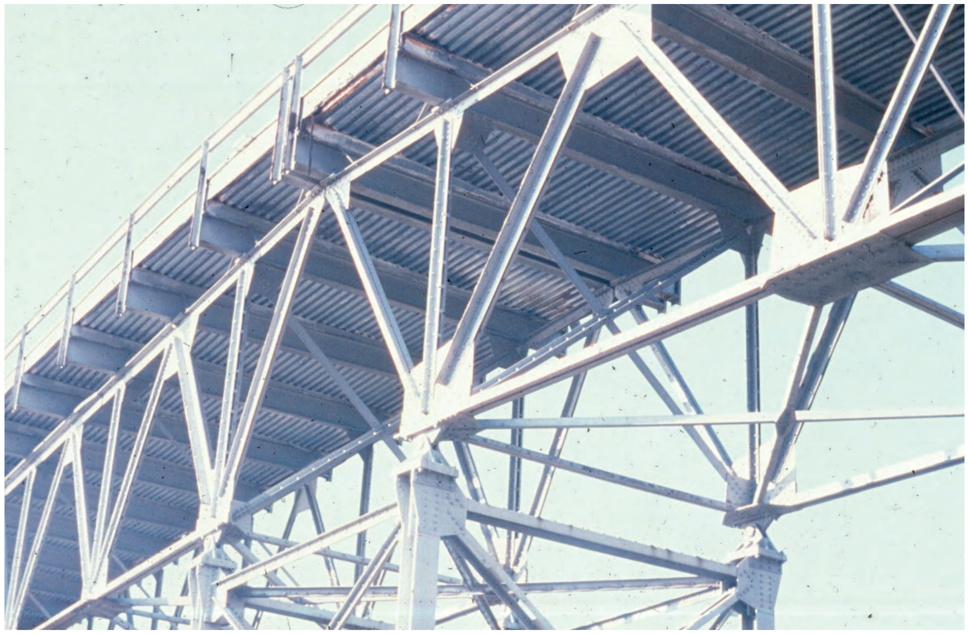

Figure 8.6.34 Floorbeam Floor System

See Figure 8.6.18 of a sample truss schematic showing a truss floor system consisting of floorbeams and stringers.

Lateral Bracing

Upper/lower lateral bracing is in a horizontal plane and functions to keep the two trusses longitudinally in line with each other. Most trusses have upper and lower chord lateral bracing, with the exception of pony trusses, which do not have upper lateral bracing. The bracing is typically constructed from built-up and rolled shapes and is connected diagonally to the chords and floorbeams at each panel point using gusset plates (see Figure 8.6.18, Figure 8.6.35, Figure 8.6.36 and Figure 8.6.37). Lateral bracing is subjected to tensile stresses caused by longitudinal or transverse horizontal loadings.

Figure 8.6.35 Upper Lateral Bracing

Figure 8.6.36 Lower Lateral Bracing

Figure 8.6.37 Lateral Bracing Gusset Plate and Lateral Bracing

Sway/Portal Bracing

Sway bracing is in a vertical plane and functions to keep the two trusses parallel. The bracing is typically constructed from built-up or rolled shapes. The sway bracing at the end diagonal is called portal bracing and is much heavier than the other sway bracing. Sway bracing on old through trusses often limits the vertical clearance, and it therefore often suffers collision damage. Large pony trusses also have sway bracing in the form of a transverse diagonal brace from top chord to bottom chord (see Figures 8.6.18, 8.6.38, 8.6.39, 8.6.40 and 8.6.41). Sway and portal bracing are subjected to compressive stress caused by transverse, horizontal loads. They also help resist buckling of compression chords.

Figure 8.6.38 Sway Bracing

Figure 8.6.39 Sway Bracing

Figure 8.6.40 Portal Bracing

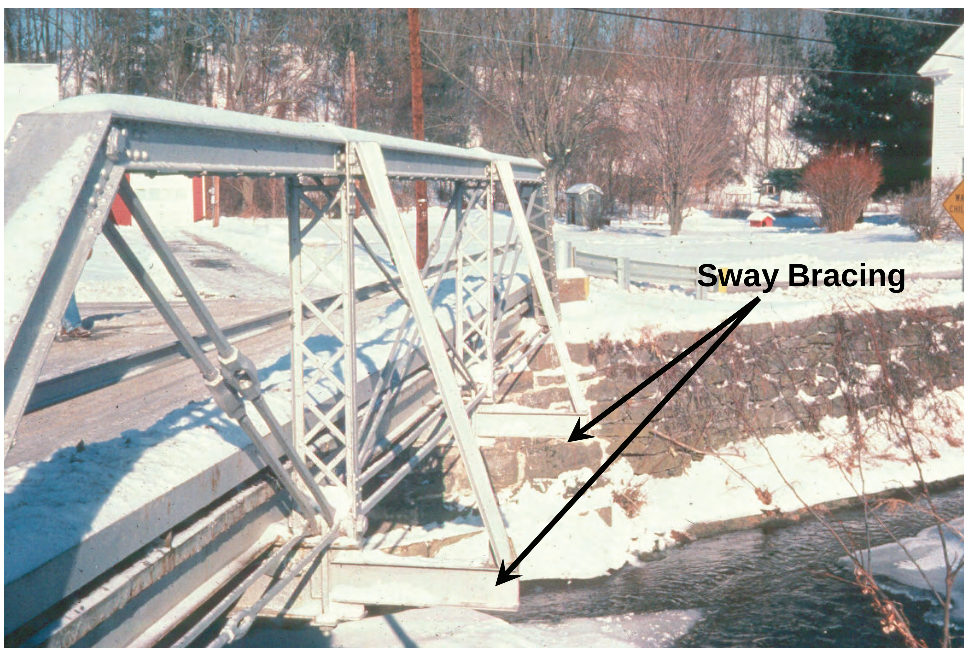

Figure 8.6.41 Pony Truss "Sway Bracing"

Primary Members and Secondary Members

Primary members carry dead load and primary live load and consist of:

- Trusses (chords and web members)
- Floorbeams
- Stringers

Secondary members resist horizontal and longitudinal loads and consist of:

- Portal bracing

- Lateral bracing
- Sway bracing

Secondary members do not contribute to the primary live load-carrying capacity of the bridge. Rather, they function only to keep the primary members properly aligned and resist secondary live loads.

Primary and secondary members are shown on Figure 8.6.18.