used efficiently in crossover structures over depressed freeways. As confidence in longer spans increased along with the demonstrated ability of the prestressing industry to produce high-strength concrete, spans of 150 feet could be constructed economically, though transporting them to the construction site could pose problems.

Highway construction began to escalate approaching the interstate boom spurred by the 1956 Federal Aid Highway Act, and thus, the arrival of prestressing was very timely. Nothing has been as beneficial to the economy and durability of American highway bridges as precast, pretensioned concrete I-beams. In the early years of interstate highway construction, prestressed beam spans were offered to contractors as alternates to continuous steel I-beam units. It soon became obvious that steel could not compete economically. Prestressed beams became the best choice for many crossover structures and stream crossings.

Although pre-stressing was first used in the United States in application to an I-beam bridge, pre-stressing can also be applied to several other bridge types, including. slabs, T-Beams, girders, box beams, and rigid forms. In fact, the first prestressed concrete beam bridge in the United States to be completed was not the Walnut Lane Bridge, but a small “block” beam bridge completed in October 1951, in Madison County, Tennessee. The Duffy’s Creek Bridge (1950), designed by Ross Bryan, is discussed in the following section of this chapter (prestressed box beams).

In prestressed concrete bridges, the tensile forces caused by the application of loads are reduced in the main structural members by inducing internal compressive forces by means of high tensile strength wires, cables or (occasionally) bars. The compressive forces may be applied during fabrication of the member by stretching the steel reinforcement prior to casting and curing of the concrete. After the concrete has cured, the tension on the steel is released, thus transferring the load to the concrete. The concrete is in direct contact with the steel so that bonding of the two materials can occur. When external loads (traffic and the weight of the deck and other bridge components) are applied to the member, tensile forces that are thus created are counterbalanced by the internal compressive forces induced by the pre-tensioning of the steel. This method of pre-stressing is called pre-tensioning.

Another method of pre-stressing, called post-tensioning, involves placing sleeves or ducts in the concrete member during fabrication, into which steel reinforcement is placed after curing of the concrete. The reinforcement is then stretched (stressed) by jacking, and locked in place by anchor plates or other locking devices. If bonding is desired, grout may be injected into the sleeves. In some cases, however, a protective covering is applied to the steel to de-bond it from the concrete in order to control cracking in end sections. Occasionally, though usually in more modern bridges that have not yet achieved “historic age,” a combination of pre-tensioning and post-tensioning is used. But, whatever the method employed, when compressive forces are properly calculated and proper fabrication methodology is followed, the prestressed bridge members will not develop stress cracks.

Significance Assessment: This type of structure was developed late in the historic period covered by this report (through 1955). Because of the influence of pre-stressed concrete I-beams on modern bridge technology, the early examples (pre-1955) that possess integrity are significant within the context of this study. It is thought that they would be highly significant, but insufficient historic context/scholarship exists for this period of bridge building to confidently assess the significance of this structural type. Character-defining features that contribute to integrity include: the slab, longitudinal beams, floor beams, a parapet or railing if integral, and abutments, piers and wingwalls, when present.

ASCE's History & Heritage Committee, under the leadership of Professor Dario Gasparini, Case Western Reserve University, is seeking assistance identifying early prestressed concrete projects that may merit designation as National Historic Civil Engineering Landmarks. The fact that ASCE is seeking identification of prestressed concrete structures means that this bridge type only recently has been perceived as significant.

Examples of Prestressed Concrete I-Beams: Because of its comparative recent vintage, meaning many of the examples are just reaching 50 years of age, only one NRHP-listed/HAER-recorded example of this type has been identified, the Walnut Lane Bridge.

1. Walnut Lane Bridge (1950); spanning Lincoln Drive & Monoshone Creek at Walnut, Philadelphia County, Pennsylvania. NRHP listed 1984. HAER PA-125.
2. Roseville Bridge (1952), CR 32 over Moxahola Creek, Muskingum County, OH. NRHP eligible 2004 in *Third Ohio Historic Bridge Inventory, Evaluation and Management Plan for Bridges Built 1951 – 1960 and the Development of Ohio's Interstate Highway System.*
3. US 37 Bridge (1960), over Scioto River, Scioto Township, OH. NRHP eligible 2004 in *Third Ohio Historic Bridge Inventory, Evaluation and Management Plan for Bridges Built 1951 – 1960 and the Development of Ohio's Interstate Highway System.*
4. Bridge 39 7301 0000 0013 (1955), 15th Street, Allentown, PA. Determined NRHP eligible in state-wide bridge survey.
5. Bridge 67 3009 0180 0721 (1955), Ridge Avenue south of Philadelphia City border, Delaware County, PA. Determined NRHP eligible in state-wide bridge survey.

Figure 3-78 depicts the Walnut Lane Bridge, a prestressed concrete I-Beam structure.

Figure 3-78. Walnut Lane Bridge (1950), Philadelphia, Pennsylvania. This structure is the first prestressed concrete beam bridge built in the United States.

3-78a. Oblique View.

3-78b. View of underside of superstructure.

3.3.9 Prestressed Concrete Box Beams

History and Description: Prestressed box beams began to appear on highways in the early 1950s, but were not common until the 1960s. According to bridge historian Patrick Harshbarger, the Pennsylvania Highway Department, which may have been the first transportation agency to employ them, began using prestressed box beams in 1951. By 1954, they were building about sixty of them a year, mostly on secondary roads.

Problems with fabrication and construction soon became evident. Even so, box beams (and I-beams) remained popular where speed of construction or minimum section depth was critical. Many state highway departments (e.g., Pennsylvania, Florida, Tennessee, California and Texas) initiated research in an effort to develop economical precast structural shapes. Research resulted in simplified box, (as well as I-beam and double tee) standards and, in 1962, AASHTO and the Prestressed Concrete Institute (PCI) published recommendations for standard shapes. Construction experience improved and more prestressed structural shapes, such as box beams, were built.

Most bridges of this type have a rectangular cross section in which the top and bottom slabs act as the flanges and the side walls act as webs; however, the interior void of many early box beams were circular in section.

A similar type of prestressed structure is the “block” beam bridge. Although begun after the Walnut Lane Bridge, the Duffy’s Creek Bridge (1950) in Madison County, Tennessee, was completed first, thus making it the first prestressed concrete bridge to be put into service in the United States. This bridge features a “block” beam design developed by Ross Bryan (1910-2002). A 1933 graduate of the civil engineering program at the University of Kansas, Bryan worked early in his career at the Kansas Highway Department. He was also a structural design engineer in the Panama Canal Zone before and after World War II, and a structural engineer with Marr and Holman Architects until establishing Bryan and Dozier Consulting Engineers in 1949. Approximately four years later he formed Ross Bryan Associates, Inc., in Nashville, Tennessee; a company that still exists. Bryan led the firm until his retirement in 1977. He also designed a stadium in Fayetteville, Tennessee, which is credited as being the first prestressed concrete non-bridge structure in the country. Like many designers of concrete bridges, he was apparently more interested in building designs than in bridges. A small handful of bridges were designed by Bryan using this method, which does not appear to have been widely used.

According to a 1951 article in the *Engineering News Record* (*33*), the Duffy’s Creek Bridge consisted of pre-cast concrete standard machine blocks compressed by seven-wire galvanized wires. Each block had three cores. Special end blocks were made for anchoring the prestressed strands, and special depressor blocks held the strands in place. The blocks were strung over the prestressing strands and mortared together. An initial tension was then placed in the strand. After the mortar had been allowed to set for a day, additional force was applied. The unified beams thus formed were lifted onto the substructure to form the superstructure of the bridge. A concrete deck slab and integral curb was then cast. Transverse strands were then placed and tensioned so that the beams would work together to handle the loads imposed on the bridge.

In 1996 Bryan was awarded the Medal of Honor by the Precast/Prestressed Concrete Institute in recognition of his contributions to the design of prestressed concrete structures (*32*). The Precast/Prestressed Concrete Institute also recognizes a prestressed block beam bridge built in Michigan by C. L. Johnson in 1950, but little is known about this designer or his work.

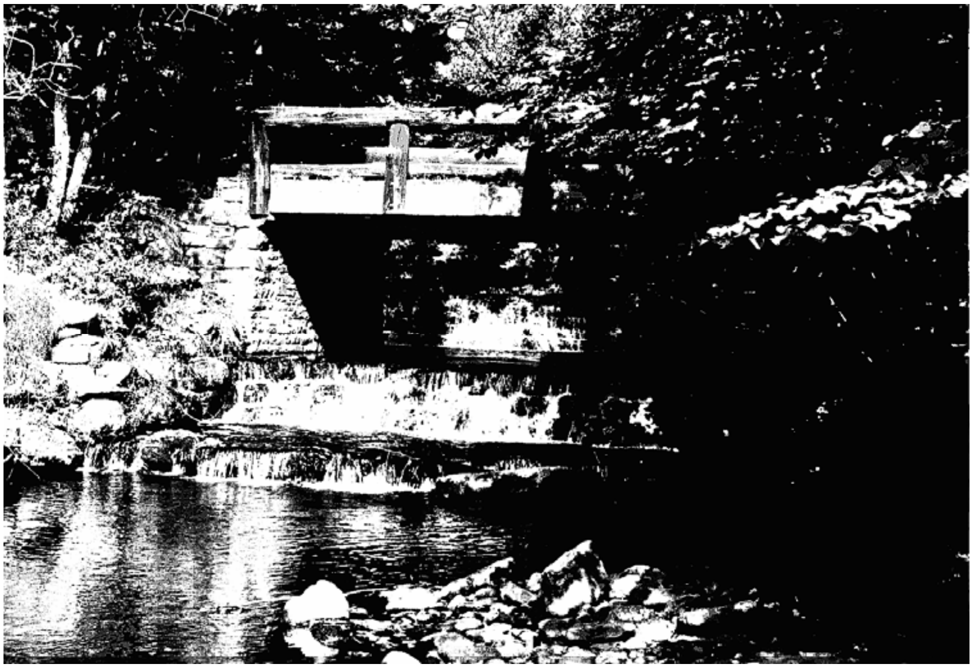
Significance Assessment: This type of structure was developed late in the historic period covered by this report (through 1955). Because of its relative commonness, the prestressed concrete box beam possesses a low level of significance within the context of this study. Early examples (pre-1955) that possess integrity are the most significant of this type. However, insufficient historic context/scholarship exists for this period of bridge building to confidently assess the significance of this structural type. Character-defining features that contribute to integrity include the slab, the box-shaped longitudinal beams, parapet or railing if integral and abutments, wingwalls and piers when present.

Examples of Prestressed Concrete Box Beams: Due to the fact that these structures are just reaching 50 years of age, no know examples are listed in the NRHP or HAER-recorded. The only readily identifiable examples that have been labeled as NRHP eligible are listed below.

1. Middle Pike Bridge #0630535 (1956), over Dry Run, AuGlaize County, OH. NRHP eligible 2004 in *Third Ohio Historic Bridge Inventory.*
2. Lippincott Road Bridge #1130234 (1956), over Mad River, Champaign County, OH. NRHP eligible 2004 in *Third Ohio Historic Bridge Inventory.*
3. Middleburg Road Bridge #1130412 (1954), over Branch of Big Darby Creek, Champaign County, OH. NRHP eligible 2004 in *Third Ohio Historic Bridge Inventory.*
4. Suder Avenue Bridge #4860098 (1959), over Ottawa River, Lucas County, OH. NRHP eligible 2004 in *Third Ohio Historic Bridge Inventory.*
5. Hempt Road Bridge (1952), over Hogestown Run, Silver Spring, Cumberland County, PA. NRHP eligible in state-wide bridge survey.
6. Scenic Drive Bridge (1950), over Hickory Run, Kidder, Carbon County, PA. Recommended NRHP eligible in statewide bridge survey.

Figure 3-79 depicts an example of a concrete box beam bridge.

Figure 3-79. Scenic Drive Bridge (1950), over Hickory Run, Carbon County, Pennsylvania. This 24-foot long structure was built as part of improvements at Hickory Run State Park. Photographs courtesy of PENNDOT.



3-79a. West elevation.

3-79b. Underside of box beams at stone abutment.

3.3.10 Metal Rolled Multi-Beams

History and Description: Bridge historians and bridge engineers frequently use the terms “beam” and “girder” interchangeably, however, for the purposes of this report, a distinction will be made between the two. As the FHWA *Bridge Inspector’s Reference Manual* (*23*, p. 8.2.1) states, “In steel fabrication, the word ‘beam’ refers to rolled shapes, while the word ‘girder’ refers to fabricated members.” Another term that is widely used in discussion of historic bridges is “stringer,” which generally refers to a type of bridge in which a series of parallel, relatively shallow, longitudinal beams (usually I-beams) serve as part of the superstructure in support of the deck or travel surface. The longitudinal beams are the “stringers” in a stringer bridge.

Iron I-beams were available to bridge designers prior to the Civil War, but the limited fabrication capabilities of iron mills in the nineteenth century dictated that metal beams were generally used only in place of timber stringers in short span bridges. In the 1890s, steel began to replace iron as the preferred material for metal bridge members as advances in technology lowered costs**,** enhanced the consistency, and increased the fabrication capabilities of the steel making industry. This shift was first observable in regard to metal truss bridges, which basically retained their primary design characteristics when expressed in steel rather than iron. Eventually, however, the increased ability of steel plants in the early twentieth century to roll steel I-beams and channels of just about any length and depth required by bridge designers, without warping of the member, facilitated development of the steel beam (stringer) bridge.

Although fabricated in the United States in the 1850s to 1860s, rolled beams were not generally used on highway bridges until the 1920s and 1930s. The earliest known standard drawings of the rolled beam bridge were prepared by the U.S. Government’s Bureau of Public Roads in 1917. The earliest structures were simple I-beam spans with timber decks, but reinforced concrete decks soon became standard. Span length capabilities were eventually increased through the use of cantilever drop-in units. Some of the advantages of continuity could be obtained without the structure being statically indeterminate. Hinges were notched beam seats with bearings first and pin and hangers later.

By the early 1940s, continuous units with riveted splices were being designed. Simple spans still retained popularity because of simpler construction. I-beams, in general, ceased to be economical by the early 1960s, succumbing to rising steel prices and a new and vital prestressed beam industry. There has been a slight resurgence in the use of steel I-beam spans as their cost has become comparable to concrete box beams, and steel is much easier to adapt to severe geometric constraints.

The *Bridge Inspector’s Reference Manual* states that the steel rolled multi-beam bridge is made up of three or more parallel rolled beams with a deck placed on top of the beams. The primary structural members of a rolled multi-beam bridge are the beams, and the secondary members are the diaphragms, when present. This type of superstructure is commonly used for simple spans, but continuous span designs have also been erected.

The "jack arch" is a deck support system comprised of a concrete (or, in rare cases, brick) arch springing from the bottom flanges of adjacent rolled steel beams, with the beams extending from abutment to abutment, or (for continuous spans) from pier to pier. The principle load carrying element is the steel beam. The concrete stiffens and strengthens the beam by preventing buckling of the compression flange while also protecting the beam from corrosion. Concrete was poured into corrugated metal form liners to encase the beams and integrate them with the deck. The concrete often extended up from the deck along both sides of the roadway to form a low curb or a parapet, with metal railings of various types frequently attached to the concrete extensions. In some cases a metal rail was attached to the sides of the deck without any extension of the concrete. This type was constructed from the late 1890s to the early 1930s, usually as simple span bridges on county roads. Examples have been identified in New York, New Jersey, Maine, Pennsylvania, Georgia, and Texas. These structures are very strong, but very difficult to rehabilitate; thus, not many extant NRHP-eligible examples survive in most states. However, more than 100 jack arch deck bridges were found during research for the Georgia *Historic Bridge Inventory Update* (June 2001), and thirty-nine pre-1930s examples were identified during research for the New York State *Final Report: Evaluation of National Register Eligibility* (*34*).

Significance Assessment: Metal rolled multi-beam bridges possess low significance within the context of this study. The level of significance within this category will depend on the structures' dates, span lengths, integrity; and use of early, innovative fabricating techniques, such as welded splice connections. Character-defining features that contribute to a structure's integrity include the rolled longitudinal I-beams or wide flange beams, floor beams, and original rails, piers, wingwalls and abutments.

Examples of Metal Rolled Multi-Beams

1. Twin Bridge (1900), Cherry County, Nebraska. NRHP listed 1992 in Highway Bridges in Nebraska MPS.
2. Brevard Bridge (1913), spanning Westland Run at Ullom Road, Expot vicinity, Washington County, PA. HAER PA-215.
3. South Euclid Road Bridge (ca.1900), spanning Squaconning Creek, Bay City, Bay County, MI. HAER-MI-42.
4. Parryville Bridge (1933), State Route 2008 over Pohapoco Creek, Parryville, Carbon County, PA. HAER PA-480.
5. Bridge 021-0182 (1929), Jefferson Road over Walnut Creek, Bibb County, GA. Determined NRHP eligible in statewide bridge survey.

Figures 3-80 and 3-81 illustrate a metal rolled beam structure.

Figure 3-80. Elevation drawing of a metal rolled beam bridge.

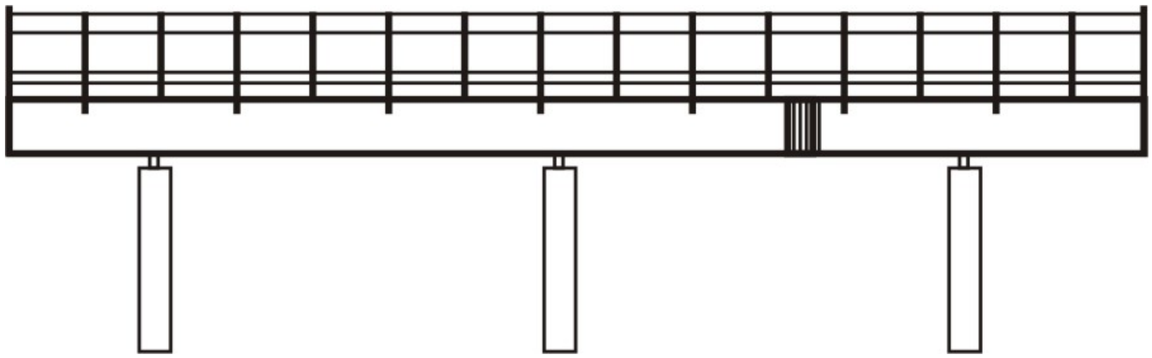


Figure 3-81. Parryville Bridge (1933), State Route 2008 over Pohapoco Creek, Parryville, Pennsylvania. This bridge is an example of the metal rolled multi-beam type.

3.3.11 Metal Built-up Girder

History and Description: The first plate-girder bridge in the United States was a single track deck-girder with clear span of 50 feet built for the Baltimore & Susquehanna Railroad by James Millholland at Bolton Station, Maryland, in 1846. Fabricated in the shop, the 14-ton bridge was hauled to the site and set in place. Millholland anticipated by 30 years the standard type girder bridge for short railway spans.

Built-up, riveted plate girders were introduced to highways in the late-nineteenth and early twentieth centuries, but this was rare due to the expense of fabricating built-up plate girder beams. Less expensive alternatives such as rolled girders and the early concrete forms were available.

Since the 1930s, I-shaped plate girders have been used to span beyond the range of rolled beams. Originally, girders were fabricated by riveting flange angles to a web plate and adding cover plates top and bottom. The most common configuration was two girders connected by transverse floor beams with rolled beam stringers parallel to the girders, topped by a one-way deck slab. Built-up steel plate girders remain one of the common bridge types for highway construction.

Welded girders replaced riveted built-up beams as fabrication and welding techniques improved. Design, detailing, and fabrication of welded steel girders became much simpler when welding was accepted as a quality connection technique. However, weld details were shown by numerous laboratory tests to be highly susceptible to fatigue crack failure in bridge girders and I-beams. In the late-1970s, weld flaws were discovered in the first generation (1950s) of welded girders and many states began ultrasonic testing. Numerous welds were found to be outside the limits of acceptable ultrasonic performance. The use of this type of girder on highway bridges was discontinued in favor of bolted connections and splices.

Multi-girder bridges often look similar to rolled multi-beam bridges, but the fabricated girders are generally larger than what rolling mills produce. Older multi-girder bridges use built-up members consisting of angles and plates that are riveted or welded together. This type of superstructure is used for simple and continuous spans, and is widely used for curved portions of bridges.

The two-girder bridge is similar to the multi-girder bridge in most respects, and may have web insert plates and transverse or longitudinal web stiffeners, but is differentiated by having just two primary girders. The floor system may be a girder-floorbeam, or girder-floorbeam-stringer configuration. Two girder bridges may be deck bridges with a floor system that supports the deck, which rests on the top of the flanges of the girders and floor system, or may be through girder bridges in which the deck is located between the girders, which extend above the travel surface. Pin and hanger connections are common features of two-girder deck bridges.

Although two-girder bridges are usually simple span structures, multiple span and continuous span configurations are not uncommon. The majority of older two-girder bridges are likely to feature riveted girders, but welded girders may also be found. Riveted through two-girder bridges, often referred to as “plate-girder” bridges, were once very popular with railroads for watercourse crossings and for grade separation structures where there was a need to achieve maximum vertical clearance between the rail deck and the water feature or the roadway.

Significance Assessment: Metal built-up girders possess moderate significance within the context of this study. Within this type, surviving riveted, built-up girders, dating from the early-twentieth century, of reasonable integrity, are more significant because of their relative rarity. The first generation, welded steel girders that survive from the 1950s are also of higher significance within this bridge type, as these structures have mostly been replaced due to their structural deficiency. Character defining features of this structure include riveted or welded metal plate girders, its floor system and abutments and/or wingwalls, when present.

Examples of Metal Built-up Girder

1. Francis Street Bridge (1894), Providence, Providence County, RI, HAER RI-33
2. North Kinney Road Bridge (c.1910), spanning Brown Creek, Rock City vicinity, Stephenson County, IL, HAER IL-129.
3. Georgetown Loop Plate Girder Bridge (n.d.), Clear Creek County, CO. NRHP listed 1970.
4. Bridge 191-0007-0 (1944), US 17 over Darien River, McIntosh County, GA. Determined NRHP eligible in statewide bridge survey.
5. Peartown Road Bridge (1909), SR 1053 over Cocalico Creek, West Cocalico, Lancaster County, PA. Determined NRHP eligible in statewide bridge survey.

Figures 3-82 and 3-83 contain photographs of metal fabricated girder bridges.

Figure 3-82. Georgetown Loop Plate girder Bridge (n.d.), Clear Creek County, Colorado. This railroad bridge is a metal built-up girder. Photograph from *Historic Bridges of the Midwest.*

Figure 3-83. Francis Street Bridge (1894), near Union Station, Providence, Rhode Island. This structure is a metal, built-up girder.

3-83a. Side Elevation.

3-83b. View of underside of structure.

3.3.12 Metal Rigid Frame

History and Description: Steel rigid frame bridges are popular designs used by many state departments of transportation for span lengths of about 50 to 200 feet because they are generally considered to be aesthetically pleasing structures that allow elimination of intermediate supports. The inclined frame sides or "legs" of rigid frame bridges are integral components of the entire structure and combine with the horizontal frame girders to contribute to the overall load-bearing capacity of the bridge. The superstructure can be constructed of two frames, as in a two-girder bridge, or of multiple frames, as in a multiple girder bridge. Moreover, rigid frame bridges can have web stiffeners or diaphragms, and floor systems composed of floorbeams and stringers.

Although most of the rigid frame bridges of the Merritt Parkway in Connecticut were constructed of concrete, not all were. The bridge spanning New Canaan Road/ Route 123 in Norwalk, Fairfield County, was built as a single-span deck bridge composed of six steel rigid frames that spanned about 66 feet. This bridge has been widened to accommodate new traffic lanes.

Significance Assessment: Metal rigid frame bridges were developed simultaneously with concrete rigid frames, but they are much less common than the concrete versions. The use of steel would have been a matter of choice, based on economics, or simply to lend some variety to the more typical concrete span. The rigid frame, primarily built between the early 1920s and 1950 and much less common than the concrete rigid frame, possesses significance within the context of this study. The more highly-significant rigid frames are those that possess integrity and date early in the period of the structure's development in the United States (1920s), and those that can be documented as a representative example of a department of transportation's standard bridge design. Also significant are those built on parkways, as they possess both engineering significance and historic significance for their association with the development of the parkway.

Character-defining features that contribute to integrity include a monolithic substructure and superstructure of one continuous fabric (legs integral with horizontal girders), parapet or railing and piers, wingwalls and abutments. The outside elevations of these structures may be sheathed in concrete.

Examples of Metal Rigid Frame

1. M-27 Au Sable River bridge (1935), Crawford County, MI. NRHP Eligible in 1999, Highway Bridges of Michigan MPS.
2. New Canaan Road/Route 123 Bridge (1937), Fairfield County, CT. NRHP listed 1991 as part of Merritt Parkway MPS. HAER CT-87.
3. US 1 Bridge (1935), City Line Avenue over Amtrak, Philadelphia, PA. Determined NRHP eligible in statewide bridge survey.

Figure 3-84 shows a historic and current photograph of a metal rigid frame bridge. For a drawing of the type, refer to Figure 3-75, concrete rigid frame structure.

Figure 3-84. Merritt Parkway, New Canaan Road/Route 123 Bridge (1937), spanning New Canaan Road/Route 123, Norwalk, Connecticut. This is an example of a metal rigid frame structure, sheathed in concrete.

3-84a. Historic photograph of Merritt Parkway bridge.

3-84b. Recent photograph of same Merritt Parkway bridge.

3.4 Movable Spans

The machinery for swinging, lifting or opening is the distinguishing feature of moveable bridge spans. The development of reliable electric motors and techniques for counter balancing the massive weights of the bascule, lift, or swing spans marked the beginning of modern moveable bridge construction.

In order to keep navigable waterways free of obstruction, movable bridges or bridges with movable spans are sometimes required when the erection of a non-movable bridge of sufficient clearance is uneconomical or physically difficult. These movable bridges played a crucial role in eliminating many of the great navigable rivers of the nation as barriers to westward expansion, and became distinctive elements of many urban landscapes. There are several different types of movable bridges, but certain types, such as transporter and retractable, are uncommon. The three main types of commonly encountered movable bridges in the United States are the swing, bascule, and vertical lift. Swing spans may be sub-divided into three types: center pivot, rim bearing, and combination (rim bearing and center pivot), with the last constituting an uncommon type.

3.4.1 Center-Bearing Swing Span

History and Description: Dating from the 1890s to the 1920s, swing bridges were the earliest of the movable bridge types. They were simpler to build and operate than the other movable forms, but were slow to open and required large piers in the center of the shipping channel.

Although swing spans were once the most popular form of movable bridge in the United States, they were gradually supplanted by bascule and vertical lift designs because with a swing bridge there is always a structure (the pivot pier) in the waterway that serves as an obstruction to navigation, thus somewhat defeating the purpose of the span. Moreover, the clearance required for swinging the span tended to reduce the value of dock-front property in urban areas.

In the center pivot design, the span turns on a central pin or pivot, which bears the entire dead load of the span, and most of the live load. Part of the live load may also be transmitted to adjacent fixed spans through a locking mechanism when the span is in the closed position. Usually there are two trusses making up the swing span, although single truss designs may be found in smaller bridges. Occasionally, the swing span is composed of trusses of unequal mass, but this variation is very rare and most likely found in rim-bearing designs. The motive power of a swing bridge is usually supplied by electric motors or hydraulic motors, although older, smaller bridges are sometimes turned by manual power.

Although Waddell (*9*, p. 685) wrote in his highly regarded 1916 treatise that the choice between a center-pivot span and a rim-bearing span was “almost entirely a matter of taste; for there is no great difference between them in the cost, what little there is being favor of the latter,” he seemed to contradict himself by also stating that the choice between types “will often depend upon the character of the pivot pier.” Rim-bearing spans were briefly more popular for use by railroads when rolling stock was increasing in weight because it was believed that they were more rigid than center-bearing spans, but center-bearing spans are somewhat less complex and easier to construct than rim-bearing spans. Whatever the reason one type was selected over the other, the center pivot design is more commonly encountered in extant structures.

Except for the operating mechanisms that provide movement, swing spans tend to resemble fixed spans in that they are likely to be trusses or girders. The operation of a swing span, however, creates stresses that would not occur in a fixed span; therefore, swing spans, particularly trusses, tend to be built more robustly than fixed spans, with heavier structural members and more counters or braces. Connections are usually made with bolts or rivets in older spans, or by welds in newer spans. Pinned connected trusses are very rare in swing spans due to the stress placed upon the points of connection when the span is in operation.

Significance Assessment: Center bearing swing span bridges are among the least common bridge types in this study and are considered significant. Less common than other types of moveable spans, center bearing swing span bridges from the late nineteenth and early twentieth centuries possess a high level of significance within this type if they retain their integrity. Examples built late in the historic period covered by this study would be considered moderately significant, possessing less significance than the early structures. Character-defining features that contribute to integrity include a swing span that possesses the features of its respective type (e.g., truss or beam), central pier of masonry or concrete, pivot, and end rests. Features such as control houses, other operational machinery, and abutments, piers or wingwalls may also be character-defining features.

Examples of Center-Bearing Swing Spans

1. Hargrove Pivot Bridge (1917), Butler County, MO. NRHP listed 1985.
2. Judsonia Bridge (1924), White County, AR, NRHP listed 1990 in Historic Bridges of Arkansas MPS. HAER AR-73.
3. Great Northern Railway Company Bridge (ca. 1915), Cass County, MN. NRHP listed 1980.
4. Colusa Bridge (1901), spanning Sacramento River, Colusa, Colusa County, CA. HAER CA-7.
5. Chester & Delaware River Railroad (1907), spanning Chester Creek at Edgemont Avenue, Chester, Delaware County, PA. HAER PA-525.

Figures 3-85 through 3-87 depict center bearing swing span structures.

Figure 3-85. Elevation drawing of a center bearing swing span.

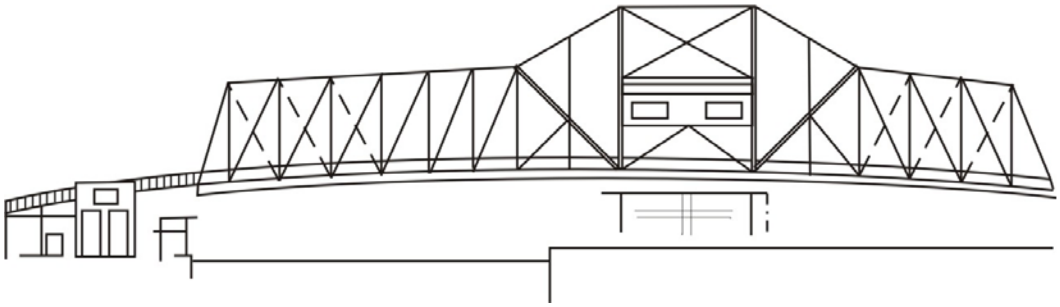


Figure 3-86. Colusa Bridge (1901), spanning Sacramento River, Colusa, California. The swing span of this bridge is pin connected.

Figure 3-87. Chester & Delaware River Railroad (1907), spanning Chester Creek, Chester, Pennsylvania. When built, this swing bridge was hand operated.

3.4.2 Rim-Bearing Swing Span

History and Description: Like center bearing swing spans, rim bearing swing spans date primarily from the 1890s to the 1920s. Both type swing spans were once the most popular form of movable bridge in the United States, but they were gradually supplanted by bascule and vertical lift designs because with a swing bridge there is always a structure (the pivot pier) in the waterway that serves as an obstruction to navigation, thus somewhat defeating the purpose of the span. Rim-bearing spans were briefly more popular for use by railroads than center swing spans when rolling stock was increasing in weight because it was believed that they were more rigid than center-bearing spans.

In the rim bearing design, the dead load is borne by a circular drum, which moves upon rollers. Live (traffic) loads are also borne by the drum, but part of the live load may also be transmitted to adjacent fixed spans through a locking mechanism when the span is in the closed position. Rim-bearing swing spans are usually composed of trusses of equal mass, but rare "bob-tailed" bridges with trusses of unequal mass are still extant. The drum of a rim-bearing swing span sits atop tapered wheels or rollers that are evenly spaced around the circumference of the drum. These rollers move within a raceway or track that is situated inside the periphery of the pier, and are held in position by steel radial roller shafts which radiate out from a capstan or center pivot bearing located at the center of rotation. Connections are usually made with bolts or rivets in older spans, or by welds in newer spans. Pinned connected trusses are very rare in swing spans due to the stress placed upon the points of connection when the span is in operation. The motive power is usually supplied by electric motors or hydraulic motors, although older, smaller bridges are sometimes turned by manual power.

Significance Assessment: Less common than other types of moveable spans, rim-bearing swing span bridges from the late nineteenth and early twentieth centuries are considered significant within the context of this study if they retain their integrity. Character-defining features that contribute to integrity include a swing span that possesses the features of its respective type (e.g., truss or beam), pier of masonry or concrete, pivot, and end rest. Features such as control houses, other operational machinery (e.g., drums, rollers, wheels), and abutments, piers or wingwalls may also be character-defining features. Examples built late in the historic period covered by this study would be considered moderately significant, possessing less significance than the early structures.

Examples of Rim-Bearing Swing Spans

1. Center Street Bridge (1901), Cleveland, Cuyahoga County, OH. HAER OH-10.
2. Northern Avenue Swing Bridge (1908), spanning Fort Point Channel, Boston, Suffolk County, MA. HAER MA-37.
3. Romeo Road, Sanitary & Ship Canal Bridge (1899), spanning Sanitary & Ship Canal, Romeoville, Will County, IL. HAER IL-41.

4. New York, New Haven & Hartford Railroad Bridge (1913), spanning Shaw's Cove, New London, New London County, CT. HAER CT-24.

Figure 3-88 contains photographs of a rim-bearing swing span bridge.

Figure 3-88. Northern Avenue Swing Bridge (1908), spanning Fort Point Channel, Boston, Massachusetts. The structure is a pin-connected rim bearing swing span.

3-88a. Oblique view.

3-88b. Span in open position.

3.4.3 Vertical Lift Span

History and Description: Dating from the late nineteenth century, the vertical lift type flourished for the next thirty years.

In 1872, Squire Whipple patented a vertical lift design that was used to span canals or small streams in New York and other Eastern states. These were modest structures of short span that were not required to elevate more than a short distance. The first vertical lift span of large scale in the United States was designed and patented by J. A. L. Waddell (1854-1938) in 1893 for the City of Duluth, Minnesota, which required a 250-foot wide clear channel and a 140-foot vertical clearance. Although this structure was never built, due to factors unrelated to the suitability of its design, it showed so much promise for addressing the limitations of swing, retractable and bascule bridges that the City of Chicago asked Waddell to design a similar bridge with a clear span of 130 feet and a vertical clearance of 150 feet for erection over the South Chicago River at South Halstead Street. Completed in 1894, the South Halstead Street Bridge was the first large-scale vertical lift bridge constructed in the United States.

Waddell made his principal assistant engineer, Ira G. Hedrick, his partner in 1899, but these men apparently did not design any vertical lift bridges together. In 1907, Waddell formed a new partnership with John Lyle Harrington (1868-1942), and the new firm soon won several contracts for vertical lift bridges of improved design that reflected Harrington’s contribution. Before dissolving their partnership about 1915, Waddell and Harrington designed more than thirty bridges together. The Hawthorn Bridge across the Willamette River in Portland, Oregon, completed in 1910 and extensively renovated in 1999, is the oldest bridge designed by the partners that still retains its full functionality.

Harrington’s new firm, Harrington, Howard and Ash, was recognized as a leader in vertical lift bridge design for many years. When Harrington left to form a partnership with Frank Cortelyou in 1928, his former company reorganized as Ash, Howard, Needles, and Tammen. The Stillwater Bridge, connecting Houlton, Wisconsin, with Stillwater, Minnesota, is NRHP-listed, Waddell-Harrington design built by this company in 1931. In 1941, there was a further reorganization of the firm as Howard, Needles, Tammen and Bergendoff, now known as HNTB Corporation.

After dissolution of his partnership with Harrington, Waddell was joined by his son, Needham Everett, to form Waddell and Son. Following his son’s death in 1919, Waddell moved his office to New York and practiced alone for several years until making his principal assistant, Shortridge Hardesty, his partner in 1927. Hardesty had been an employee of Waddell since about 1908, and undoubtedly made significant contributions to the designs of Waddell well before becoming a partner. The Newark Bay Railroad Bridge, completed in 1925 (demolished in 1980), was one of the most notable works of Waddell during the 1920s. Waddell and Hardesty became widely known for designing a number of vertical lift railroad bridges in the New York metropolitan area, and also expanded their practice to include many non-movable highway bridges.

The great majority of historic-age vertical lift bridges are composed of two towers located on either side of a waterway, with a truss span between. The truss span is lifted by cables that are attached at the ends of the span and run over pulleys at the tops of the towers down to counterweights on vertical runways within the towers (*8*, pp. 103-4). The truss remains in a horizontal position throughout the operating cycle, and can be raised far enough to provide clearance for the largest ships or boats. (There is a newer vertical lift design that operates differently, but this sub-type does not fall within the parameters of this study.)

The vertical lift type was developed to replace the swing span because it was less obstructive of the channel and quicker to operate. Vertical lifts usually are found in flat terrain where the cost of long approaches to gain high-level crossings is prohibitive. Advantages included rapidity of operation, adjustable openings depending on the size of the vessel, and the ability to build in congested areas adjacent to other bridges. Many of the surviving vertical lift structures are railroad bridges.

Significance Assessment: Most vertical lift bridges are works of late nineteenth and early twentieth century civil and mechanical engineering and tend to dominate both urban and rural landscapes with their distinctive towers. These bridges are less common than many of the bridge types described in this study and, if the structures possess their character-defining features, they possess a high level of significance within the context of this study. Character defining features include two towers, the lift span (which will possess the character-defining features of the relevant span type), drive machinery, cables, pulleys, counterweight and piers or abutments. Another feature that may be considered character-defining is the operator's house.

Examples of Vertical Lift Spans

1. Snowden Bridge (1913), Richland County, MT. HAER MT-27.
2. City Waterway Bridge (1911), Pierce County, WA. NRHP listed 1982 in Historic Bridges/Tunnels in Washington State Thematic Resource. HAER WA-100.
3. White River Bridge at De Valls Bluff (1924), Prairie County, AR. NRHP listed in 1990, Historic Bridges of Arkansas MPS.
4. Meridian Bridge (1924), Cedar County, NE. NRHP listed 1993 in Highway Bridges in Nebraska MPS.
5. Sacramento River (Tower) Bridge (1936), Sacramento County, CA. NRHP listed in 1982. NRHP listed in 1982. HAER CA-73.

Figures 3-89 and 3-90 depict, respectively, a drawing and a photograph of a vertical lift bridge.

Figure 3-89. Elevation drawing of a vertical lift bridge.

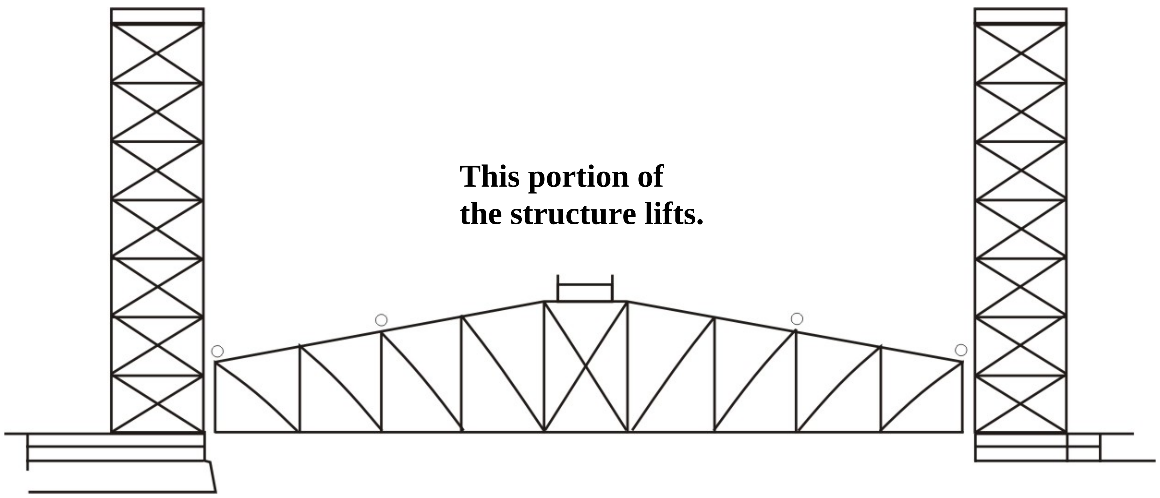


Figure 3-90. Snowden Bridge (1913), spanning Missouri River, Nohly vicinity, Richland County, Montana. This structure is an example of a vertical lift.

3.4.4 Simple Trunnion (Milwaukee, Chicago) Bascule

History and Description: Bascules were developed in the United States to replace its predecessor, swing spans, thus eliminating the central pier from the waterway. It was less obstructive of the channel and quicker to open. Engineers in Chicago and Milwaukee pioneered solutions at the turn of the century improving the mechanics of the lift and locking mechanisms resulting in an efficiently operating movable bridge in tight, constricted areas. Bascules quickly replaced swing spans.

Waddell (*9*, p. 700) states in *Bridge Engineering* that the first important bascule bridge in the United States was the Michigan Avenue Bridge at Buffalo, New York. He does not, however, provide a date for this bridge, which replaced a swing span that had been erected in 1873. Some authors have cited a completion date of 1897, which would seem to bring Waddell in contradiction with himself and others who cite construction of the rolling lift bascule, Van Buren Street Bridge in Chicago, Illinois, (opened to traffic in February 1895), as the beginning of the modern age of bascule bridges in America. Another date sometimes given for the Michigan Avenue Bascule Bridge is 1891, which seems to make more sense. But whatever the date of completion, it was certainly a version of the type first designed by Bernard Forest de Belidor in France about 1729 (*35*). It had cables attached to the free end of the span, which ran diagonally to pulleys at the top of the tower and then down to cast iron counterweights rolling on curved tracks that were designed so that the tension on the cables decreased as the lever arm of the center of gravity of the leaf diminished. This was supposed to address one of the main drawbacks of the simple trunnion design; it was difficult to balance and control the forces produced by operation, thus making it difficult to start and stop the motion of the leaf. Although Waddell claims that several examples of this particular type of bridge were built, they proved to be less efficient than other types and fell out of favor.

By the end of the nineteenth century there were independent movements in Chicago and Milwaukee to develop simpler bascule bridge designs. The Bridge Division of the Chicago Department of Public Works led the way by undertaking a study in 1899 to select a type of bridge most suitable for erection over the Chicago River and its tributaries. This study led to a juried competition the following year that was won by City Engineer John Erickson. The first simple trunnion bridge over the Chicago River was completed at Clybourn Place (now Cortland Street) in May 1902. A refined version of the design submitted by Ericson, this double-leaf structure provided a clear channel of about 115 feet. Typical of the eight other bascule highway bridges built by the city in the first decade of the twentieth century, this bridge was composed of trusses supported by trunnions located in line with the bottom chord, placed slightly behind the center of gravity of the span. Counterweights were attached to the shorter, shore arm, and descended into a pit in the pier when the bridge was open. The leaves were operated by a pinion and segmented, curved rack at the rear of the short arm. Refined over a period of thirty years, the "Chicago type" bascule bridge has become a symbol of the city and the most known type of simple trunnion bascule bridge. There was, however, another type of simple trunnion bascule developed at about the same time as the Chicago type.

A simple trunnion bascule bridge built by the Wisconsin Bridge Company at Grand (Wisconsin) Avenue in Milwaukee opened for traffic in March 1902, approximately two months before the Cortland Street Bridge, which is often erroneously credited with being the first of its type. In 1904 the Muskego Avenue (Emmber Lane) Bridge over the Menominee River was completed, incorporating several improvements to the design used for the Grand Avenue Bridge and establishing the basic design that would be followed in all thirteen bascule spans built by the City of Milwaukee before World War II. The distinctive features of this design that differentiated it from the Chicago-style bascule bridge were plate girder construction and a bottom mounted segmental rack. According to Hess and Frame, this design may have been more popular than the Chicago-style simple trunnion bascule bridge due to increased ease of construction and maintenance. The lack of a comprehensive national historic bridge inventory makes this claim difficult to prove, but it is certain that the Milwaukee design should deserve at least equal credit with the better known Chicago design as representative of the simple trunnion type of bascule bridge. This is confirmed by illustration of the Milwaukee type in the U. S. Department of Transportation *Bridge Inspector's Manual for Movable Bridges* (1977), which presents the plate girder bascule span with bottom mounted segmented rack as a "typical" type of trunnion bascule bridge (*36*, p. 46).

The word "bascule" comes from the old French word "bacule," which means "seesaw," and denotes a type of bridge so balanced that when one end is lowered the other is raised. The simplest type of bascule bridge is the single trunnion, in which the truss or girder (leaf) rotates vertically on a single, fixed-axis (or nearly fixed) horizontal shaft or pivot at or near the center of gravity of the rotating leaf. In the often-used example of the simple castle drawbridge, virtually all of the mass of the rotating leaf is located on one side of the pivot point. Since the drawbridge is unbalanced, however, it is not a true representation of type. In most modern versions of the bascule span there is a long arm on one side of the pivot point and a shorter arm, which is called the tail, and some means of countering the weight of the long arm to achieve balance, usually with a metal or concrete mass.

Significance Assessment: Simple trunnion bascule bridges are significant within the context of this study if they retain integrity. Of the highest significance within this type would be the early examples of the type (early twentieth century up to around 1930) and examples with historic associations with the Chicago Department of Public Works and the City of Milwaukee. The defining characteristic of the bascule is the upward rotating leafs, which can be single or double. Character-defining elements that contribute to the type's integrity include the trunnions, integral counterweight, cables, pulleys, counterweight, and piers.

Examples of Simple Trunnion (Milwaukee, Chicago) Bascule Spans

1. West Jefferson Avenue-Rouge River Bridge (1922). Wayne County, MI. NRHP listed 2000.
2. Bridge of Lions (1927), St. Johns County, FL. NRHP listed 1982.

3. University Avenue Bridge (1927-33), spanning Schuylkill River at University Avenue, Philadelphia, Philadelphia County, PA. HAER PA-503.
4. West Adams Street Bridge (1926), West Adams Street, Chicago, Cook County, IL. HAER IL-51.
5. Jackson Boulevard Bridge (1916), spanning Chicago River, Chicago, Cook County, IL. HAER IL-55

Figures 3-91 and 3-92 contain photographs of a Chicago simple trunnion bascule and an example in Philadelphia.

Figure 3-91. Chicago River Bascule Bridge (1916), Jackson Boulevard, Chicago, Illinois. This simple trunnion, double leaf bascule was a product of the Strauss Bascule Bridge Company.

Figure 3-92. University Avenue Bridge (1927-33), spanning Schuylkill River, Philadelphia, Pennsylvania. This bridge has historical significance through its association with noted Philadelphia architect Paul Philippe Cret.

3.4.5 Multiple Trunnion (Strauss) Bascule

History and Description: Another type of trunnion bascule bridge was developed by Joseph B. Strauss (1870-1938), builder of the Golden Gate Bridge. Strauss founded his own company in 1902 after having been a draftsman for the New Jersey Steel and Iron Company and the Lassig Bridge and Iron Works, and an apprentice of famed Chicago bridge engineer Ralph Modjeski.

The distinctive feature of the Strauss trunnion is the pivoting of the counterweight at the end of the short arm. This enables the counterweight to move parallel to itself thus avoiding the counterweight pit which is required for other bascules such as the Chicago and Scherzer rolling lift types. Strauss claims to have introduced the use of concrete rather than iron for the counterweight. The counterweight could either be placed overhead or underneath the plane of the longer arm, and the longer arm could be a truss or a plate girder. The overhead counterweight version of this design was first patented in 1905, and the underneath version was first patented in 1906, although the same basic designs were also covered by later patents. A modification of this concept, in which the main fixed pivot point is located at the end pin of the bottom chord of the truss and the counterweight trunnion is a fixed pivot point at the top of a stationary tower that is supported by the main pier and an auxiliary pier, is known as the "heel trunnion" bascule. Although Strauss bascule bridges were built in great numbers across the United States, this type is now rare in relation to highways, but may exist in greater numbers, though fixed in place and inoperable, on railroad lines.

Significance Assessment: Multiple trunnion bascule spans are rare on highways and intact examples would possess a high level of significance within the context of this study. Early examples of the type are highly significant within the context of this type. All other intact examples are also considered significant. Character-defining features that contribute to the structure's integrity include the trunnions, the integral counterweight, struts, and possibly, the control house and mechanical equipment. Since these structures may be built in any number of bridge types, they must also possess the features of the respective bridge type (e.g., truss, girder).

Examples of Multiple Trunnion (Strauss) Bascule Spans

1. Hoquiam River Bridge (1928), Grays Harbor County, WA. NRHP listed 1982 in Historic Bridges/Tunnels in Washington State Thematic Resource Nomination. HAER WA-93.
2. Philadelphia, Baltimore & Washington Railroad (1917-18), spanning Darby Creek, South of Essington Avenue, Eddystone, Delaware County, PA. HAER PA-526.
3. Henry Ford (Badger Avenue) Bridge (1924), spanning Cerritos Channel, Los Angeles-Long Beach, Los Angeles, Los Angeles County, CA. HAER CA-156.
4. NJ-127 Route 7 Bridge (1925), Route 7 (1AG) over Passaic River, Belleville, Essex County, NJ. HAER NJ-127.

5. Congress Street Bascule Bridge (1929-31), spanning Fort Point Channel at Congress Street, Boston, Suffolk County, MA. HAER MA-38.

Figures 3-93 through 3-95, depict, respectively, a drawing and photographs of the multiple trunnion lift type.

Figure 3-93. Elevation drawing of a multiple trunnion lift.

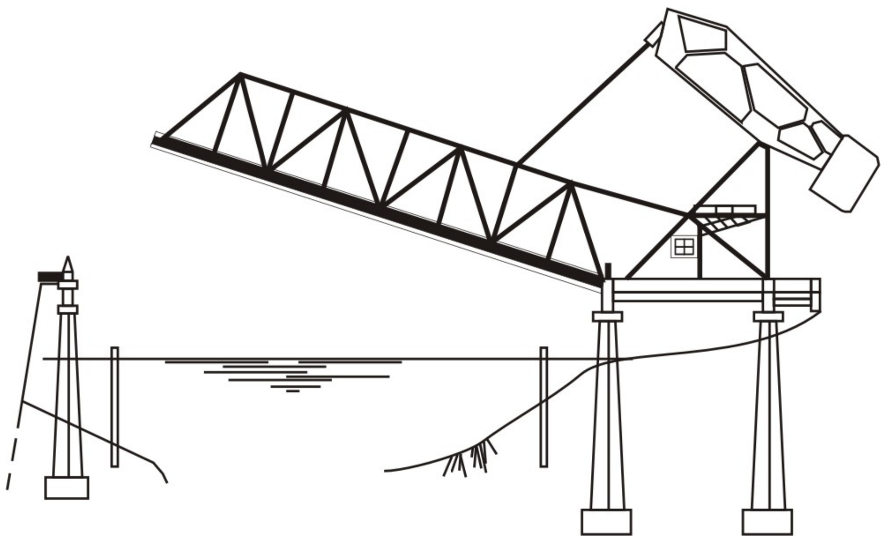


Figure 3-94. Philadelphia, Baltimore & Washington Railroad, spanning Darby Creek, Eddystone, Pennsylvania. This Strauss Bascule Bridge Company-designed structure was fabricated and built by Bethlehem Steel.

Figure 3-95. NJ-127 Route 7 Bridge (1925), Route 7 (1AG) over Passaic River, Belleville, New Jersey. This Strauss Bascule Company structure is a heel trunnion bascule.

3-95a. Oblique view.

3-95b. Detail of counterweight.

3.4.6 Rolling Lift (Scherzer) Bascule

History and Description: This bridge design was first patented by William Scherzer (1858-1893) in 1893, but following his death the patent was taken over by his brother Albert (1865-1916), who also founded the Scherzer Rolling Lift Bridge Company. Over a number of years the design was improved in a number of ways, including substitution of concrete for iron in the counterweight and an option of moving the counterweight to an overhead position. Scherzer rolling lifts were popular from the early 1900s well into mid-century because of their simplicity and the fact that they were quick to open and required a small amount of power for operation.

The Scherzer rolling lift bascule bridge became the favored replacement for swing spans in many parts of the United States, and was a design widely used by railroad companies. It was not a perfect design, however, because the point of pressure where the segmented girder encounters the horizontal track constantly changed as the span was in motion, thus tending to weaken bridges that were not securely founded on bedrock. This shortcoming had much to do with the eventual preeminence of simple and multiple trunnion types of the bascule bridge.

The rolling lift Van Buren Street Bridge (1895) was a double leaf bridge that exhibited two types of movement. As the leaves rose vertically they also moved horizontally away from the Chicago River. The leaves were girders segmented at the bottom that moved along a segmented horizontal track. A fixed cast iron counterweight located on the rear of the girder dropped down into a pit in the bridge's base as the girder "rocked" back along the horizontal track. In the Scherzer rolling lift form, the center of gravity moves in a horizontal line constantly shifting the point of application of the load to the pier or abutment. As the bridge lifted, the weights shifted back to the pier.

Until engineers were able to design good, solid foundations, the design was flawed because the rolling action caused piers to shift position. Engineers were eventually able to resolve this problem, which had afflicted the earlier bridges. Scherzer rolling lifts continued to be built into the 1940s because they were quick to open. Primarily used by railroads, Scherzer rolling lifts are less common in the context of the bascule type for vehicular spans.

Significance Assessment: Scherzer lift bridges are not common amongst bascule vehicular bridges. Intact examples of rolling lift bascule bridges are highly significant within the context of this study. Of the highest level of significance within this category are early (late nineteenth to early twentieth century) examples of the type. The character defining features are steel trusses or girders across the navigable channel that retain the features of their respective bridge type, and rigidly connected large steel rollers or rockers that have a weight at the rear to counterbalance the truss span. The rollers are cast in the form of a segment of a circle describing an arc of ninety degrees.

Examples of Rolling Lift (Scherzer) Bascule Spans

1. Blossomland Bridge (1949), Berrien County, MI. SHPO determined NRHP eligible.
2. DesPlaines River Bridge (1932), Jefferson Street, Joliet, Will County, IL. HAER IL-58.
3. Rehoboth Avenue Bridge (1926), State Route 1A (Rehoboth Avenue), Rehobeth Beach, Sussex County, DE. HAER DE-22.
4. New York, New Haven & Hartford Railroad Bridge (1907) spanning Niantic River, East Lyme, New London County, CT. HAER CT-27.
5. Seddon Island Scherzer Rolling Lift Bridge (1906), spanning Garrison Channel from Tampa to Seddon Island, Tampa, Hillsborough County, FL. HAER FL-3.
6. Pennsylvania Railroad "Eight-track" Bascule Bridge (1901), spanning Sanitary & Ship Canal, west of Western Avenue, Chicago, Cook County, IL. HAER IL-99.

Figures 3-96 and 3-97 contain photographs of Scherzer rolling lift bascule bridges.

Figure 3-96. DesPlaines River Bridge (1932), Jefferson Street, Joliet, Illinois. This bridge is an example of the Scherzer rolling lift bascule.

Figure 3-97. New York, New Haven & Hartford Railroad Bridge (1907), spanning Niantic River, East Lyme, Connecticut. This Scherzer rolling lift bridge is a through girder built for railroad use.

3-97a. Scherzer rolling lift in open position.

3-97b. Detail of control house and lift in open position.

3.5 Suspension

History and Description: In 1801, James Finley (1756-1828), a justice of the peace and judge in Fayette County, Pennsylvania, constructed the first metal suspension bridge in the United States over Jacob's Creek near Mt. Pleasant, on the highway between Uniontown and Greensburg, Pennsylvania. It had a clear span of about 70 feet and featured a wood truss-stiffened vehicular deck suspended from wrought iron chains. Although forty or more chain bridges were built according to Finley's 1808 patent, they tended to fail after only a few years of use. Some critics felt that the Finley design was only as good as the weakest link in one of the chains. This fear was addressed by the introduction of metal cables.

In 1816, wrought iron wire manufacturers, Josiah White (1780-1850) and Erskine Hazard (1790-1865), erected a wire pedestrian suspension bridge spanning about 410 feet across the Schuylkill River near Philadelphia, Pennsylvania. Although short-lived, this is believed to be the first wire suspension bridge in the country.

The first wire cable suspension bridge to carry vehicular traffic was the bridge over the Schuylkill River at Fairmont Park in Philadelphia, which is sometimes referred to as the Callowhill Street Bridge. Charles Ellet, Jr. (1810-1862) designed this bridge, which opened on January 1, 1842. The bridge had a clear span of 358 feet between the towers, supported by five cables on each side, and a generous deck width of 25 feet. This structure utilized the abutments of Lewis Wernwag's Colossus Bridge, a wood arched truss design completed in 1812 that was destroyed by fire in 1838. The bridge at Fairmont was well regarded, and encouraged the construction of other wire cable suspension bridges. It also established Ellet as a leading designer of suspension bridges, and led directly to his involvement in the planning for two important bridges, one at Wheeling, West Virginia, and the other across the Niagara Gorge between New York and Canada (*37*, p. 19).

In 1847, Ellet won the contract to design and build a bridge over the Ohio River at Wheeling, West Virginia. According to Emory Kemp, this victory may well have led to Ellet's success in beating out three other competitors, including John Roebling, for the right to construct a bridge over the Niagara Gorge. Completed in 1848, the first Niagara Suspension Bridge was designed to only carry pedestrian and carriage traffic. It was the unauthorized taking of tolls for this traffic that caused Ellet to have a falling out with the bridge owners. He quickly turned his full attention to the Wheeling Bridge, which was completed in 1849. Spanning 1,010 feet, this was the longest bridge in the world for many years after its completion and proved to be Ellet's greatest and last triumph as a bridge engineer.

The mantle of leading suspension bridge engineer soon passed from Ellet to John Roebling, who won the contract to build the second suspension bridge, and the first railroad bridge, across the Niagara Gorge. Completed in 1855, this bridge had a span slightly longer than 821 feet, and was the longest railway bridge in the world. Despite the success of the Niagara Bridge, and Roebling's confidence in the suspension type for use by railroads, railroad company executives were not convinced that suspension bridges were capable of bearing the live loads imposed on them by heavy rail traffic. Their skepticism was not unjustified because the Niagara Bridge needed substantial repair in 1877 and 1880, and was declared inadequate in 1890. It would be 133 years before the next suspension bridge designed for railway traffic was built (*1*, p. 17).

Of greater longevity is the suspension bridge built by Roebling over the Ohio River between Cincinnati, Ohio, and Covington, Kentucky. Officially opened on January 1, 1867, this bridge has a main span of 1,057 feet. It had the longest clear span of any bridge in the world when completed, and was the first suspension bridge in the United States to use both vertical suspenders and diagonal stays fanning out from the towers. Concerns over the adequacy of the deck truss led to redesign by Wilhelm Hildenbrand and complete reconstruction in the late 1890s. In 1984 this structure was renamed the John A. Roebling Suspension Bridge.

Few suspension bridges in the world built since the time of the Roeblings can claim to stand entirely clear of the shadow cast by the Brooklyn Bridge. The plan involved two towers, cables and suspenders, anchorages and a stiffening truss - the character-defining features of a suspension bridge. Beginning with Ellet and significantly advanced by the Roeblings, Othmar Ammann, Leon Moiseiff, David B. Steinman, and others, America led the world in suspension bridge design and construction until completion of the Veranzanno Narrows Bridge (1964) when design precedent revolved back to Europe.

The deck of a suspension bridge is hung from vertical suspenders that are affixed to ropes, chains, eyebars or cables that are in tension, passing over towers that are in compression. Usually the ends of the cables are anchored in large masses of stone or concrete, but a rare form of suspension bridge is “self-anchored.” Suspension bridges are particularly suited for spanning great distances, and some of the most monumental and historically significant bridges in the United States are of this type. At one time, however, a great number of suspension bridges of very modest span length were built across the country due to the type’s basic simplicity and ease of erection. But in some states, such as Oklahoma, the once common small suspension bridge has virtually disappeared.

Significance Assessment: Suspension bridges are the quintessential statement for elegant, vehicular, long-span bridges. The monumental examples often symbolize an urban gateway and many have become symbols of the cities for which they provide ingress. Most nineteenth century suspension bridges that retain integrity are highly significant within the context of this study and most have been determined NRHP eligible. Twentieth century examples are also considered significant; some possess high significance for the engineering challenges faced or for association with significant bridge designers.

Also significant are the short-span and/or vernacular suspension bridges found in smaller communities or the rural countryside of the United States, Appalachia for example. Unlike the more monumental spans, many of these structures have been lost, rendering them increasing less common.

Character defining features of suspension spans include the towers, cradles, cable or chain, suspenders, anchors, stays and piers.

Examples of Suspension Bridges

1. Brooklyn Bridge (1883), Kings County, NY. NRHP listed 1966. HAER NY-18.
2. Covington & Cincinnati Suspension Bridge (1867), Kenton County, KY. NRHP listed 1975. HAER KY-20.
3. Wheeling Suspension Bridge (1849), Wheeling, WV. NRHP listed 1970. HAER WV-2.
4. Dresden Bridge (1914), Muskingum County, OH. NRHP listed 1978. HAER OH-93.
5. Regency Suspension Bridge (1939), Mills County, Texas. NRHP listed 1976. HAER TX-61.
6. Mid Hudson Suspension Bridge (1930), spanning Hudson River, Poughkeepsie, Dutchess County, NY. HAER NY-160.
7. Seventh Street Bridge (1924-26), spanning Allegheny River at Seventh Street, Pittsburgh, Allegheny County, PA. HAER PA-490.
8. Clear Fork of Brazos River Suspension Bridge (1896), spanning Clear Fork of Brazos River, Albany vicinity, Shackelford County, TX. HAER TX-64.

Figures 3-98 through 3-102 provide examples of suspension bridges.

Figure 3-98. Covington & Cincinnati Suspension Bridge (1856-67), spanning Ohio River, between Covington, Kentucky and Cincinnati, Ohio. This Roebling bridge is a landmark structure across the Ohio River.

Figure 3-99. Mid Hudson Suspension Bridge (1930), spanning Hudson River, Poughkeepsie, New York. This suspension bridge was designed by noted bridge engineer Ralph Modjeski.

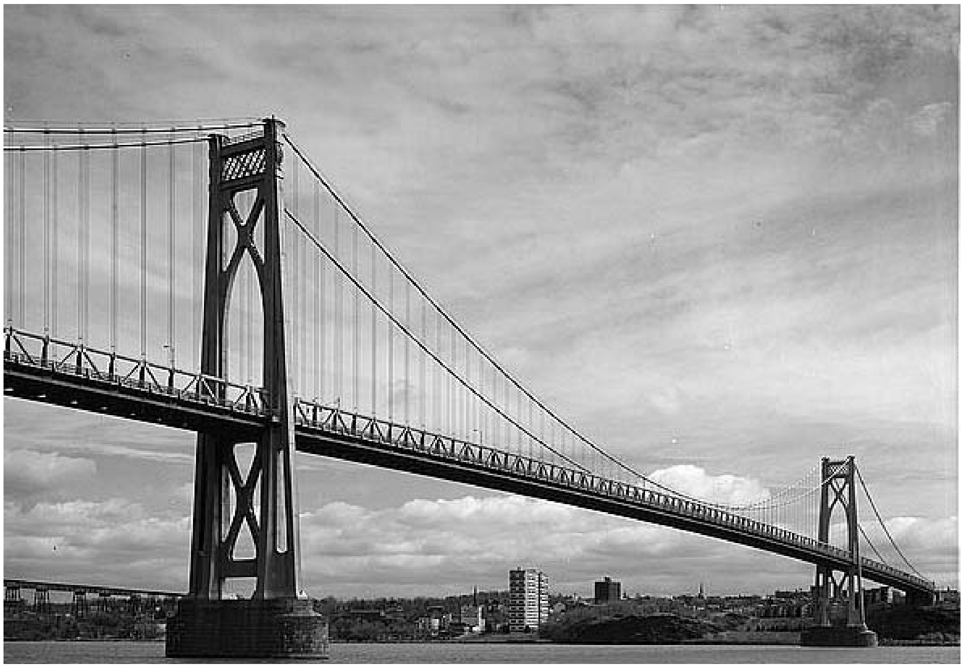


Figure 3-100. Seventh Street Bridge (1924-26), spanning Allegheny River at Seventh Street, Pittsburgh, Pennsylvania. One of the Three Sisters bridges, this self-anchored suspension bridge was designed by the Allegheny Department of Public Works and built by the American Bridge Company.

Figure 3-101. Clear Fork of Brazos River Suspension Bridge (1896), Shackelford County, Texas. The original cables have been replaced and the towers encased in concrete on this 312-foot long bridge.

Figure 3-102. Middle Bridge (1913), spanning Osage River, Warsaw, Missouri. This bridge is an example of a locally built and designed suspension bridge.

102a. Detail of tower.

102b. Through view.

3.6 Trestles and Viaducts

History and Description: In *Bridge Engineering* (1916), Waddell (*9*, p. 534) struggled to differentiate between trestles, viaducts and bridges, and noted that there was a tendency in the engineering profession to use the terms "trestle" and "viaduct" interchangeably, even though a trestle is a viaduct, but a viaduct is not necessarily a trestle. Both, of course, are bridges, even though all bridges are not viaducts or trestles. Dictionary definitions do not completely clear the matter up, as it is common to define a trestle as "an open braced framework to support a bridge," which seems to ignore the fact that the supporting framework is an integral *part* of the bridge. Waddell's perspective is more useful, in that he states, "a trestle consists of a succession of towers of steel, timber, or reinforced concrete, supporting short spans, while the piers of a viaduct may be of masonry, steel, or timber, and the spans may be either long or short." If we add to this that a viaduct is a bridge-like structure, especially a large one composed of arches, carrying a roadway or railway across a valley or ravine, we begin to arrive at useful definitions of these types of bridges. We might also note that the term "trestle" has often been used for timber approaches to bridges.

The reason for considering trestles and viaducts as separate from other types of bridges is that they both have design attributes that were generated by the need of railroad engineers to maintain easy gradients, especially when crossing deep ravines or depressions, to compensate for the limited traction of railroad engines. As Eric DeLony (*38*, p. 29) has noted, "Viaducts and trestles were the engineering solution for maintaining a nearly straight and horizontal line where the depth and width of the valley or gorge rendered embankments impracticable."

The earliest stone arch railroad bridge built in the United States, and the world's oldest stone railroad span still in service, is the Carrollton Viaduct over Gwynn's Falls on the old B & O Railroad line near Baltimore, Maryland. Completed in 1829, this National Historic Landmark and National Civil Engineering Landmark was designed by B&O engineer Casper Weaver and built by James Lloyd, a mason from Chambersburg, Pennsylvania, whose family built many stone arch highway bridges in Maryland (*39*). This 312-foot long bridge has a centered arch with a clear span length of 80 feet and clearance of about 51 feet above the stream, and has a small arched passageway through one of the approaches that accommodated an old wagon road.

The first multi-span stone arch railroad bridge in the United States was the Thomas Viaduct, completed in 1835 over the Patapsco River near Relay, Maryland. Designed by B&O Chief Engineer Benjamin Henry Latrobe II, and built by John McCartney, a master mason from Ohio, this structure includes eight Roman arches built on a four-degree curve. This 612-foot long bridge is a National Historic Landmark. Latrobe (1807-78) became famous within the engineering profession for executing the very difficult task of extending the B&O across the Allegheny Mountains. He formed Smith, Latrobe & Company with Charles Shaler Smith in 1866, and that firm became the Baltimore Bridge Company in 1869. Smith, Latrobe & Company built the Zoarville

Station Bridge in Ohio, which is the only Fink through truss known to exist in the country.

The Starrucca Viaduct on the New York & Erie Railroad (1848) rises 110 feet above Starrucca Creek between Lanesboro and Susquehanna, Pennsylvania. It is approximately 1,200 feet long, with eighteen arches, each spanning about 50 feet. The piers, arch rings and parapet walls are of blue stone obtained from a quarry about three miles above the creek. The engineer who built the viaduct, James P. Kirkwood (1807-77), was a Scotsman trained at Edinburgh College who gained practical experience working for the Stonington Railroad and the Boston & Albany Railroad. He is said to have accepted the challenge of bridging the very deep and wide valley of the Starrucca with the stipulation that the railroad company owners not be too averse to incurring the high cost of construction. When completed, the viaduct was the most expensive railroad bridge yet built, and the longest stone rail viaduct of its era. This bridge has been listed on the NRHP since 1975.

According to Waddell (*9*, p. 21), the first wood railroad trestle was built on the Philadelphia and Reading Railway in 1840. This type of structure used widely in the west during construction of the various transcontinental rail lines (although usually the wood had to be shipped to the site on rail cars), and was frequently used by railroads in the South where wood was more plentiful and easier to use for the erection of bridges than stone. Although often replaced by metal structures, wood railroad trestles may still be found in scattered locations across the country. One notable example is the Mexican Canyon Trestle near Cloudcroft, New Mexico. In the first half of the twentieth century, wood approach trestles were sometimes built to serve metal and even concrete highway bridges, but extant wood highway trestles are very rare.

Significance Assessment: The stone railroad viaducts of the early days of the railroad (second quarter of the nineteenth century) possess a high level of significance within the context of this study. Of slightly lesser significance are other, intact nineteenth century masonry, timber and steel viaducts, mainly constructed for railroads. In the twentieth century, viaducts built to carry roadways over the railroad may possess significance, but they are generally evaluated under the bridge type in which they fit. For example, to name a few types, concrete viaducts of the twentieth century can be built as concrete arches, girders or steel beam structures. Viaducts should possess integrity. Character defining features that define integrity include the features of the respective bridge type (e.g., concrete arch, girder).

Also significant within the context of this study are nineteenth century trestles that retain their integrity. It is important to note, however, that timber structures often have undergone substantial replacement of materials, a factor that may damage the structure's integrity. Twentieth century trestles are less significant within the context of this study, but may possess significance for factors such as a great length or solving a topographical engineering problem. Trestles should possess their character defining features, which include beams, abutments and timber or steel piers or bents.

Examples of Trestles and Viaducts

<u>Viaducts</u>

1. Carrollton Viaduct (1828-29), Baltimore County, MD. HAER MD-9. National Historic Landmark and National Civil Engineering Landmark.
2. Starrucca Viaduct (1848), Erie Railway spanning Starrucca Creek, Susquehanna County, PA. HAER PA-6.
3. Fourteenth Street Viaduct (1899), Fourteenth Street at Wazee Street, Denver, Denver County, CO. HAER CO-52.
4. Brownson Viaduct, Cheyenne County, NE. NRHP listed 1992 in Highway Bridges in Nebraska MPS.
5. Long Bridge, Baltimore & Ohio Railroad (1860-69), Keedysville Vicinity, Washington County, MD. HAER MD-37.
6. Dallas-Oak Cliff Viaduct (1910-12), spanning Trinity River at Houston Street, Dallas, Dallas County, TX, NR Listed. HAER TX-33.

<u>Trestles</u>

1. Mexican Canyon Trestle (Cloudcroft Railroad Trestle) (1899), NRHP listed 1979.
2. Mahoning Creek Trestle (1899), spanning Mahoning Creek, 1 mile West of Goodville, Goodville vicinity, Indiana County, PA. HAER PA-266.
3. Adelaide Bridge/Trestle (1894), Phantom Canyon Road over Eightmile Creek, Fremont County, CO. NRHP listed 1985.
4. West James Street Bridge (1924), over the Union Pacific Railroad on West James Street in Redfield, Jefferson County, AR. NRHP listed 1995
5. Promontory Route Railroad Trestle 790B (1872), 11 miles west of Corrine, Box Elder County, UT. HAER UT-64E.
6. Marquette Ore Dock No. 6 Timber Trestle (1931-32), Between East Lake Street and Ore Dock No. 6, Marquette City, Marquette County, MI. HAER MI-45.

Figures 3-103 through 3-108 depict examples of viaducts and trestles.

Figure 3-103. Baltimore & Ohio Railroad Carrollton Viaduct (1828-29), spanning Gwynn's Falls near Baltimore, Maryland. This stone railroad viaduct is a National Civil Engineering Landmark and a National Historic Landmark.

Figure 3-104. Fourteenth Street Viaduct (1899), Fourteenth Street at Wazee Street, Denver, Colorado. This structure is a typical concrete viaduct built to carry traffic over the railroad.

Figure 3-105. Dallas-Oak Cliff Viaduct (1910-12), spanning Trinity River at Houston Street, Dallas, Texas. This early twentieth century viaduct is a concrete open spandrel arch.

Figure 3-106. Promontory Route Railroad Trestles 790B (1872), Corinne vicinity, Box Elder County, Utah. This nineteenth century structure was built by the Central Pacific Railroad Company.

Figure 3-107. Marquette Ore Dock No. 6 Timber Trestle (1931-32), between East Lake Street & Ore Dock No. 6, Marquette City, Marquette County, Michigan. This structure is an example of a high timber trestle.

Figure 3-108. Mahoning Creek Trestle (1899), spanning Mahoning Creek, Goodville vicinity, Indiana County, Pennsylvania. This high steel structure was built to carry the railroad.

3.7 Cantilevers

History and Description: If you hold your arm straight out from your shoulder, it is acting as a cantilever. The equivalent engineering definition of the extended-arm analogy is that a cantilever is a continuous girder with hinges at the points of zero moments (the extended-arm theory is much easier to understand). The form was statically determinant, which meant that it was easy to calculate and the members did not have the inherent deficiency of the continuous beam or girder developing indiscernible internal stresses and possibly failing should one of the piers or abutments subside. Unstable soil conditions plagued foundation, pier, and abutment design, so the ability of a bridge's superstructure to adjust should one of the piers or abutments sink, was a significant design breakthrough.

The form originated in the Far East with the fourth century AD Shogun's Bridge, which still spans 84 feet over the Daiya-gawa River in Nikko, Japan. Another ancient example is the Wandipore Bridge (ca. 1643) high in the Himalayan Mountains in Bhutan, a cantilever of layered timbers projecting forty feet and carrying a simple timber platform--the suspended span. It was illustrated in Thomas Pope's *Treatise on Bridge Architecture*, the first American book on bridges published in 1811. The book was a summary of world bridge building and featured Pope's own "Flying Pendant Lever Bridge." Though never built, Pope proposed to span the Hudson River with a flying pendant of 3,000 feet and the East River with a span of 1,800 feet. This was the cantilever's first introduction in the United States.

The cantilever was not practical and did not achieve widespread use until the structural behavior of trusses was better understood half a century later. These mathematical issues were resolved by a German engineer, Heinrich Gerber, who built the Hassfurt Bridge over the River Main in Germany in 1867 with a central span of 124 feet, the first modern cantilever.

Cantilever bridges are a modified form of beam bridge. A cantilever is essentially a beam that is unsupported at one end but supported at the other, like diving boards. The cantilever was developed to solve the problem of increasing the length of the bridge to enable crossing wide bodies of water like the Ohio and Mississippi rivers, or wide and deep gorges like the Niagara Gorge separating the United States from Canada. It provided alternatives to beam and arch bridges, which had limited spans not exceeding 200 to 300 feet when constructed of steel or reinforced concrete. This configuration made longer spans possible and wider clearance beneath. The cantilever also eliminated the high cost of building anchorages required by the other long span bridge type, suspension bridges, thus saving money and materials.

Charles Conrad Schneider helped develop the cantilever form in the United States with the design of the counterbalanced cantilever with the arms supporting a simple suspended span. Cantilevers first were used by the railroads (Poughkeepsie, Memphis, High Bridge) and then as highway bridges with many notable examples such as the Lyon's Ferry and Longview bridges in Washington. Cantilever bridges over the Ohio and

Mississippi rivers at Pittsburgh, Cincinnati, Louisville, Cairo, St. Louis, Memphis and New Orleans date from the last quarter of the nineteenth century up until the 1950s and 1960s. One great advantage of a cantilever is that it can be built outwards from the towers without falsework to block the channel below. Then the suspended span can be lifted into place. Another is that it is inherently rigid so that heavy locomotives pulling trains of cars are no threat to the structure if properly designed.

In 1877, American engineer C. Shaler Smith, Baltimore Bridge Company, and Louis Frederic Gustav Bouscaren, chief railroad engineer, built the world's longest cantilever for the Cincinnati Southern Railroad over the 275-foot deep Kentucky River gorge at Dixville. No longer extant, it had three spans of 375 feet each. The bridge was selected by ASCE for the 1878 Paris Exposition as one of the prime examples of American bridge ingenuity.

America's oldest surviving cantilever is a railroad bridge spanning the Hudson River at Poughkeepsie, NY, dating from 1889. This structure was notable for the depth of its foundations, which were constructed in timber caissons using the open dredging method developed in America by James Buchanan Eads for the Eads Bridge (1874) and Washington Roebling for the Brooklyn Bridge (1883). Other early notable bridges by Schneider include the 1883 Niagara River Bridge and the Fraser River Bridge of the Canadian Pacific Railroad located in British Columbia.

The Queensboro Bridge over the East River in New York City was the longest cantilever in the United States when completed in 1909. It had no central suspended span which was unique among cantilevers of its size designed with a single hinge to prevent the reversal of stresses.

Development of the cantilever form led to the Tappan Zee Bridge (1955) over the Hudson connecting Tarrytown and Nyack, New York. It is part of the New York State Throughway System and Interstate I-87/287, and is a superlative example of the bridge type used by highway engineers to span larger rivers when the interstates were being constructed during the 1950s and 1960s. With a cantilever span of 1,212 feet and an overall length of 16,013 feet, the Tappan Zee Bridge is a significant bridge system that turns 50 years old in 2005. It is being considered for NRHP listing at a level of national significance as a bridge achievement of the national defense highway system.

With deep canyons carved by the Columbia River and its tributaries, the state of Washington has more cantilever bridges than any other state: at least fifteen remain. Other states with large rivers have cantilevers, as they are the ideal for intermediate to long span bridges. In the last twenty years, however, cable-stayed suspension bridges have begun to supplant cantilevers because they are visually appealing and sometimes more economical.

Significance Assessment: The cantilever bridge in the U.S. dates from the 1880s to the 1960s and is one of the standard bridge types for intermediate to longer spans, crossing deep, broad river gorges where it was difficult, if not impossible, to erect falsework. Cantilever bridges are significant within the context of this study. Of the highest level of significance are the early structures of the type and the structures of great length.

Cantilevers include two types of structure, cantilever and suspended span. The character defining features of most cantilever bridges will consist of two towers or piers with a pair of cantilever arms, or beams sticking out from the support towers. The beams taper in depth as they project from the towers and usually are truss-like in appearance. These well-secured arms carry a central span suspended over the water way. The cantilevers and suspended span are counterweighted by truss-like back spans that complete the connection to land. Unlike a simple beam supported at both ends, the cantilever must resist tension in its upper half and compression in its lower.

Examples of Cantilevers

1. Poughkeepsie Bridge (1889), spanning Hudson River, Poughkeepsie, Dutchess County, NY. HAER NY – 131.
2. Memphis Bridge (1892), spanning Mississippi River, Memphis, Shelby County, TN. HAER TN-14.
3. Queensboro Bridge (1909), spanning the East River & Blackwell's Island, New York City, New York County, NY. HAER NY- 19.
4. High Bridge (1910, double tracked 1929), spanning Kentucky River, 4 miles Southwest of Wilmore, High Bridge, Jessamine County, KY. HAER KY-37.
5. Longview Bridge (1930), spanning the Columbia River at State Route 433, Longview, Cowlitz County, WA. HAER WA-89.

Figures 3-109 through 3-111 depict examples of cantilever structures.

Figure 3-109. Queensboro Bridge (1909), spanning the East River and Blackwell's Island, New York City, New York.

Figure 3-110. Memphis Bridge (1892), spanning Mississippi River, Memphis, Tennessee.

Figure 3-111. Longview Bridge (1930), spanning the Columbia River at State Route 433, Longview, Washington.

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