HISTORICAL DEVELOPMENT: METAL ARCH BRIDGES

Like metal suspension bridges, arch bridges of iron and steel evolved in form from early types built in traditional materials. Metal arch bridges may be usefully classified by degree of articulation (type of pinned connection found at the bridge supports and at its midpoint or arch crown) or by the form or configuration of the arch employed. In a fixed, or hingeless, metal arch structure, the ends of the main spans are embedded in large supports (abutments or piers). When articulated with a pinned connection at each support (a method utilized to allow the bridge some movement under rotational forces), the bridge is a two-hinged arch. When end supports are pinned and another hinge or pin is located at or near the arch crown or midpoint, the structure becomes three-hinged. Rarely built, the one-hinged variant employs a single pinned connection near mid-span at the arch crown.

Three major varieties of metal arch bridge, categorized by type of arch configuration, may be. Solid-ribbed arches are constructed of plate girder ribs cast in a curved form. The deck of such a structure is carried on metal posts resting on top of the arches, or (if the bridge is a through, or bowstring, arch) from suspenders hung from the arch bottoms (Figure 17; Plate 12). Solid-ribbed arches were built in hingeless, one-hinged, two-hinged, and three-hinged variants. By contrast, the brace-ribbed arch features two parallel, or near-parallel, arch chords linked by a system of open webbing consisting of truss members (hence, a second name for this subtype is the trussed arch). Brace-ribbed structures were similarly erected in all hingeless and hinged variants.

The third basic subtype by arch configuration, the spandrel-braced arch, is characterized by the roadway or deck carried atop the arch (hence, these structures are deck arches). The main arch of a spandrel-braced arch consists of its curved bottom members. The roadway is carried on the horizontal top chord, while a web trussing system, typically composed of Pratt trusses, links the top chord to the arch (Pennsylvania Historical and Museum Commission, and Pennsylvania Department of Transportation 1986:93-94).

Adapting the familiar arch form of stone bridges, metal arch technology first developed in England as a result of the mid-eighteenth century advances in the iron industry. The earliest iron bridge in the world, Ironbridge at Coalbrookdale in England, was built in 1781 and consisted of five semicircular cast-iron arch ribs with a 300x150-millimeter rectangular cross section. The eminent American revolutionary writer Thomas Paine designed an iron arch featuring a linked array of block-shaped cast iron voussoirs, but this configuration did not readily attract backers and was not regularly employed. The English pioneer in highway engineering, Thomas Telford, advanced metal arch technology considerably during the late eighteenth and early nineteenth century, with his design and construction of a number of flat (high span-to-rise ratio) cast-iron arches formed by latticed trusses rather than iron voussoirs (Lay 1992:271-272).

Telford's engineering innovations brought the metal arch into prominence in the United States. The oldest extant all-metal arch, the Dunlap's Creek Bridge at Brownsville in Fayette County, Pennsylvania, was built in 1838 under the direction of Captain Richard Delafield of the U.S. Army, who had charge of all construction and maintenance efforts along the National Road east of Ohio. This bridge, which demonstrated the feasibility of using iron in bridge construction, was an 80-foot arch with a rise of 8 feet. The arch was supported on massive sandstone abutments with heavy wingwalls. The bridge as finally erected consisted of a timber plank deck atop stringers and beams which were, in turn supported by means of a latticed frame above five hollow cast iron segmental tubes built up in short lengths and bolted together at circumferential flanges to form each arch (Schodek 1987:79-81).

The Brownsville arch inaugurated the nineteenth century period of construction and experimentation in the metal arch form. As in the case of other metal bridges such as trusses and girder spans, metal arch structures were first built of iron, then were constructed of steel in the late nineteenth century and throughout the twentieth century. A large two-span iron arch bridge (each span 185 feet long) was completed in Philadelphia in 1863 to carry Walnut Street across the Schuylkill River. In 1869, the innovative three-hinged metal arch was pioneered by Pennsylvania Railroad engineer John M. Wilson, in his bridge built to take the railroad over Philadelphia's 30th Street (Pennsylvania Historical and Museum Commission, and Pennsylvania Department of Transportation 1986:95). Five years later, self-trained bridge engineer and Civil War hero James B. Eads successfully erected his monumental Eads Bridge over the Mississippi at St. Louis. Eads's bridge is a fixed three-span metal arch featuring tubular truss-arch ribs; also, it was the first bridge in the world to utilize high-strength steel for structural components (Lay 1992:292).

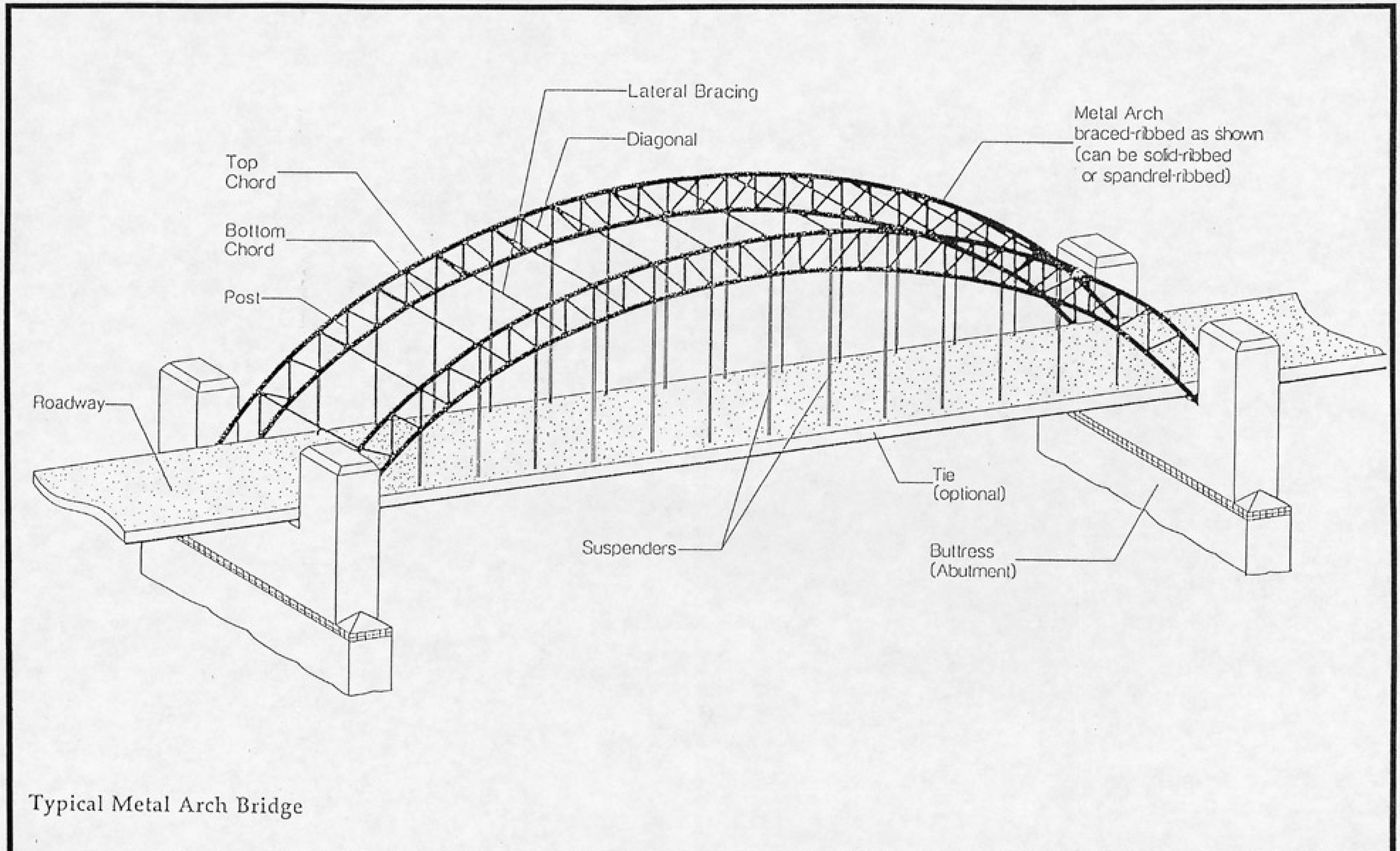

FIGURE 17: Typical Metal Arch Bridge

SOURCE: Pennsylvania Historical and Museum Commission and Pennsylvania Department of Transportation 1986

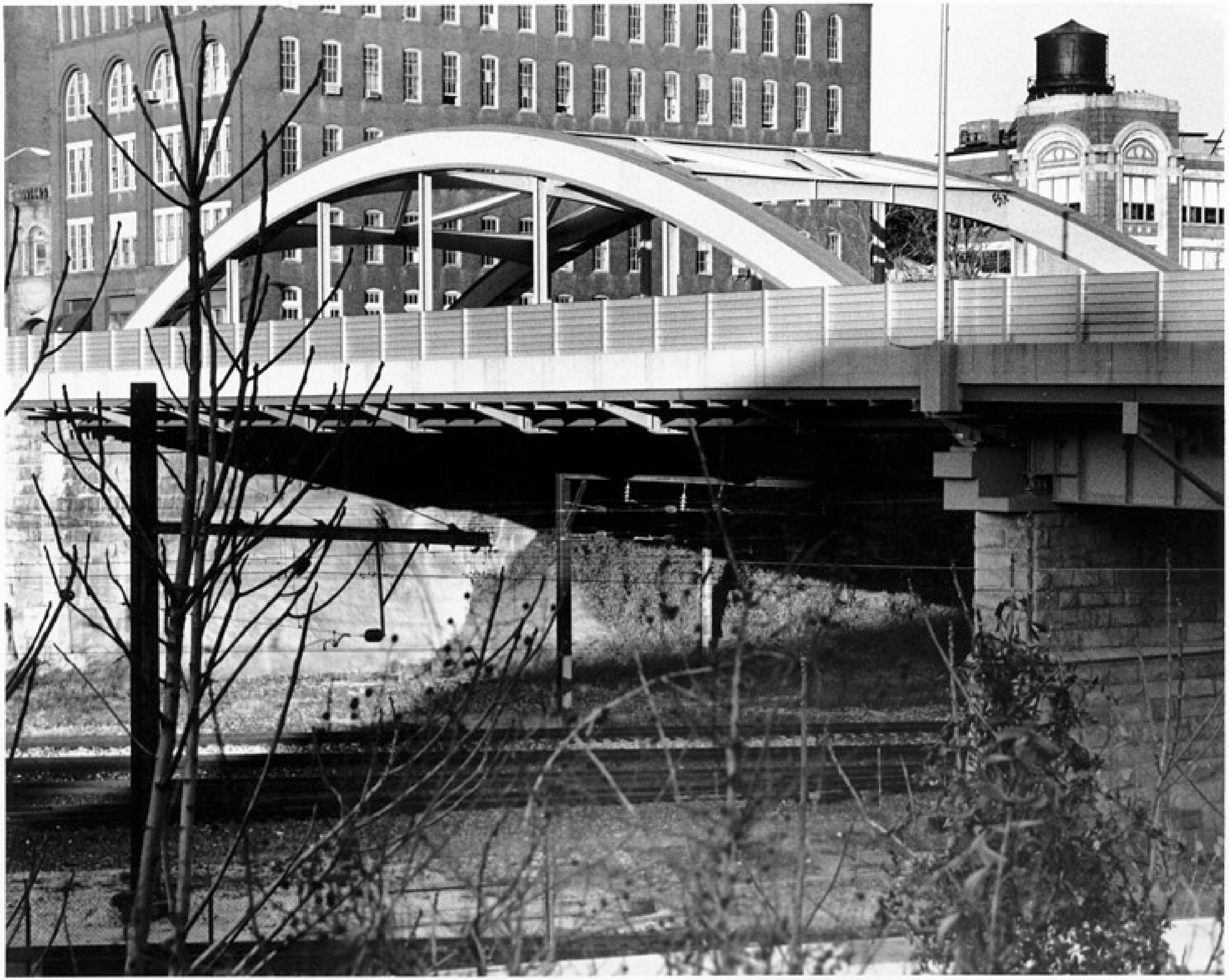

PLATE 12: Typical Metal Arch Bridge: Bridge on Guilford Avenue in Baltimore SOURCE: MDOT Photographic Archives

Bowstring metal arches, in which the arch ribs ascend above the roadway deck, became popular under the impetus of the metal bridge innovations of such engineers as Squire Whipple and Thomas Moseley. Prior to the Civil War, Whipple built bowstring arch bridges over the Erie Canal and patented a design which, though essentially a truss bridge, nonetheless relied on the inherent strength of its arched upper chord (see report section entitled "Metal Truss Bridges" for further discussion of Whipple's work with arch truss structures). Bowstring bridges incorporating features of the metal arch as well as the metal truss were frequently built during the latter half of the nineteenth century by many of the same bridge companies (such as the King Bridge Company of Canton, Ohio) that popularized Pratt and Warren trusses. In most instances, field survey alone can determine precisely whether these structures relied primarily on a truss system for support, they were essentially metal arches utilizing suspended verticals or trusses to support the roadway deck.

By 1890, the three-hinged metal arch had gained general acceptance as a suitable structure for highway bridges. Metal arch bridges in the United States during the late nineteenth and early twentieth centuries were primarily utilized in highway construction, as the railroads usually preferred metal truss bridges to carry the generally heavier loads of locomotives and trains. Perhaps the best known and most significant major metal arch bridge of the early twentieth century is the Hell Gate Bridge, a massive two-hinged through arch designed by master bridge engineer Gustav Lindenthal and built in 1914-1916. Lindenthal's Hell Gate Bridge has a clear arch span of a remarkable 977 feet; the upper chord is curved and is connected to the arch rib by a network of Pratt trusses, which together with the chord serves to stiffen the bridge against traffic and wind pressures (Pennsylvania Historical and Museum Commission, and Pennsylvania Department of Transportation 1986:94-96).

More modest metal arch bridges continued to be built in the United States during the first half of the twentieth century. The aesthetic, classic appeal of the arch form, often a public consideration in design of stone arch and concrete arch bridges, also frequently made metal arches an attractive twentieth century alternative. J.A.L. Waddell in his 1916 *Bridge Engineering* noted that "where steel construction is adopted, attempts are being made to obtain the best possible appearance, either by means of the arch (the ideal solution when practicable) or by polygonal top chords, which tend to produce a graceful effect" (Waddell 1916:16).

In a 1912 article, however, bridge engineer and reinforced concrete arch pioneer Daniel B. Luten cautioned that "in steel bridges, the arch is difficult to fabricate and difficult to erect, and consequently steel trusses and girders have a distinct advantage" (Luten 1912:631). Although metal arch bridges in the modern, automotive era did not attain the general versatility and adaptability of steel girder and reinforced concrete structures, the metal arch form remains a significant

American historic bridge type, displaying a technological continuity of development in the United States similar to that of the more common metal truss bridges.