7. Gulph Creek Stone Arch Bridge (1789), spanning Gulph Creek at Old Gulph Road, Upper Merion, Montgomery County, PA. HAER PA-309.
8. Possum Kingdom Stone Arch Bridge (1940-42), spanning Brazos River at State Route 16, Graford, Palo Pinto County, TX HAER TX-62.

Figures 3-42 through 3-46 depict a drawing and examples of stone arch structures.

Figure 3-42. Elevation drawing of stone arch bridge.

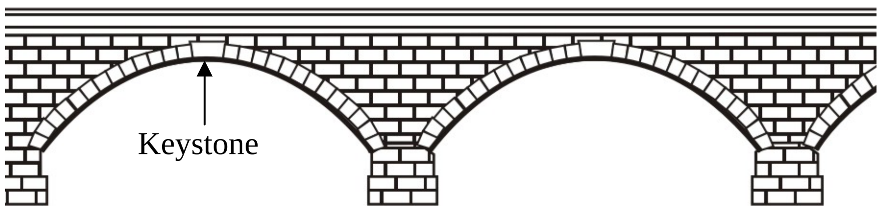


Figure 3-43. Gulph Creek Stone Arch Bridge (1789), Old Gulph Road, Upper Merion, Montgomery County, Pennsylvania. This eighteenth century stone arch bridge is one of the oldest surviving bridges in Pennsylvania.

Figure 44. “S" Bridge (first quarter nineteenth century), West of Cambridge, Ohio. This 1933 photograph shows an “S” Bridge on the Old National Road.

Figure 3-45. Cabin John Aqueduct Bridge (1864), MacArthur Boulevard, spanning Cabin John Creek at Cabin John, Maryland. With a single arch span of 220 feet, this bridge was the longest masonry arch bridge in the world until 1905.

Figure 3-46. Possum Kingdom Stone Arch Bridge (1940-42), spanning Brazos River at State Route 16, Graford, Texas. This structure is an example of a Works Progress Administration-built stone arch bridge.

3.2.2 Reinforced Concrete Melan/von Emperger/Thacher Arch

History and Description: The first concrete arch bridge in the United States was a plain, un-reinforced concrete footbridge with a 31-foot span, constructed in Prospect Park, Brooklyn, New York, in 1871. This little bridge, however, was not to have many successors. Despite the advantages of plasticity and good compressive strength, un-reinforced concrete has little tensile strength, and thus its usefulness for bridge construction was limited. The path to full exploitation of concrete as a building material lay in the development of a system of reinforcement that made use of the tensile properties of metal.

The oldest reinforced concrete bridge in the United States is the National Historic Civil Engineering Landmark Alvord Lake Bridge (1889) in San Francisco's Golden Gate Park (HAER CA-33). It was one of two bridges built in San Francisco that were designed by Ernest L. Ransome (1844-1917), the "father" of reinforced concrete construction in the United States. Reinforced with rods or bars, which were twisted in accordance with the design Ransome patented in 1884, this modest structure was the predecessor of thousands of reinforced concrete bridges built across the nation in the twentieth century.

After serving as an apprentice in the family concrete factory in England, Ransome immigrated to the United States in the late 1860s to exploit his father's patent for "concrete stone." In the early 1870s, while working as superintendent of the Pacific Stone Company of San Francisco, he established a factory to make concrete blocks. According to Waddell (*9*, p. 28), Ransome introduced reinforced concrete to America in 1874, but it was not until 1884 that he received the patent (# 305,226) that became the basis of the Ransome System for reinforcing concrete. Ransome also adapted a concrete mixer to twist iron bars up to two inches in diameter, believing that twisted bars had greater tensile strength than smooth round bars. His primary focus was on finding the best way to make the concrete adhere to the metal.

Hoping to capitalize on his invention in non-bridge applications, he moved to New York City and opened the Ransome Concrete Company at 11 Broadway Avenue. At this point, Ransome had clearly left bridge design behind him in favor of building system development. The Ransome system proved to be very popular for building construction, and several notable buildings were erected using it, including the Artic Oil Works in San Francisco, California (1884), an early American reinforced concrete building; the Leland Stanford Junior Museum in Palo Alto, California (1894), the largest reinforced concrete public building in the world at the time; and the Ingalls Building in Cincinnati, Ohio (1903), the first reinforced concrete skyscraper.

In 1902, Henry C. Turner, a former Ransome assistant, founded the Turner Construction Company and began fully exploiting the Ransome System. Apparently Turner had acquired some rights to the Ransome patent. Ransome continued to work on his own, however, and the Foster-Armstrong piano factory in Rochester, New York, was built in 1905 according to the "Ransome-Smith reinforced concrete method." The "Smith" in the name referred to borax king Francis M. Smith, who, along with Ransome, formed the Ransome & Smith Contracting Company and built an addition to the Pacific Coast Borax Company factory in Alameda, California, in 1889, and a warehouse for the Pacific Coast Borax Company facility in Bayonne, New Jersey, in 1898, using Ransome's method. Ransome also designed an elegant little arched footbridge over a pond at Presdeleau, Smith's estate at Shelter Island, New York. This structure, which still exists, and the two bridges erected in San Francisco, are the only bridges known to have been designed by Ransome. Other engineers and builders eventually propagated his design for use in buildings, but in the late 1890s and well into the twentieth century there were other reinforcing systems for concrete bridges that were better promoted by their designers and much more widely used in bridge construction.

In 1893, a Viennese engineer named Joseph Melan (1853-1941) patented in America a concrete reinforcing system using parallel metal I-beams curved to the form of the arch and embedded in the concrete (#505,054). This was a fairly conservative system because the bridges in which it was employed were basically steel arches encased in concrete rather than concrete arches with metal reinforcement. That conservatism appealed, however, to bridge engineers who preferred the Melan system over a rival methodology of reinforcement that had become popular in Europe, developed by Joseph Monier and his son, Jean. The Monier system, patented in France in 1873 and in the United States in 1883, used a mesh of small rods to add tensile strength to concrete. It was virtually impossible to calculate strains in the structure using this system, but tests proved that the system would work, with limitations. With faith in the superiority of his own design, Melan opened the Melan Arch Construction Company in New York City soon after acquiring his patent. It would be left to others, however, to fully exploit the Melan method of concrete reinforcement.

In April 1894, an Austrian engineer named Fritz von Emperger (1862-1942) presented a paper on the Melan system at a meeting of the American Society of Civil Engineers. The Society later published his paper as "The Development and Recent Improvement of Concrete-Iron Highway Bridges" in volume 31 of *Transactions*. Soon after von Emperger's presentation, a contractor from Minneapolis, Minnesota, named W. S. Hewitt contacted the Austrian and asked him to design a bridge according to the Melan system in Rock Rapids, Lyon County, Iowa. The plans were complete by June 1894, and the closed-spandrel arch bridge, with a span of about 30 feet, was finished soon thereafter. The Rock Rapids Bridge (now called simply the Melan Bridge) became the first bridge to be built using the Melan design methodology (*16*). Although relocated and no longer in use as a vehicular bridge, this structure still exists. Less than a year later, von Emperger designed and built a slightly larger bridge in Eden Park, Cincinnati, Ohio, with a span of approximately 70 feet. This bridge remains in very good condition, and is still in service (*17*).

In 1897, von Emperger patented a system of reinforcing concrete arches with steel ribs consisting of a pair of parallel, curved, rolled I-beams, each beam placed near one surface of the concrete, with secondary members connecting the beams (#583,464). Both bars extended into the abutments of the arch. This system was enough of a refinement of the one developed by Melan to win a patent, but it still followed the ideas espoused by the Austrian engineer. With confidence in the future of the Melan system, von Emperger had earlier founded the Melan Arch Construction Company in New York City, and went on to build several Melan-style bridges. One small Melan-system bridge that may have been built by von Emperger's company was the Doan Brook Bridge over Jephta Road in Cleveland (1900). By the turn of the century, however, von Emperger had left his company in the care of his design engineer, William Meuser, who formed a new partnership about 1900 with a western agent for the von Emperger firm, Edwin Thacher (1840-1920), who had built the first large Melan arch bridge in 1896 over the Kansas River in Topeka, Kansas. In 1901, Meuser and Thacher renamed their firm the Concrete Steel Engineering Company, and under this name built more than 200 Melan arch bridges across the country by 1912, with Thacher acting as the chief engineer and dominant partner.

Prior to his association with Meuser, Thacher had a varied career that was similar in many respects with other bridge engineers of his time. He received a degree in civil engineering from Rensselaer Polytechnic Institute in 1863, and like so many of his peers, began the acquisition of practical experience by working for a number of railroads, before relocating to Pittsburgh to serve as Design Engineer with one of the most important bridge companies of the nineteenth century, the Keystone Bridge Company. In 1899, Thacher was granted a patent (#617,615) for an arch construction similar to that of von Emperger in that ribs in pairs, one near the intrados and one near the extrados, are placed one above the other, and one, if not both ribs extend into the abutment. The difference with the von Emperger patent is that in the Thacher system the ribs are independent of one another.

Reinforcement of concrete with I-beams used far more steel than reinforcement systems using bars or rods, which could be more economically and selectively located in areas of high tensile stress. There were many patents issued in the early decades of the twentieth century covering variations in shape, deformation, and methods of bending or shaping the bars. Although not all of these methodologies relied upon some version of the twisted bar system patented by Ransome, his emphasis on metal bars as a strengthening element for concrete bridges, rather than metal beams, eventually began to predominate over the Melan/von Emperger/Thacher line of development. Although Melan-style bridges may be found in the East, Midwest and in California, they are relatively rare in the South, Southwest, and in the mountain states.

Significance Assessment: This group represents the first generation of patented reinforced concrete arch bridges constructed in America. They were built in the late 1890s through the first decade of the twentieth century, prior to the establishment of state highway departments. All documented Melan, von Emperger and Thacher bridges in reasonably good condition and retaining their character-defining features are highly significant within the context of this study. Character-defining features include the arch ring, barrel, spandrel wall, railing or parapet, abutments and wingwalls.

Along with these patented examples are a group of small, experimental, reinforced concrete arch bridges built by county engineers and engineers working locally.

Survey work has begun to turn up these early experimental examples though there has been little in-depth research. These early examples have not been widely included in many statewide bridge surveys, since the bridges are locally- or municipally-owned. Yet they illustrate the variety and interest that the new material of the twentieth century, concrete, incited in engineers. Most of these structures would be short to intermediate spans located on rural country roads or lightly trafficked municipal roads. Because some of these bridges might be the earliest examples of reinforced concrete bridge construction in the United States, further study is required to determine their significance.

Examples of Reinforced Concrete Melan/von Emperger/Thacher Arch

1. Melan Bridge (also known as Rock Rapids Bridge) (1893), Emma Slater Park (Moved from Dry Run Creek), Rock Rapids vicinity Lyon County, IA. NRHP listed 1974. HAER IA-15.
2. White Bridge (1897); Hyde Park, Duchess County, New York, part of Roosevelt-Vanderbuilt Historic Site. HAER NY-138.
3. Frankford Avenue Bridge (1904); Philadelphia County, Pennsylvania. NRHP listed 1988. HAER PA-471.
4. Sandy Hill Bridge, Bridge Street (1906-07), spanning Hudson River, Hudson Falls, Washington County, NY. HAER NY-185.
5. Alvord Lake Bridge (1889), San Francisco, San Francisco County, CA. HAER CA-33.

Figures 3-47 though 3-49 depict, respectively, the first reinforced concrete bridge in the United States, and two structures built using the Melan system.

Figure 3-47. Alvord Lake Bridge (1889), San Francisco, San Francisco County, California. Designed by Ernest Ransome, this is the first reinforced concrete bridge in the United States.

Figure 3-48. Melan Arch Bridge (1893), Emma Slater Park (Moved from Dry Run Creek), Rock Rapids vicinity, Lyon County, Iowa. The photograph illustrates an example of a von Emperger bridge.

Figure 3-49. Sandy Hill Bridge, Bridge Street (1906-07), spanning Hudson River, Hudson Falls, New York. This structure was built using the Melan system.

3.2.3 Reinforced Concrete Luten Arch

History and Description: As James L. Cooper (*18*, p.37) has stated, "Daniel B. Luten did more than any other single person to advance the movement from concrete-steel to reinforced concrete bridge design…." What Cooper means by this is that Luten diverged from the relatively conservative Melan/von Emperger/Thacher line of development that placed the importance of steel (or iron) as a load-bearing element in bridge arches above that of concrete, and aggressively promoted a system that stemmed more from the Monier methodology that gave primacy to concrete in load bearing, with metal as a strengthening element. And he did so with great success. As Cooper also notes, "Luten's considerable influence reached towards the continent's corners from Maine to California and from Canada to Mexico. Probably a thousand out of approximately twelve thousand of his structures remain to bear witness to his once ubiquitous presence."

Luten (1869-1946) received a Bachelor of Science degree in civil engineering from the University of Michigan in 1894, and taught civil engineering and surveying there for a year after graduation. From 1896 to 1900, he taught at Purdue University as an instructor of architectural and sanitary engineering. Finding the life of an academic too confining, he left the university in 1900, secured the first of many patents for reinforced concrete bridges, and published a catalog for the "Timber-Tie Concrete Arch Company" (*19*, p. 4). He only secured one contract in response to his catalog, but the following year he formed the National Bridge Company. With an entrepreneurial flair that surpassed his considerable skills as an engineer, he began to market and construct reinforced concrete bridges across the Midwest. He also began submitting articles to the *Engineering News-Record* and the *Railroad Gazette* about this time, and continued to be a major contributor to these and other professional publications for more than twenty years.

Although Luten built all three types of reinforced concrete arches, including open spandrel deck arches and open spandrel through arches, an article entitled "The Proper Curvature for a Filled Spandrel Arch," published in the September 12, 1902, edition of *Railroad Gazette* illustrates the bridge form that became the focus of Luten's design practice, the filled spandrel "timber" tied deck arch (*20*, p. 11).

Luten was prolific in his acquisition of patents, and he acquired nearly fifty by the early 1920s. He was granted so many patents that, according to him, it was virtually impossible for anyone else to build a reinforced concrete arch without infringing on one of his designs. To a large extent, Luten's strategy for success, and that of other entrepreneurial designers, relied on exploitation of the patent system in the United States. As bridge historian James Hippen (*21*, p. 6) has stated, "the trick became to include in a patent claim as many as one could of the possible arrangements of reinforcing and other elements in a concrete bridge, and then collect royalties or sue for infringement" *(21).* Eventually the royalty costs paid by private and public bridge builders and the cost of battling Luten in court became so great that an organized resistance to his way of doing business arose. The tide of opposition from the engineering profession and the legal establishment finally washed over Luten in 1918, and his patents, along with some of Thacher's, were invalidated.

Despite his defeats, by 1919 Luten claimed to have designed at least 17,000 bridges in all but three states. Although the actual number may be lower, it is certain that he did more than any other designer or builder to encourage the construction of reinforced concrete arches by county and municipal governments, and hundreds of Luten designed bridges still exist across the country, although the largest groupings may be found in California, the states of the Midwest, and in the states along the Atlantic seaboard. The popularity of his design did not continue far beyond the first two decades of the twentieth century, however, due both to the patent issues and because his designs were simply not efficient in the use of steel and concrete. Other engineers eventually surpassed Luten in the area he thought most his own; the practical combination of theory and empirical practice.

Significance Assessment: Thousands of Luten arches likely survive nationwide out of the 17,000 claimed to have been built during the 1910s and 1920s. They are characterized as having either open or closed spandrels, single and multiple rib or barrel arches of short to intermediate span (40 to 150 feet). However, since this describes most arch forms, documentation is needed to established whether a bridge is a Luten patented or designed example. Documentation includes bridge plaques, city and county records and comparison to known Luten bridges in state bridge surveys.

Documented Luten arches with a high level of integrity, although quite common, are significant within the context of this study if they retain their character-defining features. Character-defining features include the arch ring, spandrels, ribs or barrel, railing or parapet, and abutments and wingwalls. Luten was an important promoter and builder of the reinforced concrete arch form in the early-20th century.

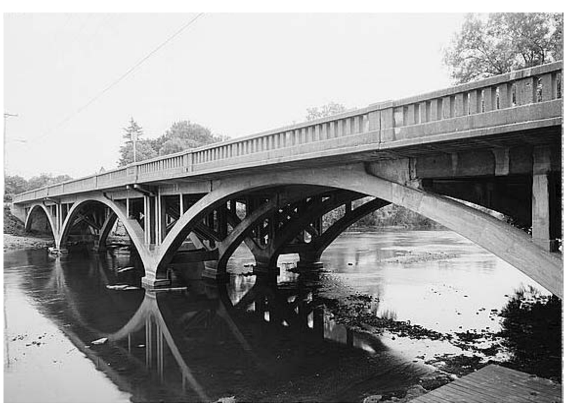
Examples of Reinforced Concrete Luten Arch

1. Illinois River Bridge (1922), Benton County, AR. NRHP listed 1988 in Benton County MRA.
2. Harp Creek Bridge (1928), Newton County, AR. NRHP listed 1990 in Historic Bridges of Arkansas MPS.
3. Andrew J. Sullivan Bridge (1928), Whitley County, KY. Determined NRHP eligible by SHPO.
4. American Legion Memorial Bridge (1930), Grand Traverse County, MI. NRHP listed 2000 in Highway Bridges of Michigan MPS.
5. Andrew J. Sullivan Bridge (1928), spanning Cumberland River, Williamsburg vicinity, Whitley County, KY. HAER KY-51.
6. Milwaukee Street Bridge (1930), spanning Rock River, Watertown, Jefferson County, WI. HAER WI-33.

Figures 3-50 and 3-51 depict examples of Luten closed and open spandrel designs.

Figure 3-50. Andrew J. Sullivan Bridge (1928), spanning Cumberland River, Williamsburg vicinity, Whitley County, Kentucky. This structure is an example of a Luten closed spandrel arch.

Figure 3-51. Milwaukee Street Bridge (1930), spanning Rock River, Watertown, Wisconsin. The photographs below show an example of the Luten open-spandrel arch.



3-51a. Three-quarter view.

3-51b. Detail of open spandrel.

3.2.4 Reinforced Concrete Marsh and Rainbow (Through) Arch

History and Description: Another type of reinforced concrete arch bridge that was built in considerable numbers throughout the United States is the through arch, which was developed in the 1910s. In this type, the crown of the arch is above the deck and the foundations of the arch are below the deck, and hangers suspend the deck from the arch. The best known patented design of this type was developed by James Barney Marsh (1856-1936), an engineer from Des Moines, Iowa. After graduating with a Bachelor of Mechanical Engineering in 1882 from the Iowa State College of Agriculture and Mechanical Arts (now Iowa State University) in Ames, Iowa, Marsh moved to nearby Des Moines to become a contracting agent for the King Bridge Company of Cleveland, Ohio. Through the end of the century, Marsh sold and supervised the erection of iron, and then steel truss bridges in Iowa, Montana, South Dakota, Minnesota, Colorado, and five other western states (*21*, p. 5).

By 1896, Marsh had decided to turn the skills he had learned working for others to his own advantage, and he founded the Marsh Bridge Company. Marsh built both steel and reinforced concrete bridges for city and county governments, including a Melan arch at Waterloo, Iowa, in 1903, and an eight-span Melan arch for Second Avenue in Cedar Rapids, Iowa, in 1906. In 1909, the company was put in the hands of a receiver, and Marsh reorganized his business as the Marsh Engineering Company. Late that year he completed a non-Melan style, three-span arch bridge in Dunkerton, Iowa, which still stands. The royalties that Marsh had to pay to American holders of the Melan patent were becoming increasingly onerous, and soon after being sued by Daniel Luten in 1911 over a bridge built by Marsh's company in Minnesota, Marsh began experimenting with his own designs for reinforced concrete bridges. In 1912 he received patent number 1,035,026, which covered the basic design for which he would be best known, the Marsh arch. The deck of a Marsh arch is supported by vertical ties between the crown of the arch and the floor beams, and all forces in tension are exerted on the vertical members. Most Marsh arches were small highway bridges with span lengths from 40 to 100 feet. Although most bridge historians have tended to assert that the Marsh arch was, like many other reinforced concrete arch designs of the time, somewhat wasteful of materials, Hippen (*21*, p. 6) has argued that the design is "more sophisticated, both structurally and economically, than has been thought in the past."

Commonly called a "rainbow" arch, the Marsh design was not constructed in large numbers outside the Midwest, but scattered examples still survive in other regions. One of his earliest bridges, built the same year that he filed his first patent application (1911), is the bridge over the Little Cottonwood River in Blue Earth County, Minnesota. Oklahoma still has an example across Squirrel Creek in Pottawatomie County (1917); one of two built in that state. Possibly the largest Marsh arch is a five-span bridge built at Cotter, Arkansas, in 1930. Each span of this National Historic Civil Engineering Landmark is 190 feet in length. It is similar in many respects to the only remaining multi-span Marsh Arch Bridge in Iowa, the Lake City Bridge (1914), which has three spans of 80 feet each. Another multi-span Marsh Arch Bridge listed in the NRHP is located at Fort Morgan, Colorado. Other multi-span Marsh Arch Bridges, now demolished, have been documented across the Little Wabash River at Carmi, Illinois (1917); and across the Cannonball River at Mott, North Dakota (1921). The greatest number of extant Marsh Arch Bridges, however, may be found in Kansas, Iowa and Ohio.

The Marsh arch design covered by his 1912 patent is not a tied arch because the floor system did not serve as a tie between the ends of the arch ribs. According to Hippen (*21*, p. 7), the Marsh patented design allowed the floor to slide independently of the arches so that longitudinal expansion and contraction would be transmitted between the floor system and the arches only through the hangers, which were flexible enough to bend slightly. This was achieved through use of a slip joint between the deck and the arch where they intersect (*20*, p. 27). Marsh secured another patent in 1921 (#1,388,584) for a supposedly flexible short hanger to be used as a modification of the 1912 design, and this modification assumes a continuance of the sliding deck concept. Marsh was known to have produced both a fixed arch design and a tied arch design, and his company built both types. Apparently, he did not have a patent for the fixed arch design (*21*, p. 9).

Many tied arch spans are called "rainbow" arches, but a clear distinction should be made between those spans based on the 1912 Marsh patent and true tied-arch designs. Occasionally, confusion has arisen in the literature of bridge history due to the tendency to characterize both Marsh patented designs and non-Marsh designs as "rainbow arches." As an example, in *Historic Highway Bridges in Pennsylvania*, the Second Street Bridge in Delaware County is referred to as a "bowstring arch," and it is stated that concrete bowstring arch bridges are sometimes known as "Rainbow" and "Marsh" arches. However, a bowstring span, whether expressed as a metal truss or a reinforced concrete arch, is by definition a tied-arch design, whereas the Marsh arch, as covered by the 1912 patent, is not. Care should be taken in identification and evaluation of reinforced concrete through "rainbow" arches to differentiate between fixed and tied arch designs.

Significance Assessment: The Marsh arch is another example of the early proprietary patented reinforced concrete arch form built during the first few decades of the 20th century (1910-1920). A technological characteristic of the Marsh arch was its ability to be fabricated without the use of falsework. All concrete arches need a temporary wooden scaffolding to support the formwork until the concrete is cured and structurally stable. March arches essentially are a steel armature around which concrete is formed – a steel framework incased in concrete. Hence, the formwork for the concrete could be hung from the reinforcing armature without the need for scaffolding in the bed of the river.

March arches are an aesthetic and pleasing form contributing to the cultural landscape, especially in the Midwest. Bridges documented to have been built by Marsh or under his patent are significant within the context of this study if they retain their character-defining features, which include the arch (from below to above the deck) end posts, suspenders (vertical ties), lower chord, floor beams, railing and piers or abutments. Documentation might be found in the form of a bridge plaque or local government records. Kansas has completed a study of its Marsh arches, which can be found at http://midwestbridges.com/marsharch.html.

In addition to the documented Marsh arches found in the mid-western states, there are other rainbow type arches built in other parts of the country. Examples that visually resemble Marsh arches but cannot be documented, possess less significance within the context of this study than the documented Marsh arch, but are still considered significant if they retain their character-defining features.

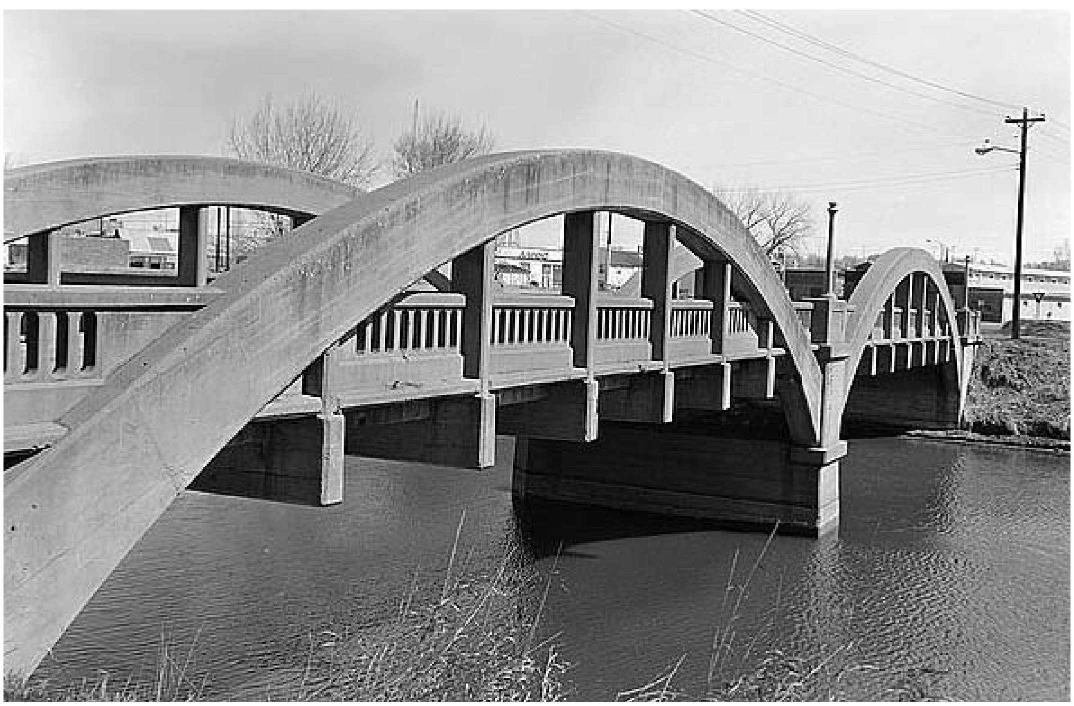
Examples Reinforced Concrete Marsh or Rainbow (Through) Arch

1. Marsh Concrete Rainbow Arch Bridge (1911), Blue Earth County, MN. NRHP listed 1980 in Blue Earth County MRA.
2. Lake City Bridge (1914), Calhoun County, IA. NRHP listed 1989.
3. Marsh Rainbow Arch Bridge (Spring Street Bridge) (1916), Chippewa County, WI. NRHP listed 1982.
4. Cotter Bridge (1930), Baxter County, AR. NRHP listed 1990 in Historic Bridges of Arkansas MPS.
5. Blacksmith Creek Bridge (1930), Topeka, Shawnee County, KS. NRHP listed 1983 in Rainbow Marsh Arch Bridges of Kansas Thematic Resource Nomination.
6. Mott Rainbow Arch Bridge (1921), spanning Cannonball River, Mott, Hettinger County, ND. HAER ND-1.
7. Spring Street Bridge (1916), spanning Duncan Creek, Chippewa Falls, Chippewa County, WI. HAER WI-37.

Figures 3-52 and 3-53 are examples of the patented Marsh arch.

Figure 3-52. Spring Street Bridge (1916), spanning Duncan Creek, Chippewa Falls, Wisconsin. This structure is the state's only example of a patented Marsh arch.

Figure 3-53. Mott Rainbow Arch Bridge (1921), spanning Cannonball River, Mott, North Dakota. This two-span bridge is an example of the patented Marsh arch.



3.2.5 Reinforced Concrete Closed Spandrel Arch

History and Description: Closed spandrel arch bridges are the most basic of reinforced concrete bridge types in that they mimic the appearance of masonry arch bridges.

Closed spandrel means that the area between the travel surface (deck) and the arch ring was filled in, thus replicating the massive appearance of the masonry arch bridge. The spandrel wall actually serves as a retaining wall in a closed spandrel arch bridge, holding in the fill material, which could be earth, rubble, or some combination of materials. Live (traffic) loads are borne by the fill material and, to a lesser extent, by the spandrel walls. The arch may be constructed either as a single structural element (an arch barrel) or in separate parallel longitudinal ribs, which are usually braced with cross ties. Although the rib design requires more formwork to construct, it also requires less material. The barrel arch design, which has some structural and visual similarities to stone arch bridges, is more likely to be found on older and smaller bridges while the rib design is more likely to be found on larger bridges. The barrel arch bridge is also sometimes faced with brick or stone, making it appear similar to a masonry arch bridge.

This type of bridge is suitable for short span lengths, and may be found in all regions of the country, however, representation tends to be greatest in states that were settled early and have a tradition of stone arch construction. A rare variation is the closed spandrel arch with no fill material. This type of arch has a floor system similar to that of an open spandrel arch bridge (*23*, p. 7.5.2). The concrete arch was often not among the standardized bridge types developed by the state departments of transportation in their early years.

Significance Assessment: Closed spandrel concrete arches predate open spandrels, as the closed spandrel type harkens back to the stone arches that the earliest forms imitated. This type was not built for long as engineers soon realized that significant material could be saved and a consequent reduction of weight could be achieved by eliminating the triangular section between the deck and arch. Hence, open spandrels were born (despite the additional costs of constructing formwork for the spandrel columns).

Filled spandrel concrete arches date primarily from the earliest decades of reinforced concrete, i.e., the 1890s through the 1920s. They are not as common (then and now) as many of the standardized bridge types built during this same era, such as concrete slabs and girders. Because they are not as common, they are significant within the context of this study, as they represent the evolution of concrete technology. Filled spandrel arches that are built under standardized transportation department plans would also be considered significant.

To be considered significant, filled spandrel arches should have integrity, through the retention of their character-defining features, which include the arch ring, barrel, spandrel wall, railing or parapet, end posts, piers and/or abutments and wingwalls.

Examples of Reinforced Concrete Closed Spandrel Arch

1. Alvord Lake Bridge (1889), Golden Gate Park, City of San Francisco, San Francisco County, CA. HAER CA-33.
2. Queene Avenue Bridge (1905), Hennepin County, MN. NRHP listed 1989 in Reinforced Concrete Highway Bridges in Minnesota MPS.
3. Fromberg Bridge (1914), Carbon County, MT. NRHP listed 1993 in Fromberg MPS. HAER MT-7.
4. Market Street Bridge (1928), Dauphin County, PA. NRHP listed 1988 in Highway Bridges Owned by the Commonwealth of Pennsylvania, Department of Transportation Thematic Resource Nomination. HAER PA-342
5. Penns Creek Bridge (1919), State Route 1014 at Penns Creek, Selinsgrove vicinity, Snyder County, PA. HAER PA-284.
6. Curry Creek Bridge (1926), spanning Curry Creek at State Route 15, Jefferson, Jackson County, GA. HAER GA-67.

Figures 3-54 and 3-55 illustrate the filled spandrel arch type.

Figure 3-54. Elevation drawing of filled spandrel concrete arch.

Figure 3-55. Penns Creek Bridge (1919), State Route 1014 at Penns Creek, Selinsgrove vicinity, Snyder County, Pennsylvania. This bridge is an example of a reinforced closed spandrel concrete structure.

3.2.6 Reinforced Concrete Open Spandrel Arch

History and Description: This type of bridge was first constructed in the United States about 1906, and was the dominant form for concrete bridges in the 1920s and 1930s (*22*, p. 20). Open spandrel concrete bridges evolved, as the span length of reinforced concrete arches increased and the weight and cost of the material of spandrel walls of the closed spandrel type bridge became prohibitive. By eliminating these walls and the fill material inside them, not only could dead loads be reduced, but cost savings were seen in materials. In addition to economics and durability, aesthetics was another factor. Open spandrel bridges had a lightness and visual appeal not possible with heavier closed spandrel bridges. This relative openness made open spandrel arch bridges more aesthetically appealing for prominent or scenic locations. Open spandrel construction marked engineering prowess during the height of long span concrete arch bridges during the 1930s and 1940s. By the 1940s, the open spandrel concrete structure began to be supplanted by the more economic pre-stressed beam and reinforced concrete girder structures.

Open spandrel arch bridges have pierced spandrel walls with no fill material, and the spandrel columns transmit dead and live loads from the travel surface (deck) to the arch. The arch ring may be either a solid barrel, as in the closed spandrel arch, or ribbed. Although open spandrel arch bridges require more formwork to construct than filled spandrel bridges, they also offer some economy of materials, particularly for long span lengths.

An example of this type of structure is Campbell's Bridge, spanning Unami Creek at Allentown Road in Bucks County, Pennsylvania, which was completed in 1907, and is the oldest of its type in the PennDOT system. It is certainly among the oldest of its type in the nation.

Significance Assessment: Open spandrel concrete arches, while not uncommon, are not as common (then and now) as many of the standardized bridge types built during this same era. Because they are not as common, they are significant within the context of this study as they represent the evolution of concrete technology. To be considered significant, open spandrel arches should have integrity through the retention of their character-defining features, which include arch ribs, ring or barrel; spandrel; spandrel columns; railing or parapet; and piers, abutments and wingwalls.

Examples of Reinforced Concrete Open Spandrel Arch

1. Tenth Street Bridge (1920), Cascade County, MT. NRHP listed 1996. HAER MT-8.
2. Gervais Street Bridge (1927), Richland County, SC. NRHP listed 1980. HAER SC-16.
3. Cedar Avenue Bridge (1929), Hennepin County, MN. NRHP listed 1989 in Reinforced Concrete Highway Bridges in Minnesota MPS.

4. George Westinghouse Bridge (1932), Allegheny County, PA. NRHP listed 1977. HAER PA-446.
5. Broad River Highway Bridge (1935), State Route 72, spanning Broad River, Carlton vicinity, Madison County, GA. HAER GA-47.

Figures 3-56 and 3-57 depict the open spandrel concrete arch type.

Figure 3-56. Elevation drawing of open spandrel concrete arch.

Figure 3-57. Broad River Highway Bridge (1935), State Route 72, spanning Broad River, Carlton vicinity, Madison County, Georgia. This bridge is an example of the open spandrel concrete arch.

3.2.7 Steel Tied Arch

History and Description: Steel arches can be fixed, hinged, or tied. Tied steel arches, also commonly referred to as "tied thru (or through) arches," are descendents of the iron "bowstring" trusses (discussed in Section 3.1.6) that were patented in the mid-nineteenth century.

Structurally, the advantage of the steel tied arch is that they do not require large abutments to counter the thrust of the arch action. Abutments could be smaller and more economic. A tied arch span has a structural element, usually a floor system, which ties the ends of the arch together. According to the FHWA *Bridge Inspector's Training Manual*, a tied arch is a variation of a through arch in which the horizontal thrust of the arch reactions is transferred to the horizontal tie, which acts in tension. The bowstring arch is essentially a tied arch expressed in metal, but not all metal tied arches should necessarily be characterized as bowstrings. The arch members are called ribs and can be fabricated as beams, girders or trusses, and can be further classified as solid rib, braced rib, or spandrel braced. The arch members can be riveted, bolted or welded together (*23*, p. 8.8.3).

Lengths vary from 30 to 50 feet for the short spans. The shorter spans were predominately constructed in the 1930s. An early steel tied-arch bridge is the Franklin Street Bridge (1939) spanning Oil Creek in Crawford County, Pennsylvania. In its modern form, tied arches have been designed for spans ranging from 180 feet to over 900 feet. The longest steel tied-arch bridge in the United States is the 912-foot long Moundsville Bridge (1986) over the Ohio River in Marshall County, West Virginia.

Significance Assessment: The tied steel arches built before 1955 (the end of the historic period covered in this study), many dating to the second quarter of the twentieth century, are notable bridge structures because of their distinctive arch form. They were not built in great numbers, thus examples that retain their character-defining features will possess significance within the context of this study. Character-defining features include the curved top girder or truss (ribs), suspenders, ties, the bottom chord and floor system.

Examples of Steel Tied Arch

1. West End—North Side Bridge (1932), Allegheny County, PA. NRHP listed 1979.
2. Franklin Street Bridge (1939), spanning Oil Creek at Franklin Street, Titusville, Crawford County, PA. HAER PA-494.
3. Braceville Bridge (1939), spanning Southern Pacific Railroad tracks at State Route 129, Braceville vicinity, Grundy County, IL, HAER IL-141.
4. I-95 Bridge over Myrtle Avenue (1955), Jacksonville, FL. Considered NRHP eligible in *Historic Highway Bridges of Florida* (2004).
5. Blue River Bridge (1933), Jackson County, MO. Listed as NRHP eligible in Missouri Historic Bridge Inventory (1996).
6. John McLoughlin Bridge (1933), Oregon 99E, spanning Clackamas River, Oregon. NRHP eligible 1985. HAER OR-67.

Figure 3-58 depicts an example of a steel tied arch.

Figure 3-58. Franklin Street Bridge (1939), spanning Oil Creek at Franklin Street, Titusville, Pennsylvania. Designed by a county engineer, this bridge is a steel tied arch.

3-58a. Three quarter view.

3-58b. Detail of connection.

3.2.8 Reinforced Concrete Tied Arch

History and Description: Reinforced concrete arch spans can be fixed, hinged or tied. Like tied steel arches, reinforced concrete tied arches (or through arches) are a phenomena of the twentieth century and were built to avoid heavy massive abutments, thus saving money. They were constructed during the "heroic" period of reinforced concrete arch construction, which began in the 1920s and extended till the end of the 1930s.

Unlike traditional fixed through arches, the ends of the ribs of the concrete tied arch are not integral parts of the piers resulting in the containment of the horizontal thrust action by the pier mass. Instead, the arch rib ends are connected to the deck by hinged shoes and rebar. The advantage of the tied arch design is that the entire structure acts as a beam and places the entire vertical load on the supporting abutments or piers, thus negating the need for large abutments to resist the thrust of the arch. Lighter, less expensive abutments could then be used. Lengths ranged from short spans of 30 to 40 feet to moderately long spans in excess of 200 feet.

Tied concrete arches are architecturally distinctive due to their prominent arch form. Larger spans exhibit monumental qualities, like some of Oregon state bridge engineer Conde McCullough's coastal spans. One early example of a reinforced concrete tied-arch through bridge is the Benson Street Bridge (1910) over the gate fork of Mill Creek, about eight miles north of the Cincinnati central business district in Hamilton County, Ohio. Designed by Deputy County Surveyor E. A. Gast, this bridge may be the oldest, and first, tied arch, reinforced concrete bridge in the United States. The deck is suspended from two arch ribs by nine hangers, with the steel rods hooked around rib reinforcement above and floor rods below. The arch ribs are entirely above the travel surface. This design was chosen because studies had shown that the surviving masonry abutments from an earlier truss bridge at the site could support the load of a new bridge, if the weight of the bridge could be distributed evenly over the width of the abutments.

A more modest example is State Bridge NC-246 (1942) in New Castle County, Delaware, which is that state's first and only remaining example of this type. Like so many of the earlier tied-arch bridges that preceded it around the country, this structure replaced a metal truss bridge. Although the specific reasons for selection of a tied-arch design at this site are unknown, the type was generally employed where subsurface conditions made massive abutments or piers impractical.

Significance Assessment: The concrete tied arches built before 1955 (the end of the historic period covered in this study), many dating to the second quarter of the twentieth century, are notable bridge structures because of their distinctive arch form. They were not built in great numbers, thus examples that retain their character-defining features will possess significance within the context of this study. Character-defining features include the curved top chord (rib), bottom chord, suspenders/ties/hangers, hinged shoes, floor beams, and wingwalls, abutments or piers. Railings may also be character-defining features of some bridges.

Examples of Reinforced Concrete Tied Arch

1. Benson Street Bridge (1910), Hamilton County, OH. HAER OH-50.
2. Quarry Road Bridge (1916), spanning Conestoga Creek, Lancaster County, PA. Determined NRHP eligible in 1993 as part of state-wide historic bridge survey.
3. Rumsey Bridge (1930), County Road 41 over Cache Creek, Yolo County, CA. Determined NRHP eligible in 1986 as part of state-wide historic bridge survey.
4. Wilson River Bridge (1931), US 101 over Wilson River, Oregon. NRHP listed 1985. HAER OR-39.

Figure 3-59 depicts a reinforced concrete tied arch structure.

Figure 3-59. Wilson River Bridge (1930-31), spans Wilson River at United States Highway 101, Tillamook, Tillamook County, Oregon. This bridge was designed by Oregon state bridge engineer Conde McCullough and was the first reinforced concrete tied arch built in the Pacific northwest.

3-59a. View from below.

3-59b. Through view.

3.2.9 Steel Hinged Arch

History and Description: Hinged steel arches usually are large spans built where navigational requirements or, more likely, bearing conditions, precluded more common multiple span structures. These structures were built in the United States in the decades before the Civil War, through the nineteenth century, and reached monumental lengths with the perfection of high strength alloy steels beginning in the 1930s. They continue to be built to this day.

Hinged metal arch bridges may be differentiated from other metal arches by the degree of articulation of the arch. When there are hinged bearings at each end of the arch, the span is a two-hinged arch. When there are hinged bearings at each end of the arch and a hinge at the crown of the arch, the span is a three-hinged arch. The three-hinged arch was mainly used for highway bridges because the design was too flexible for railroad use, but it fell out of favor and is not commonly found today. Single-hinge spans, with the hinge usually located at the crown of the arch, were rarely built and the type is not considered "common." The two-hinged arch is therefore the sub-type of metal-hinged arch most likely to be found in extant bridges. Lengths range from 500 feet to a monumental 1,675 feet.

The Hell Gate Bridge (1916) is a two-hinged spandrel braced arch bridge; often referred to as a "truss-stiffened arch." At just over 1,017 feet in length, it was the longest bridge of its type when opened. The bridge's designer was Gustave Lindenthal (1850-1935), a German-born engineer from Pittsburgh. Like many other bridge engineers of his era, Lindenthal had no formal training in his profession, and learned how to design bridges by working for various railroads. He had earlier designed the Smithfield Street Bridge (1882) in Pittsburgh. Around 1901, Lindenthal was appointed commissioner for the New York City Department of Bridges, which resulted in his design of several New York area bridges, including the Williamsburg Bridge (1903) and the Queensboro Bridge (1907).

One of the most spectacular two-hinged arch bridges is the Bayonne Bridge (1931) over the Kill van Kull, linking Bayonne, New Jersey, with the Port Richmond area of Staten Island, New York. It has an arch span of 1,675 feet and was the longest arch bridge in the world, exceeding the length of the Sydney Harbor Bridge in Australia by just two feet. The Bayonne Bridge is a spandrel-braced truss arch in which the manganese-steel lower chords form a perfect parabolic arch. The silicon-steel top chords act as stiffeners only, while the bottom chords bear the main compressive forces. This bridge was designed by one of the great bridge engineers of the twentieth century, Othmar Ammann (1879-1966), who had served as an assistant engineer under Lindenthal.

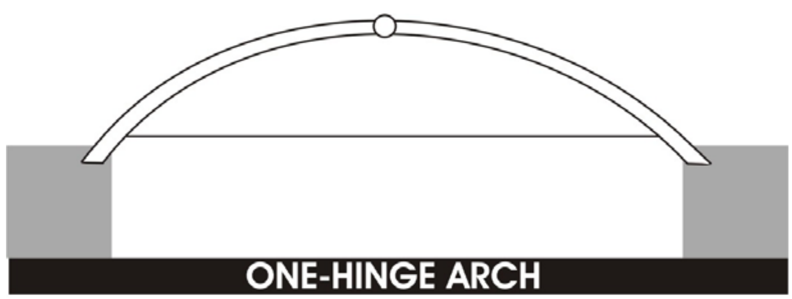
Significance Assessment: Hinged steel arches built during the historic period covered in this study (through 1955) are not among the most common bridge types in this study. Due to this fact and the fact that most are monumental structures, they are highly significant within the context of this study if they retain their character-defining features, which include curved girder or truss top chord, bottom chord, suspenders, ties and piers, hinges and hinges, and abutments (buttresses). Most possess historic as well as engineering significance, as through their construction they solved transportation problems encountered at major river crossings. Many also have important scenic qualities.

Examples of Steel Hinged Arch

1. Washington (Heights) Bridge (1889), Bronx County, NY. NRHP listed 1983. HAER NY-130.
2. Navajo Steel Arch Bridge (1929), Coconino County, AZ. NRHP listed 1981 in Vehicular Bridges in Arizona MPS. HAER AZ-28.
3. Bayonne Bridge (1931), over the Kill van Kull linking Bayonne, New Jersey and Port Richmond area of Staten Island, NY. HAER NJ-66.
4. Yaquina Bay Bridge (1936), Lincoln County, OR. HAER OR-44.
5. Sturgeon River Bridge (1947), Missaukee County, MI. NRHP listed 1999 in Highway Bridges of Michigan MPS.
6. Gordon Park Bridge (1952), Cleveland, OH. Determined NRHP eligible in *The Third Ohio Historic Bridge Inventory, Evaluation and Management Plan for Bridges Built 1951 – 1960 and the Development of Ohio's Interstate Highway System.*
7. Washington Crossing Bridge (1924), spanning Allegheny River at Fortieth Street, Pittsburgh, Allegheny County, PA. HAER PA-447.

Figure 3-60 contains an elevation drawing of two types of hinged arches. Figures 3-61 and 3-62 present two examples of monumental steel hinged arches.

Figure 3-60. Elevation drawing of one-hinged and two-hinged arches.



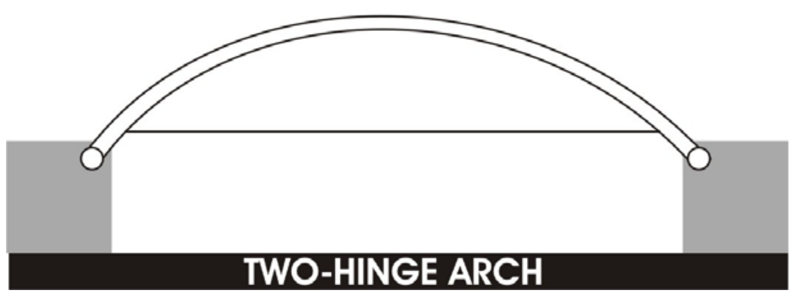
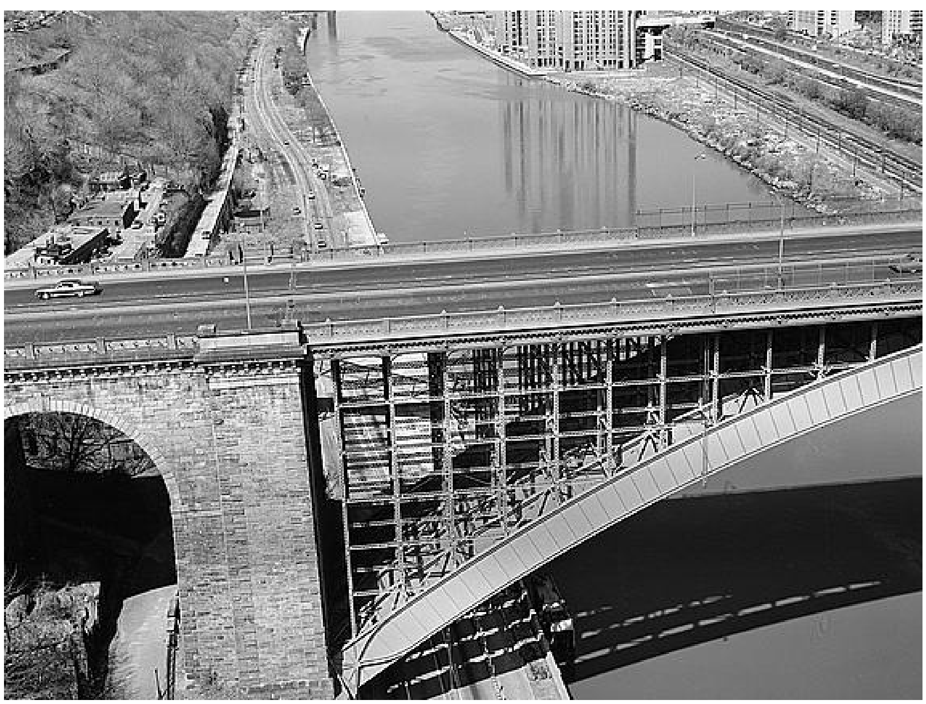


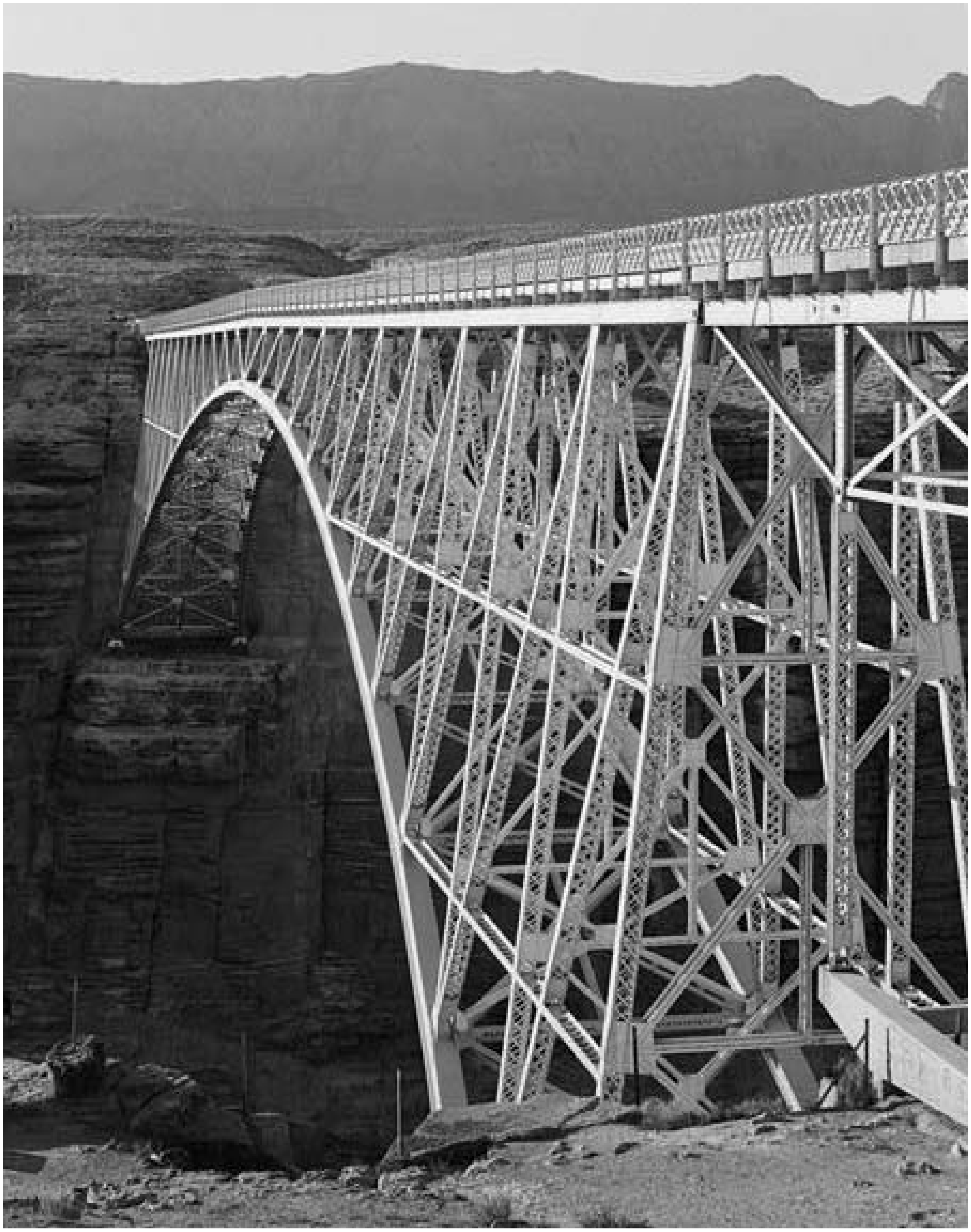
Figure 3-61. Washington (Heights) Bridge (1889), Bronx County, New York. This bridge is an example of a two-hinged steel arch.

3-61a. View towards Manhattan.



3-61b. Detail of approach and span on Manhattan side.

Figure 3-62. Navajo Steel Arch Bridge (1929) spanning Colorado River, Coconino County, Arizona. This important hinged arch bridge opened construction from the north to the Grand Canyon, and made U.S. Highway 89 a valuable tourist route.



3.2.10 Reinforced Concrete Hinged Arch

History and Description: Hinged concrete arch bridges began to be built early in the twentieth century, flourished during the 1920s, peaked during the 1930s, and waned by the time America entered the Second World War. Engineers were trying to achieve a thin sinuous arch rib that used less material, theoretically lowering construction costs. European bridges, like those designed by Robert Maillert and Eugene Freyssinet, best illustrate what designers were seeking in hinged concrete arches. But, in the United States, with the exception of some of Oregon State Engineer Conde McCullough's Oregon bridges, bridge designers opted for more conservative, heavier arches with standard reinforcing patterns.

The use of hinges simplified the design of bridges by allowing stresses in the arches to be calculated as if the bridge behaved as a statically determinate structure, which is much simpler mathematically than a statically indeterminate structure. Hinges also allowed for incremental movement and settlement as the concrete cured. Once the concrete had cured and the hinges were cemented in, the bridge behaved as a fixed arch.

Hinged reinforced concrete arch bridges may be differentiated by the degree of articulation of the arch. When there are hinged bearings at each end of the arch, the span is a two-hinged arch. When there are hinged bearings at each end of the arch and a hinge at the crown of the arch, the span is a three-hinged arch. The three-hinged arch is the sub-type most likely to be found in reinforced concrete arch bridges. Span lengths were of an intermediate length, ranging from 100 feet for earlier examples to 230 feet by the 1930s.

Condit (*3*, p. 176), in discussing reinforced concrete, stated "one other innovation served to round out the development of construction up to the end of the [nineteenth] century." He then mentions a proposal made by David A. Molitor in 1894 for a three-hinged concrete arch bridge with pinned steel connections, which was never erected, but goes on to state that "the first arch of this kind was built at Mansfield, Ohio, between 1903 and 1904." However, *The Ohio Historic Bridge Inventory, Evaluation, and Preservation Plan* (*24*, p. 99) indicates that the first three-hinged concrete arch bridge in the United States was a footbridge across Big Creek in Brookside Park, Cleveland, Ohio, designed by Assistant Park Engineer A. W. Zesiger and completed in 1906.

Although the 1906 bridge has been demolished, an approximately 66 foot-long stone faced, concrete hinged arch bridge built over the same creek in the park in 1909 still exists. Identified as the Brookside Park Bridge in the HAER Collection, it may more properly be called the Big Creek Bridge to differentiate it from other Brookside Park bridges, which were listed in the NRHP as a group in 1977. It is an early Melan-style pedestrian bridge with embedded plates, angles, steel shafting, and cast-iron bearing plates.

The earliest extant three-hinged reinforced concrete arch bridge in the nation is the Ross Drive Bridge in Rock Creek Park, Washington, DC. Originally built in 1907, this NRHP-listed bridge was widened in 1968. It is a rare example of a hinged concrete arch bridge in which the hinges were left exposed. Most hinged concrete arch bridges have hinges that are imbedded in the concrete.

A fairly early example of a three-hinged concrete arch bridge with enclosed hinges was the Ash Avenue Bridge (1913) in Tempe, Arizona. Demolished in 1991, this was the first reinforced concrete multi-arch bridge erected in Arizona, the first large highway bridge across the Salt River, and the first automobile bridge between Phoenix and Tempe.

The largest number of extant reinforced concrete hinged arch bridges in the United States may be found on the west coast, with examples in California, Oregon and Washington. One of the most spectacular examples of type is the 1,898-foot long Rogue River/Gold Beach Bridge (1931) in Curry County, Oregon. The bridge was designed by Conde B. McCullough (1887-1946), one of America's greatest highway bridge engineers. In his design of the this bridge, McCullough used a European technique (developed by Freyssinet) for decentering reinforced concrete deck arches that had not previously been used in the United States. Although his belief that the Freyssinet method of pre-compressing arch ribs would reduce the cost of construction proved to be illusionary due to high labor and material transportation costs, the technique did reduce the amount of reinforcing bar and concrete in construction. The bridge is one of several in Oregon designed by McCullough that used a system of hinged articulation and expansion joints to make the ribs move flexible during construction, even though they were eventually imbedded in concrete, and thus acted as fixed arches following completion.

Significance Assessment: Exposed hinged concrete arches are not common, but hinges that were encased in concrete would have been a standard construction technique especially for larger arches. Unless you have documentation or drawings, however, it is difficult to determine whether arches that do not have exposed hinges are indeed hinged.

The total population of hinged concrete arch bridges in the United States is unknown, and is unlikely to be of a great number, but the type exists in different regions of the country and is an important type within the overall historical context of bridge design evolution. This type is considered significant within the context of this study if they retain character-defining features, such as arched ribs, suspenders or ties, and hinged bearings, which are generally not visible. An above-deck arch features floor beams and a bottom chord, which are character defining elements. The railing may or may not be character-defining features.

Examples of Reinforced Concrete Hinged Arch

1. Ross Drive Bridge (1907), Washington, DC. NRHP listed 1980. HAER DC-13.
2. Tempe Concrete Arch Highway Bridge (Ash Avenue Bridge) (1913); Maricopa County, AZ. NRHP listed 1984 in Tempe MRA. HAER AZ-29.
3. Georgia Street Bridge (Caltrans Bridge) (1914), San Diego County, CA. NRHP listed 1999.

4. Moffett Creek Bridge (1915), Multnomah County, OR. HAER OR-49.
5. North Hamma Hamma River Bridge (1923), Mason County, WA. NRHP listed 1982 in Historic Bridges/Tunnels in Washington State Thematic Resource Nomination. HAER WA-97.
6. South Hamma Hamma River Bridge (1924), Mason County, WA. NRHP listed 1982 in Historic Bridges/Tunnels in Washington State Thematic Resource Nomination. HAER WA-96.
7. Depoe Bay Bridge (1927), Lincoln County, OR. HAER OR-36.
8. Rogue River Bridge (1931), Curry County, OR. HAER OR-38.

Refer to Figure 3-60 for elevation drawings of the hinged arch type. Figures 3-63 and 3-64 illustrate examples of the reinforced concrete hinged arch.

Figure 3-63. North Hamma Hamma River Bridge (1923); Mason County, Washington. This structure is a three-hinged concrete arch bridge built by Washington State Highway Department.

Figure 3-64. Depoe Bay Bridge (1927), Lincoln County, Oregon. This Oregon coast hinged concrete arch bridge spans the bay between Newport and Lincoln City.

3.3 Slab, Beam, Girder and Rigid Types

Driven by the unprecedented growth of the highway system following the Second World War, engineers working for state highway departments developed standardized slab, girder, T-beam and stringers of steel and concrete that number by the thousands in every state. Timber stringer bridges were also a standardized bridge in many areas of the country in the first half of the twentieth century.

The slab, beam, girder and rigid structures (with the possible exception of the single-intersection Pratt truss and the Warren pony truss) are truly the "common" bridges of all those addressed in this study. It only has been in the last few years that bridge historians are beginning to come to terms with these bridge types, embracing these truly ubiquitous bridges which span America's highways by the thousands.

As with truss bridges, beam and girder bridges may be built as simple spans, with abutments or piers at either end of the span, or as continuous spans, with intermediate piers, bents or columns supporting the superstructure. A cantilevered beam or girder bridge consists of anchor arms supported by piers, and a cantilevered span that is supported by the anchor arms.

Like truss bridges, girder bridges are usually differentiated by the location of the deck or travel surface in relation to the rest of the superstructure. In a deck girder bridge the superstructure is entirely below the travel surface of the bridge. In a through girder bridge the travel surface is flanked by extensions of the girder that are not connected above the deck.

3.3.1 Timber Stringer

History and Description: Wood stringer (or beam) bridges are a very old type of design that dates back to the origins of bridge building. Ancus Martius' Roman Pons Sublicius (third to fourth century, B.C.) was a wood pile and stringer structure. In the United States, timber stringer bridges were amongst the earliest built, simple waterway crossings. Long after wood truss bridges had ceased to be competitive with metal truss bridges for use in short spans in the nineteenth century, timber beam bridges were still being built. Because of the structure's simplicity and readily available material (wood), the timber beam has endured to the present day in the form of rot-resistant timber laminated stringer, or beam, bridges. Today, these structures are built on low-trafficked, rural backcountry roads, private roads, or in national forests and parks.

In the early twentieth century, a design for a timber stringer was included in the standardized designs of a number of the state departments of transportation. The Montana Highway Commission, for example, developed a standard design for simple-span timber bridges in 1915. By the 1920s it became necessary to modify this design, due to higher vehicle weights, using creosote-treated timbers. In 1933, the Maryland State Roads Commission issued plans for "Standard Timber Beam Bridges for Secondary Roads." The Montana Highway Department built hundreds of timber stringer bridges up to the mid-1950s, when prestressed concrete and steel bridges began to be used (*26*). In New Jersey, timber stringer bridges were reportedly built as late as the 1990s, particularly in the southern portion of the state (*27*). In Maryland, timber beam bridges were once found in abundance in the Tidewater region. In Colorado, they have historically been the most common bridge type and there are seven timber stringer bridges in the state that are NRHP listed or eligible. In West Virginia, there are currently 24 timber stringer bridges on the Department of Transportation state inventory (not all of historic age). In Georgia, the State Highway Department adopted a standard design for timber beam bridges in 1919, and more than 100 pre-1956 examples were identified during research for the *Historic Bridge Inventory Update* (*28*).

Timber stringer (beam) bridges consist of a wood plank deck supported by heavy, square or rectangular, solid-sawn wood beams. Short span timber stringer bridges in the 10- to 30-foot range were and are built in areas that do not carry a high level of traffic and in parks. They are built as approach spans to metal truss, beam or girder bridges or as trestles. The timber beam (stringer) bridge differs from the wood trestle bridge, which is addressed in Section 3.6 of this chapter, primarily by the type of substructure employed. According to *Historic Bridges in North Dakota* (*29*), whereas the ends of the stringers in a timber stringer bridge rest on a single vertical support constructed of stone, concrete, wood, or steel piles, the stringers of a timber trestle bridge rests on a framework of vertical members joined together with horizontal and diagonal bracing.

Significance Assessment: Timber stringer bridges have a relatively low level of significance within the context of this study. Very old (pre-twentieth century) examples would possess significance as an early representative example of the type if they retain integrity. Character-defining features include the longitudinal beams (or, stringers) and often the pile bents. Railings and abutments may or may not be considered character-defining features. Intact examples in parks are also significant as they generally have scenic values and often possess additional significance for their association with parks and/or Depression-era federal work programs. If a stringer bridge could be identified as having been built according to the standard plans of the state transportation departments, it would also be considered significant within the context of this study. One problem with timber stringers and integrity, often maintenance results in the loss of the structure's materials to a point where little will remain of the historic fabric.

Examples of Timber Stringer

1. Maitland Arroyo Bridge (1940), Huerfano County, CO. NRHP listed 2002 in Highway Bridges in Colorado MPS.
2. Grist Mill Bridge (ca. early 1950s), York County, ME. NRHP listed 1990.
3. Fishing Bridge (1937), spanning Yellowstone River at East Entrance Road, Yellowstone National Park, Park County, WY. HAER WY-9.
4. Lithodendron Wash Bridge (1932), AZ. NRHP listed 1988 in Vehicular Bridges of Arizona MPS.
5. Warrens Bridge (1930) over Lambrook Levee Ditch on CR 14, Phillips County, AR. NRHP listed 1995.

Figures 3-65 and 3-66 present a drawing and photographs of a timber stringer bridge.

Figure 3-65. Elevation drawing of timber stringer.

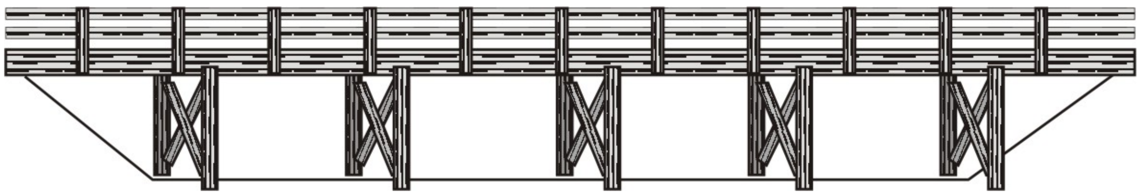


Figure 3-66. Fishing Bridge (1937), spanning Yellowstone River at East Entrance Road, Yellowstone National Park, Park County, Wyoming. This NPS-built rustic timber bridge was erected on pile bents.

3-66a. Elevation view.

3-66b. View of bents and underside of structure.

3.3.2 Reinforced Concrete Cast-in-Place Slabs

History and Description: The cast-in-place flat-slab bridge, which is the simplest type of reinforced concrete bridge, dates to the first decade of the twentieth century. This type of structure began to appear in numbers about 1905 (*30*). But even earlier examples of flat-slab culverts and short flat-slab bridges can be found in engineering texts, promotional materials of construction companies, and in professional engineering journals. These bridges were constructed using what eventually became a conventional system of reinforcement that acted "one-way" in flexure. But as Case Western Reserve University civil engineering professor Dario Gasparini and engineer William Vermes (*31*, p. 12) assert, from 1905 to the end of 1909, the technology of constructing reinforced concrete floors that act in flexure in two directions underwent a revolutionary transformation in the United States, largely due to the work of Claude A.P. (C.A.P.) Turner (1869-1955). Moreover, Turner's work led directly to the advancement of flat-slab bridge technology for longer structures than had previously been constructed (*31*, p. 12).

In a January 1910 article in *Cement Age*, Turner described four reinforced concrete flat-slab bridges built in the previous year: a three-span bridge on Mississippi Boulevard in St. Paul, Minnesota, with two spans of 27 feet and one span of 28 feet in length; an arch bridge with a flat-slab deck on Mississippi Boulevard; a three longitudinal span bridge on Lafayette Street over the Soo Line Railroad tracks with a 37-foot central span; and the Westminster Street Bridge over the Soo Line Railroad tracks. These structures were built using a methodology that Turner had been developing since at least 1905 for use in building construction, which featured a method of shear reinforcement that was characterized by a unique "mushroom head" column design. He first applied that methodology in 1906 to construction of the Johnson-Bovey building in Minneapolis, Minnesota, and to the Hoffman Building (also know as the Marshall Building) in Milwaukee, Wisconsin, an ASCE National Historic Civil Engineering Landmark. In late 1909 or early 1910, Turner also designed a flat-slab bridge for the Superior Street crossing of Tisher's Creek in Duluth, Minnesota, with five 26-foot spans (*31*, p. 16).

The essential technological advancement of Turner's design methodology is that, in contrast to slabs, walls, or floor systems that act "one-way" in flexure, Turner devised a "cage" of reinforcement that included diagonal members as sheer reinforcement. Among other advantages, this system eliminated the need for expansion joints, which often become points at which degradation from water and road salt occur.

Although much historic bridge literature parrots the assertion of historian Carl Condit, that flat-slab construction was invented by Swiss engineer Robert Maillart in 1900, as Gasparini and Vermes point out (*31*, p. 13), Turner had been experimenting with his system before Maillart, and he applied it to bridge construction before Maillart, who did not build his first flat-slab bridge until a year after Turner built his first. It is clear, however, that small-span reinforced concrete flat-slab bridges were being constructed in the United States long before Maillart or Turner ever built a bridge, and it is questionable whether the technology was derived from that applied to floor and wall systems of buildings, or was simply a progression and adaptation of earlier systems that had been applied to reinforced concrete arch bridge construction.

Turner was educated at the Lehigh University School of Engineering, receiving his degree in 1890. After a decade of employment with numerous railroad, bridge and construction companies, he founded his own firm in 1901. According to Gasparini and Vermes (*31*, p. 12), in the brief period from 1905 to 1909, concrete buildings with flat-slab floors became commonplace in the United States, largely due to the contributions of Turner. Unfortunately, as a result of losing a patent infringement lawsuit that he filed in 1911, Turner was prohibited from designing flat-slab structures beginning in 1916 unless he worked under a license from a competing designer, Orlando W. Norcross, whose 1902 patent for concrete floor reinforcement was of dubious worth to bridge designers. It would not be until after expiration of the Norcross patent in 1919 that Turner resumed the design of flat-slab bridges. Scattered extant examples of his or similar designs may still be found.

The popularity of flat-slab bridges, particularly those with "one-way" flexure systems, grew rapidly in the 1910s. A number of organizations, including public (the federal Office of Public Roads and, after 1918, the Bureau of Public Roads) and private (the American Concrete Institute), supported use of the type. Many states adopted standard plans for flat-slab bridges in the first quarter of the twentieth century, and in some cases the type became the preferred choice for spans of modest length. Although "two-way" flat slabs became the dominant system for use in buildings, two-way flat slabs for bridges, including those used by Turner, eventually fell out of favor.

During the 1930s and into the early 1940s the flat-slab bridge type was very popular for small highway bridges (and small structures/culverts) in many states. Up until about World War II, flat-slab bridge designs were advocated in books on bridge engineering, pamphlets of bridge companies, and technical circulars where the type was perceived as having the advantages of economy, stiffness, resistance to temperature cycles, resistance to shrinkage, and ease of construction.

As the FHWA *Bridge Inspector's Reference Manual* (*21*, p. 7.1.1) states, the terms "deck" and "slab" are sometimes used interchangeably to describe the same bridge component, although it is generally incorrect to do so. A deck is the traffic-carrying component of a bridge that is supported by the bridge superstructure, which can be composed of beams (girders), arches, or other structural units. A slab, however, is a superstructure unit supported by a substructure unit, such as an abutment, bent, pier, column, etc. Many of the design characteristics of decks and beams are similar, but the bridge historian should be mindful of the confusion that can be caused by tendencies in the literature of bridge history to use the terms indiscriminately. In the case of the structures that properly belong in the category of cast-in-place, flat-slab bridges, the slab is both the superstructure and the deck.

As an example of how the differentiation in bridge component terminology applies in practice, the Fort Snelling-Mendota Bridge over the Minnesota River in Dakota

County, Minnesota, was the longest concrete arch bridge in the world when it opened in 1926. Designed by Turner and Walter H. Wheeler, it originally consisted of 13 open-spandrel concrete arches, each supporting a flat-slab deck. Although this structure was probably the longest bridge in the world using a flat-slab system, it was not a flat-slab bridge. Unfortunately, the Turner-designed deck of this NRHP-listed bridge was replaced by a more modern system, thus destroying that aspect of its design most associated with Turner.

Most of the earliest flat-slab bridges were simple spans of no more than 30 feet in length, and usually less than 20 feet, in which the horizontal slab of square or rectangular shape rests on abutments or piers. When kept short, these bridges proved to be economical and easy to erect. But continuous, multi-span, flat-slab bridges were also built from the 1910s through the early 1940s, even though each incremental increase in the slab's length also required an increase in its depth or thickness, thus adding to its structural weight. The need for supporting piers tended to increase the cost and impracticality of the flat-slab bridge, at least compared to the T-beam bridge, with which it had to increasingly compete for the favor of state and county engineers.

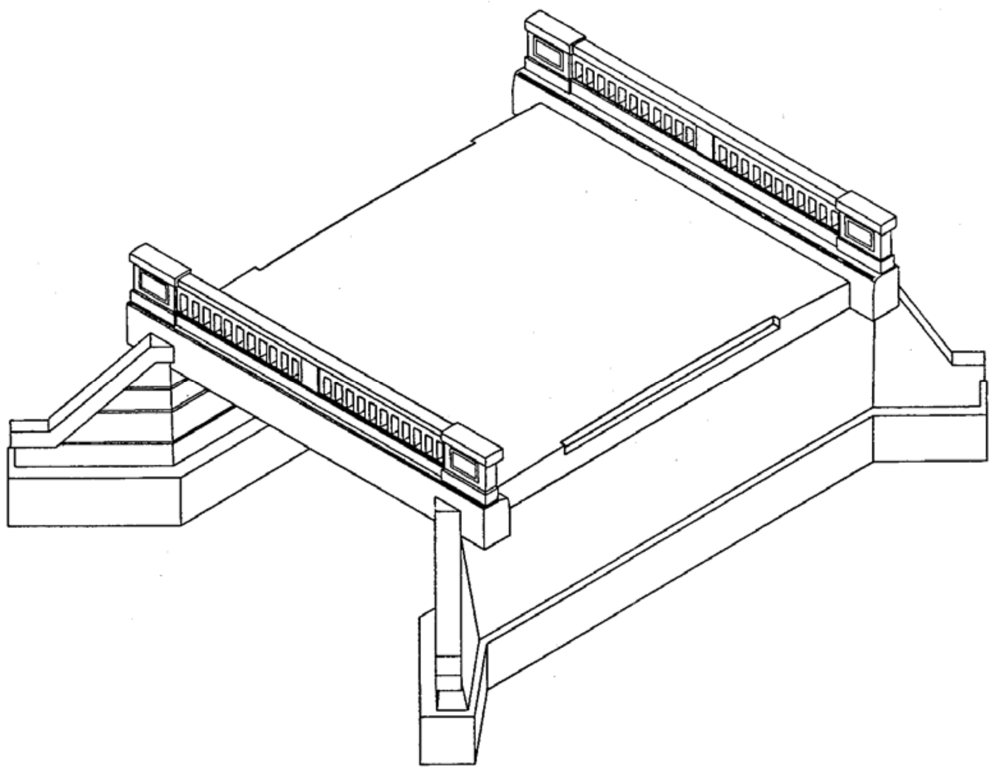
Significance Assessment: A number of pre-1955 slab bridges remain, many because they have thick slabs and are often located in rural areas not subject to roadway salting. Pre-1955 concrete slabs possess significance within the context of this study if these are intact. The most significant types of slab bridges are those that retain integrity and that can be identified as having been built according to the standard plans of the transportation departments in the first quarter of the twentieth century and particularly, those that were built very early in this type's history—within the first decade of the twentieth century. The scenic qualities of these some slab bridges, such as those that are intact and retain their original concrete rails, can elevate their significance within the slab category. Character-defining features include the slab, parapet or railing, and abutments, wingwalls and, occasionally piers.

Examples of Reinforced Concrete Cast-in-Place Slabs

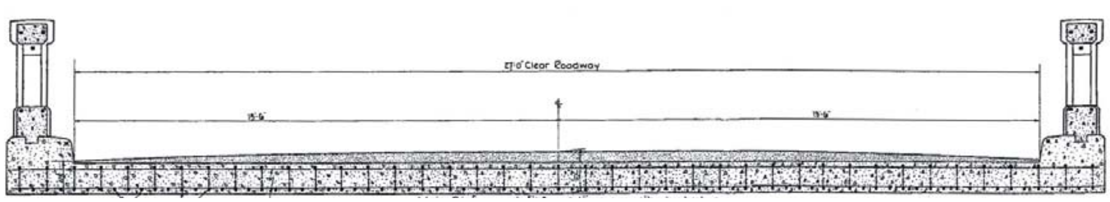
1. Dry Creek Bridge (1929), Pierce County, WA. NRHP listed 1997 in Mt. Rainier National Park MPS.
2. Chester County Bridge No. 225 (1907), spanning Tweed Creek at Hopewell Road, Oxford vicinity, Chester County, PA. HAER PA-415.
3. Coop Creek Bridge (1940), Broadway Street (CR 236), Sebastian County, AR. NRHP listed 1995.
4. Hartford Road Bridge (1943), over branch of West Creek on Hartford Road (CR 5), Sebastian County, Arkansas. NRHP listed 1995.
5. Jacks Canyon Bridge (1913). NRHP listed in 1988 in Vehicular Bridges of Arizona MPS.
6. Ramsey Park Swayback Bridge (1938), Redwood County, MN. Listed in http://www.mnhs.org/places/nationalregister/bridges/bridtype.html, *Minnesota's Historic Bridges By Type.*

Figures 3-67 through 3-69 provide a drawing and photographic examples of the concrete slab bridge.

Figure 3-67. Drawing of a concrete slab bridge. From 1930 Maryland State Roads Commission's 1930 Standard Slab Bridge plans.



3-67a. Isometric view.



3-67b. Roadway cross section.

Figure 3-68. Chester County Bridge No. 225 (1907), spanning Tweed Creek at Hopewell Road, Oxford vicinity, Chester County, Pennsylvania. This structure is an early twentieth century example of a concrete slab bridge.

Figure 3-69. Hartford Road (1943) over a branch of West Creek on Hartford Road (CR 5), Sebastian County, Arkansas. This concrete slab bridge has a stone substructure and an open concrete rail and was built by the Works Progress Administration during World War II. (Photographs from *Historic Bridges of the Midwest*, found at http://bridges.midwestplaces.com/.)

3-69a. Elevation view.

3-69b. Detail of bridge "plaque."

3.3.3 Reinforced Concrete T-Beams

History and Description: Despite the popularity of the cast-in-place flat-slab bridge in some portions of the country in the early decades of the twentieth century, the cast-in-place reinforced concrete T-Beam (or Tee beam) bridge was also widely used. For example, according to *Monuments above the Water: Montana's Historic Highway Bridges, 1860-1956* (*26*, p. 60), the T-Beam bridge was the most common bridge type in Montana between 1912 and 1956.

The T-Beam appeared about the same time as the flat-slab span, and was more economical for lengths in excess of about 25 feet than the concrete arch or slab. The span length of the T-Beam was more limited than arches or trusses, however, and long T-Beam bridges required more supporting piers or bents, thus making the type less economical than competitive types.

When viewed on end in cross-section, the upper horizontal slab (deck section) of this type of bridge constitutes the top of the "T," and the lower vertical section constitutes the stem of the "T." When viewed in side elevation, the lower stem appears as a longitudinal beam supporting the slab (deck). To address tension, steel rods are set in the bottom of the stem or lower section, and steel rods are placed transverse to the stem in the slab section. The rods of the stem and of the slab are usually tied together by U-shaped hangers, making the slab and stem unified structural components of the T-Beam. The slab is therefore an integral part of the beam.

The T-Beam may be constructed as a simple or continuous span, but is commonly found in bridges of no more than 50 feet in length. The period of construction for the T-Beam, matched closely with that of the flat-slab, began in the first decade of the twentieth century and extended into the early 1960s, with a large number built during the 1920s and 1930s.

Prestressed T-Beam bridges are rarely historic age structures, as they were generally not constructed until the late 1950s. A prestressed double T-Beam bridge resembles two capital letter T's placed side by side, when viewed in cross section, and may appear similar to a pre-cast channel beam bridge (without diaphragms) when viewed from underneath. An example is the 1954 Grinell Road bridge listed in the examples below.

Significance Assessment: Reinforced concrete T-Beams are ubiquitous to America's highways and byways – thousands were constructed from the first decades of the 20th century up until the 1950s and 1960s. T-Beams are one of the most common bridge types and were amongst the early forms to be standardized by state highway departments. The T-Beam is of moderate significance within the context of this study. Early twentieth century T-Beams possess significance as early representative examples of the type if they retain integrity. Character defining features that contribute to their integrity include: slab integrated with longitudinal beams, parapet or railing when integrated, and abutments, wingwalls or, occasionally piers.

The most significant T-Beams are early examples of the type and examples built according to early twentieth century state DOT standard plans. Intact examples that have longer than average spans (greater than 30 feet) and those with decorative features such as a balustrade or parapet may also be considered significant.

Examples of Reinforced Concrete T-Beam

1. Little Buffalo River Bridge (1939), Newton County, AR. NRHP listed 1995.
2. Johnson Bridge (n.d.), Walla Walla County, WA. NRHP listed 1982 in Historic Bridges/Tunnels in Washington State Thematic Resource Nomination.
3. Fullersburg Bridge (1924), spanning Salt Creek at York Road, Oak Brook, Du Page County, IL. HAER IL-140.
4. Jones Beach Causeway Bridge No. 1 (1929), Route 908 T, spanning Seamans Island Creek, Hempstead, Nassau County, NY. HAER NY-163.
5. Bridge #1912 (1925), Route 1 across the Appotomax River, Petersburg, VA. Listed as NRHP eligible in *A Survey of Non-Arched Historic Concrete Bridges in Virginia Constructed Prior to 1950* (1996).

Figures 3-70 and 3-71, respectively, illustrate a cross section and photographs of the T-Beam.

Figure 3-70. Section of a T-Beam structure.

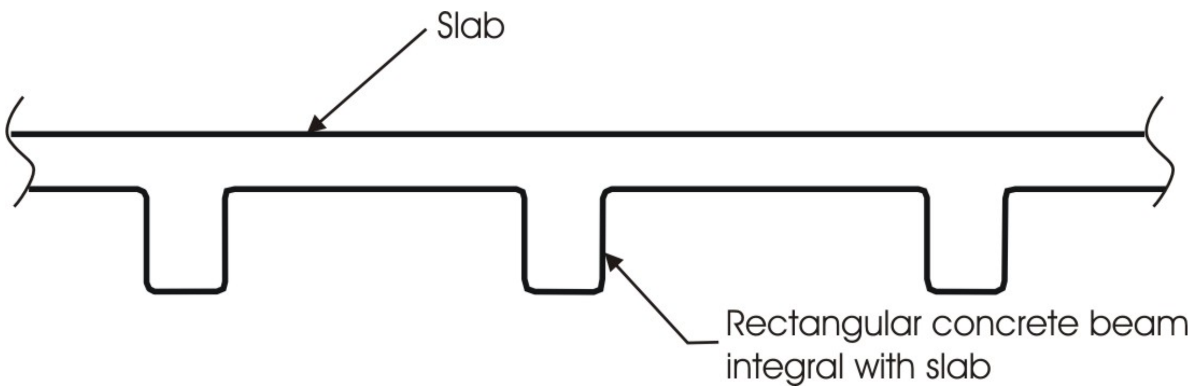


Figure 3-71. Fullersburg Bridge (1924), spanning Salt Creek at York Road, Oak Brook, Du Page County, Illinois. This is an example of a T-beam concrete bridge.

3-71a. Elevation view

3-71b. View of T-Beams on underside of superstructure.

3.3.4 Reinforced Concrete Channel Beams

History and Description: Channel beam bridges have been built since the 1910s, and were a standard type developed by some state highway departments in the second or third decade of the twentieth century. They are most often found in simple-span lengths of less than 50 feet. Channel beam bridges are similar to T-Beam bridges in that the stems of the adjacent channel beams extend down to form a single stem, but this type differs from the T-Beam because there is a full-length seam or joint along the bottom of the stem. Primary reinforcing steel consists of stem tension reinforcement located longitudinally at the bottom of the stem, and shear reinforcement or stirrups located higher up in the stem legs.

Channel beam bridges are usually precast but may be cast-in-place. When precast, the structure may be conventionally reinforced or prestressed. Cast-in-place channel beams usually have a curved under-beam soffit (without diaphragms) constructed over U-shaped removable pan forms, making them appear similar to jack arch deck bridges when viewed from underneath. In Texas, a pan form girder bridge was developed in the late 1940s that also appears similar to channel beam bridges from below, but this type does not have the characteristic seam found in the channel beam bridge. Moreover, channel beam bridges usually have diaphragms, causing them to be called “waffle slabs.”

Assessment: The concrete channel beam is of low to moderate significance within the context of this study. Some channel beams that retain integrity may be considered significant, such as early twentieth century representative examples of the type, those with decorative features such as a balustrade or parapet, or those that can be documented as having been built according to a standardized plans. Character-defining features that contribute to integrity include: deck, longitudinal beams, parapet or railing when integral and abutments, wingwalls and piers.

Example of Reinforced Concrete Channel Beams

1. CR 4048 (Brysonia Road) Bridge (1948), spanning Pleasantdale Creek, Adams County, PA. Determined NRHP eligible as part of state-wide bridge survey.

Figure 3-72 depicts an example of concrete channel beam structure.

Figure 3-72. Bridge on Cannafax Farm Road over Little Potato Creek in Lamar County, Georgia. View of concrete channel beams.

3.3.5 Reinforced Concrete Girders

History and Description: The first reinforced concrete girder bridge was built in France about 1893, and the first of the type constructed in the United States appeared in the first decade of the twentieth century. In the 1910s, several of the early state highway departments issued standardized plans for concrete girder bridges. In 1912, Maryland's State Roads Commission included a design for a girder bridge in their state's first standard bridge plans.

Although the through girder was common from the 1910s to the 1930s, the type is best suited to short spans from 15 to 40 feet and was not economical for wide roadways of more than about 24 feet. Concrete through girder bridges gradually gave way to deck girder designs, as the need for wider roadways increased and concerns about traffic safety rose in the 1930s. In many parts of the country during the 1940s, the use of concrete girders faded in favor of steel I-beam and pre-cast concrete spans due in part to the cost of scaffolding and formwork. But, many of the concrete girder bridges still in service are deck girder bridges built in the 1940s.

Precast reinforced concrete girders were used on a few projects to widen existing cast-in-place concrete girder spans. Another form of the concrete girder is the continuous reinforced concrete girder. These began being used by highway departments in the 1950s, pushing span lengths upward to between 50 and 80 feet. This type of structure was not used after the late 1960s because of the complication of falsework and forms, which increased costs and, usually, increased construction time.

According to the FHWA *Bridge Inspector's Reference Manual* (*23*, p. 7.3.1), reinforced concrete girder bridges (non-prestressed) generally consist of cast-in-place, monolithic decks and girder systems. The primary members of a girder bridge are the girders, the deck, and, in some cases, floorbeams. The deck or travel surface is cast on top of the girders in deck girder bridges, and the deck is cast between the girders in through girder bridges. In either case, the deck slab does not contribute to the strength of the girders and only serves to distribute live loads to the girders. If floorbeams are used, they are part of the superstructure and not the deck. In through girder bridges, the deck is cast between the girders and the girders extend above the deck, thus forming the bridge's parapets. This arrangement of members makes it virtually impossible to widen a through girder bridge. Most of these bridges have now been replaced because their roadway widths were too restrictive for the safety of modern traffic.

A good example of a simple-span concrete through girder bridge from the 1920s is the Main Street-Black River Bridge (1923) in Ramsey, Michigan. This bridge is a three-span configuration, with a 50-foot girder above the waterway and 40-foot girders on either end of the central span. The Michigan State Highway Department first adopted a standard design for concrete through girder bridges in the 1913-1914 biennium. Generally used for span lengths of 30 to 40 feet, this design featured a very shallow floor system that provided a maximum clearance above waterways. The Main Street-Black

River Bridge is somewhat unusual in that most bridges of this standard type were single span structures.

Significance Assessment: Concrete girders possess moderate significance within the context of this study if they retain their character-defining features, which include a monolithic deck and girder system, parapet or railing when integrated (e.g., through girders) and abutments, and floorbeams, piers and wingwalls, when present.

The most significant types of girder bridges are those that retain integrity and that can be identified as having been built according to the standard plans of the transportation departments in the first quarter of the twentieth century; those that were built very early in this type's history—within the first decade of the twentieth century; and through girders, which are not common. The scenic qualities of some of these bridges, e.g., bridges that have decorative features such as railings or balustrades, may also elevate the significance of the bridge. Another type of girder that may have a relatively high level of significance within the girder type is one that can be identified as having been manufactured by one of the precast beam or structural component companies that began to proliferate when highway construction exploded following the Second World War.

Examples of Reinforced Concrete Girders

1. Beaver Creek (Sandy River Overflow) Bridge (1912), Multnomah County; Oregon (determined eligible by SHPO).
2. Main Street-Black River Bridge (1923), Gogebic County, Michigan: (1999, Highway Bridges of Michigan MPS).
3. Monroe Street Bridge (1929), spanning River Raisin at Monroe Street, Monroe, Monroe County, MI, HAER MI-35.
4. Old US-131 Bridge (1929), spanning Big Cedar River, Mecosta vicinity, Mecosta County, MI, HAER MI-113.
5. Bridge No. 5083 (1931), Hwy. 19 over Redwood River, Lyon County, MN. NRHP Listed.

Figures 3-73 and 3-74 depict a drawing and an example of a concrete girder.

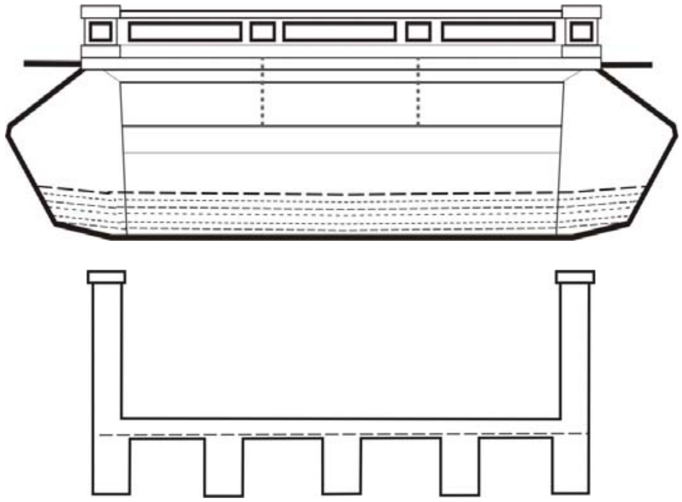


Figure 3-73. Drawings of elevation and section of concrete girder. Adapted from Maryland State Roads Commission's 1919 "Standard Girder Bridges General Plan."

Figure 3-74. Monroe Street Bridge (1929), spanning River Raisin, Monroe, Michigan. This multi-span structure is an example of a reinforced concrete girder.

3-74a. Elevation view.

3-74b. View of piers and underside of bridge.

3.3.6 Reinforced Concrete Rigid Frames

History and Description: The rigid frame was developed in Germany primarily for building construction, but proved so economical that it was adapted for bridges of moderate span and railroad grade separations. It was the last major type of reinforced concrete bridge to be developed. First used in the United States in the 1920s on urban parkways, this type proved ideal for the many grade separations required on freeways following the Second World War. The form was inexpensive, easily constructed, and aesthetically appealing for a standardized bridge structure. Rigid frames brought new economies for span lengths ranging from 40 to 120 feet.

Arthur C. Hayden, design engineer for New York's Westchester County Park Commission, brought the reinforced concrete rigid frame bridge to the attention of American engineers in the early 1920s when he advocated its use for the Bronx River Parkway. According to Plowden (*1*, p. 328), the design originated in Germany, but Plowden follows Condit (*3*, p. 259) in stating that the immediate precedent was probably the work of Brazilian engineer Emilio Baumgart. Whatever his inspiration, Hayden deserves credit for popularizing the type in the United States through publications in technical journals and a widely-read book, *The Rigid-Frame Bridge*, which was first published in 1931, with a second edition in 1940 and a third in 1950. He built approximately ninety rigid frame bridges between 1922 and 1933, and by 1939 there were an estimated 400 rigid frame bridges in the country. The most notable collection of concrete rigid frame bridges (about seventy) can be found on the Merritt Parkway in Connecticut, where the type was used extensively.

Highway engineers developed standard plans with minor variations for skews and curved alignments based on Hayden's design. The bridge is a homogenous unit of beams, slab and walls tapering down to the footing, a form representing a high point of American concrete bridge design. As with the T-Beam bridge, the vertical and horizontal components of the concrete rigid frame bridge are integral, forming one solid cast-in-place structure. The rigid frame bridge can be composed of either a single or multiple spans. The cross sections of the beams or vertical sections are usually shaped like I-beams or boxes, but there can be great variety in shape. In older rigid frame bridges, the vertical beams are often located at the ends of the "slab" or deck component when viewed in cross section. Also in older bridges of this type, the horizontal component is often haunched, and is thicker at the ends than in the middle, thus presenting the image of a shallow arch. A rigid frame bridge, particularly in more modern examples, often looks like an inverted "U," and the legs, or vertical component, are sometimes slanted at a steep angle. In some rigid frame bridges, the deck is supported by a "Pi-shaped" substructure in which the vertical and horizontal components are integral and rectangular in cross section, and separate from the deck or roadway surface.

This type was considered to be an efficient use of material in its time, and was well suited to parkways and other locations where aesthetics were important. It also worked well for river and valley crossings because the horizontal or diagonal (in V-shaped frames) pier sections, when tilted at an angle, can straddle crossings very effectively. The junction of the pier and the beam can be difficult to fabricate, however, and it takes an extensive amount of formwork to erect the rigid frame, which is particularly problematic for river crossings. After the introduction of pre-stressing in the 1950s, the rigid frame span began to lose popularity in comparison to more economical types of reinforced concrete bridges.

Significance Assessment: Rigid frame structures, primarily built between the early 1920s and 1950, possesses significance within the context of this study if they possess their character-defining features, which include a monolithic substructure and superstructure of one continuous fabric, and a parapet railing. 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.

Examples of Reinforced Concrete Rigid Frames

1. Tekamah (City) Bridge (1934), Burt County, Nebraska; listed 1992 (Highway Bridges in Nebraska MPS)
2. Merritt Parkway (1938), Comstock Hill Road Bridge, spanning Merritt Parkway, Norwalk, Fairfield County, CT. HAER CT-88.
3. Davison Freeway (1942), Second Avenue Bridge, spanning Davison Freeway, Highland Park, Wayne County, MI, HAER MI-103D
4. Bridge #1804 (1918), Mary Street crossing Norfolk Southern Railroad, Bristol, VA. Listed as NRHP eligible in A Survey of Non-Arched Historic Concrete Bridges in Virginia Constructed Prior to 1950 (1996).
5. Dodge Street Overpass (1934), over Saddle Creek Road, Omaha, Douglas County, Nebraska. Listed as a "designated historic bridge" at http://www.fhwa.dot.gov/nediv/bridges/histbrdg.htm, "Historic Bridges of Nebraska."

Figures 3-75 through 3-77 present a drawing and photographic examples of the concrete rigid frame bridge.

Figure 3-75. Elevation drawing of a rigid frame structure.

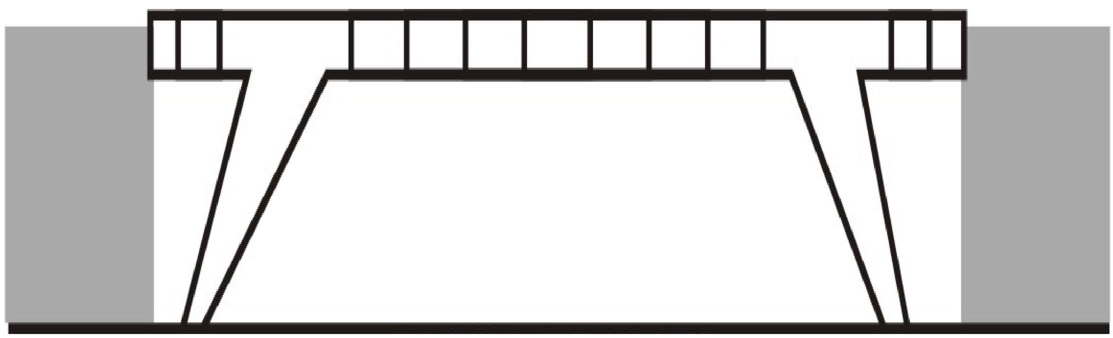


Figure 3-76. Dodge Street Overpass (1934) over Saddle Creek Road, Omaha, Nebraska. This structure was built as part of a federal aid project. Salvaged stone curbing was reused as facing for the structure. (Photograph from http://www.fhwa.dot.gov/nediv/bridges/histbrdg.htm.)

Figure 3-77. Merritt Parkway (ca. 1948), Comstock Hill Road Bridge, spanning Merritt Parkway, Norwalk, Fairfield County, Connecticut. Below is a historic (a) and current (b) photograph of one of the approximately seventy rigid frame bridges on the Merritt Parkway.

3-*77a. Historic photograph of typical Merritt Parkway bridge.*

3-77b. Current photograph of same typical Merritt Parkway bridge.

3.3.7 Reinforced Concrete Precast Slabs

History and Description: A significant population of precast reinforced concrete slab bridges built prior to 1956 exists in the United States.

In discussing the precast slab bridge, the FHWA Bridge Inspector's Reference Manual (*23*, p. 7.7.1) states that "this type of design" acts as a deck and superstructure combined." Individual members are placed side by side and connected together so they act as a single unit. The also states that "precast slabs are different from concrete decks," although the design characteristics are similar, and adds that "the precast voided slab bridge is the modern replacement of the cast-in-place slab." The manual also states "precast slab bridges with very short spans may not contain voids."

Short-span, pre-cast reinforced concrete slab bridges have been built since the first decade of the twentieth century (particularly by railroad companies), but were not constructed in limited numbers for use on highways until after the end of World War II. Information provided by Lichtenstein Consulting Engineers, Inc., indicates that their historians have found that the use of precast reinforced concrete slab bridges was particularly strong in the Southeast after World War II, and they have found that Arkansas, Georgia, Mississippi, South Carolina and Tennessee adopted their own versions of the type from the mid-1940s to the early 1950s.

Precast slabs tend to work themselves out of line laterally because of closed expansion joints over a smooth bearing surface. This tendency can be prevented with a substantial shear key in the bearing surface. The problems of earlier precast concrete slabs have been resolved as resurfacing projects such as the Woodrow Wilson Bridge over the Potomac in Washington, DC, some ten years ago, was resurfaced using pre-cast slabs.

Significance Assessment: The concrete precast slab type was fairly commonly built during the last ten years of the study period covered by this report (through 1955). Early examples of the type are considered of low to moderate significance, while other examples possess low significance. Character-defining features that contribute to the structure's integrity include the slab, parapet or railing, and abutments, wingwalls and, occasionally piers. As scholarship in this era builds, the significance of this bridge type may need to be re-evaluated.

NRHP examples of Reinforced Concrete Precast Slabs

No HAER recorded or NRHP listed examples of precast slabs have been identified. Also, no examples that have been identified as NRHP eligible were found.

3.3.8 Prestressed Concrete I-Beams

History and Description: Eugene Freyssinet (1879-1962), a French engineer, is credited with introducing the prestressed bridge to Europe in the 1940s, after many years of thought and experimentation.

The first prestressed concrete bridge in the United States, however, was not built according to the Freyssinet method. About 1947, an art jury representing the City of Philadelphia began consideration of plans for erection of a prestressed concrete bridge on Walnut Lane, spanning Lincoln Drive and Monoshone Creek in Fairmont Park. A bid based on the Freyssinet system was rejected by the jury for reasons of aesthetics in favor of a design proposed by a Belgian engineer, Gustave Magnel (1889-1955). Like Freyssinet, Magnel had been investigating pre-stressing for many years before designing his first bridge. He founded the Laboratory for Reinforced Concrete at the University of Ghent in 1926, and in 1946 published a seminal work on the subject of pre-stressing, *Practique du Calcul du Beton Arme*, which was published in English in 1948.

Philadelphia's Walnut Lane Bridge (opened to traffic in 1951) features three simple concrete I-beam spans, with the end spans measuring 74 feet, 3 1/4 inches, and the center span measuring about 160 feet. The bridge was actually a collaborative effort among Magnel; the Preload Corporation, a Philadelphia-area company that built prestressed sewage tanks; and John A. Roebling Sons, which developed a high-strength cable for use in prestressing bridge members in 1948. The Preload Corporation was the licensee in the United States for the proprietary Blaton-Magnel anchorage system. Between 300 and 400 engineers from 17 states and five countries watched on October 25, 1949, as Magnel began stressing a test beam to prove that his system, and the cable provided by Roebling Sons, would perform as designed. By the time the beam failed two days later, after loads exceeding the design limit had been applied, Magnel had proved the integrity of his design.

Interest in Magnel's efforts on the Walnut Lane Bridge was widespread in the bridge engineering community, partly because several engineers were already working on the development of standardized plans for prestressed concrete bridges before construction of the Walnut Street Bridge began, and it was not long after its completion that pre-stressing was employed for other bridges. Notable among early proponents of prestressing were Ross H. Bryan (1910-2002), who designed some post-tensioned block beam bridges in Tennessee, beginning about 1950; and C. L. Johnson, who designed prestressed block beam bridges in Michigan about the same time. In 1954 the Bureau of Public Roads, along with members of the concrete industry, developed its *Criteria for Prestressed Concrete Bridges*. Two years later the American Association of State Highway Officials (later AASHTO) developed four standard I-beam sections for use in prestressed concrete bridges.

Prestressed concrete soon became accepted as an effective procedure to increase concrete span lengths up to a length of 130 feet and to control deflections. Emphasis was placed on precast, pretensioned I-beams. Continuous prestressed concrete I-beams were