

HISTORY AND SIGNIFICANCE OF BRIDGE BUILDING TECHNOLOGY IN PENNSYLVANIA FROM THE EARLIEST DAYS UNTIL 1956

Just as Pennsylvania's transportation networks evolved in response to technological advances, the bridges that support canals, railroads, and highways also reflect the advancement of engineering and technology. As one of the most heavily travelled states in the nation, the demand to meet the ever-increasing traffic volume placed Pennsylvania in the forefront of development and application of innovative bridge technology and transportation engineering. From the 18th-century stone arch bridges on the great roads and the America's first cast iron bridge built at Brownsville in 1839 to America's first prestressed concrete bridge in 1950, the evolution of bridge engineering and the impact of technology on social and economic history is well chronicled by the assemblage of historic bridges that survive within the state.

The technology context will serve to show which applications are historically and technologically significant in Pennsylvania and in relationship to the rest of the nation.

I. MASONRY ARCH BRIDGES

Stone Arches

The earliest extant bridge type in Pennsylvania is the stone arch. The arch is curved construction with the convex side upward consisting of shaped blocks called the arch ring that compress together under vertical loads. To work, the outward thrust at the base of the arch must be countered by abutments. Regardless of size, the principle behind the arch remains the same; the vertical forces have to be balanced by equal reactions at the abutments.

This was the technology that settlers brought to this country, and it is well represented in the state. The earliest stone arch bridge in the state is documented to 1697 with five more dating to the end of the 18th century. Extremely common in the southeastern part of the state, there are over 350 stone arch bridges surviving with about a third of them being from the 20th century.

The earliest stone arches are laid up in rubble coursed fieldstone and finished with parapets that match the spandrel walls. Toward the end of the 18th and into the 19th century, the ring stones were matched and gauged, and in the 19th century, the spandrel walls are often laid up in both coursed and random ashlar (cut rectangular blocks). The arch rings themselves could be of several geometric shapes from semicircular to segmental, but regardless of the shape, the principle behind the masonry arch is the same.

Use primary and secondary research to develop how and by whom the 19th century

stone arch bridges were being built and how this factors into overall significance.

Use of stone arch technology into the 20th century.

Brick Arches

The brick arch utilizes similar engineering principles and method of construction as the stone arch, but the main material of the arch is several layers of mortared brick. Built primarily during the last quarter of the 19th century, brick arches, like other arch bridge types, are constructed with falsework and earth fill. They are finished with stone spandrel walls and parapets like those used for stone arch spans. The reason behind the frequency of the bridge type during the 1870s and 1880s is based in part on improvements in both bricks and artificial (Portland) cement mortars, availability of those materials, and ease of erection when compared to stone arches. Additionally, metal truss bridges had not yet completely come to the fore as an alternative technology for highway applications, making brick arches one of the few alternative technologies to stone arches. There are 24 brick arch bridges surviving in the state dating from 1864 through 1908.

II. TRUSS BRIDGES

The modern era of bridge technology in this country was ushered in about 1800 when the truss was applied to building longer-span bridges. Until that time, bridge technology was limited to stone arches or wood beam structures. While the truss (a triangular shape in which the diagonal members transfer vertical forces in a horizontal direction) was known since at least the third century B.C., what was innovative at the beginning of the 19th century was that the basic truss pattern was multiplied many times over to span much greater distances than those possible with timber-beam or king- or queen-post bridges of the 18th century. Truss types and designs vary according to the configuration of the members. There are three truss types. In the thru truss design the road passes between the truss lines and is carried on floor beams connected to the bottom chords. There is lateral bracing connecting the top chords of the trusses. This type is generally used for longer spans. A pony truss bridge is the same as a through truss, but it does not have lateral bracing between the top chords. This type is generally used for shorter spans. In a deck truss bridge the road is above the trusses and the deck system is on the top chords. The various truss type designs are different ways of accommodating the tension and compression forces, and they are frequently named for the engineer that patented the design such as the Pratt truss patented by Thomas C. Pratt in 1844.

Wood Truss Bridges

The need for heavy bridges of sufficient length for long waterways stimulated the burgeoning of bridge engineering during the late 18th century. By 1800 master carpenters/architects were using timber and the truss and arch principles to span greater lengths. Many of the early, impressive examples of wood truss bridge technology were built in Pennsylvania, including Timothy Palmer's 1806 Permanent Bridge

over the Schuylkill River and his 1807 bridge at Easton. Palmer's arch truss designs show the influence of Andrea Palladio, but those of Harrisburg's Theodore Burr reflect innovative thinking about stronger and longer spans. His loads were divided between the main member, a truss with parallel chords, and an arch. The arch truss was used with great frequency through the first half of the century.

Another significant innovation in the application of truss technology to bridge design was noted American architect Ithiel Town's lattice truss design. Patented in 1820, the truss with a closely spaced array of intersecting diagonal members forming a web between parallel chords has no verticals or posts. It was easy to fabricate and erect, and the simple design could be repeated for any designed length. The Town lattice truss was immensely popular and was used on local roads as well as railroad bridges.

As significant as its contribution to the history of bridge technology in Pennsylvania, the wood truss bridge type was not without inherent weaknesses that eventually made it defunct as stiffer, stronger bridge types requiring much less maintenance were developed. Wood truss bridges were particularly vulnerable to washout from floods or freshets. They were also susceptible to fire, from both locomotives and carelessness, insect damage, and moisture-related deterioration.

The most significant factor in the disappearance of the wood truss bridge from Pennsylvania's highways and byways in the late-19th century was the development and acceptance of metal truss bridges, which started in the state in the late 1850s. Wood works well in compression, but it cannot accommodate tensile forces efficiently, especially their connections. This limitation was resolved by William Howe (1803-1852) who, in 1840, patented a truss bridge design that used wrought iron rods for the tension members (posts) and wood for the bulkier compression members and top and bottom chords. His design with the iron tension rods heralded the beginning of the switch from wood to metal truss bridge technology.

Metal Truss Bridges

The most dramatic and far reaching advance in truss bridge design was the introduction of metal into truss bridges. In the 1840s American bridge designers and builders began to experiment with substituting wrought and cast iron for wood for both compression and tension members. Cast iron, due to its brittleness was used for compression members. Wrought iron possesses good tensile qualities, and William Howe, Thomas Pratt, Squire Whipple, and others all patented historically and technologically important truss designs utilizing these qualities. Their truss designs ushered in an era of unprecedented advancement in metal bridge technology that was both a product of and a response to industrial advancement in this country.

Pennsylvania became a microcosm of the national development and application of metal truss bridge technology in large part because it had to keep pace with the demands of its industrial development. The movement of coal from the anthracite coal fields in eastern Pennsylvania to the New York market put a strain on the state's transportation networks. Just as railroads made the 19th century the age of iron, they also made metal truss bridge technology a necessity (Condit, p. 103). By the 1880s, metal truss bridges, introduced less than 40 years before, had become an integral part of America's transportation networks.

The era of metal truss bridges also ushered in new scientific methods for analyzing and predicting the structural action of bridges. Squire Whipple's A Work on Bridge Building (1847) and Herman Haupt's General Theory of Bridge Construction (1851) were among the first treatises to apply mechanical and mathematical principles to stress analysis, truss design and construction. Although Whipple and Haupt attempted to place bridge building on sound theoretical grounds, most antebellum bridge builders continued to work within the craft tradition of empirically derived knowledge. After the Civil War, advances in engineering education accompanied new standards and understanding of materials, workmanship, and construction. A generation of college-educated civil engineers applied scientific theory and experimentation to bridge construction and energetically sought out the cooperation of manufacturers and builders. They established the modern approach to bridge building that includes stress analysis, plans, specifications, testing, and inspection (Condit, pp. 115, 139-140; Plowden, pp. 62-63).

Influence of the Railroads

It was the growth of railroads in the 1840s and 1850s that more than any other factor prompted advances in metal bridge development. Much of that growth was on the east coast in general and Pennsylvania in particular, owing to the state's location on the direct route between Eastern Pennsylvania and New York. As the size and weight of locomotives and rolling stock increased through the 19th century, the need for stiffer, stronger bridges forced railroad bridge engineers like Squire Whipple, Wendell Bollman, and Francis C. Lowthorp into a period of dramatic technological experimentation and advancement that resulted in a variety of truss designs in cast and wrought iron.

Examples of first-generation metal truss railroad bridges that illustrate this period of experimentation and transition are rare because subsequent technological advances rendered them obsolete. Between 1890 and 1910, most were replaced by stronger spans. An important survivor from this era is **examples to be identified and described**. It was moved to its present location and converted to highway use. Its history illustrates both the evolution of metal truss bridge design during the third quarter of the 19th century and how metal truss technology moved from railroad to highway applications.

Other important early metal railroad truss bridges that survive in a highway application include the **examples to be described**. All are significant remnants from the early days of the development of the metal truss bridge type.

Transfer of Railroad Bridge Technology to Highway Applications

The history of the Phoenix section illustrates how technology and refinements developed by and for railroad applications were transferred to highway spans, a practice that began in Pennsylvania in the late 1850s. Patented in 1862 by Samuel Reeves, president of the Phoenix Iron Company, the Phoenix column is a built-up wrought iron circular section that is stronger and more economical than its cast iron equivalent. Developed at a time when empirical formulae for columns were in their infancy, the section proved to be a stable compressive

building block that did as much as any detail to advance the promulgation of metal truss bridges for railroad use because it was economical and not prone to failure. The Phoenix Iron Company was so successful selling bridges with its proprietary section to the railroads in the 1860s and 1870s that it virtually ignored pursuing the highway bridge market. But when the Phoenix-section bridge could no longer provide the strength and stiffness that the railroads were increasingly demanding in the early 1880s, the technology was successfully redirected by the company to the highway bridge market with its lighter load requirements.

As a result of the change in application of the Phoenix section, all of the approximately 14 Phoenix section bridges in the state were built as highway spans, and about 11 of them were erected after 1884. The earliest Pennsylvania highway application of Phoenix sections appears to be two bowstring truss bridges in Crawford and Lehigh counties.

Another significant group of truss bridges that chronicle the evolution of metal truss bridges for highway applications are the early cast and wrought iron bridges fabricated in the 1860s and early 1870s by craftsmen engineers like Charles Beckel, a skilled foundryman from Bethlehem. The rare surviving examples of early patented designs like his ca. 1860 Walnut Street Pratt through truss bridge at Hellertown and the nearby ca. 1870 Old Mill Road bridge, a Pratt pony truss, are nationally significant in that they represent period thinking about metal truss bridges and chronicle the evolution of type. The Walnut Street bridge, the oldest documented non-railroad metal truss bridge in the country (DeLony 1993, p.38), incorporates construction details patented by bridge engineer Francis C. Lowthorp of Trenton, New Jersey. The collaboration between the foundryman, who cast the myriad of component members like the connecting pieces, and the engineer designer who was working out details and means of transferring stresses in a scientific manner, characterized the earliest days of metal truss bridges before standardized designs and members. The Walnut Street bridge has cast iron floor beams, a detail used commonly on railroad bridges of the day in Britain, and Lowthorp's "straining plate" lower panel point connection detail that he patented in 1857 and 1860. The plate through which the threaded ends of the lower chord rods pass was cast integral with the floor beams thus allowing the members to act as one rather than two separate units. The detail anticipates the rigid connection (rivets and gusset plates).

Other significant examples of early patented truss bridge designs and/or details include ... **This section will be greatly expanded as field inspections identify other early highway cast and wrought iron bridges.**

The application of metal truss bridges to highway use was generally not as early, quick, or crucial as with the railroads, but county commissions and private bridge companies were receptive to following the lead of the railroads. **Primary and secondary source material will be used to outline when and how counties/municipalities began utilizing metal truss bridge technology. It is presumed that the histories of some of the in-state bridge companies, like Keystone in Pittsburgh and Cofrode and Saylor of Philadelphia, will be technologically significant.**

The last quarter of the 19th century was the halcyon era of the metal truss bridge in America. During this

period bridge designs tended toward greater uniformity and standardization because of advances in understanding of engineering principles enhanced by experience, better metallurgy, and refinements in the fabricating process. Introduction in this country of the Bessemer process of making steel in 1868 made the material that works well in both tension and compression an increasingly reasonably priced option for bridge components. In the 1890s, the advantages of open hearth process steel for structural shapes came to the fore. In the majority of truss bridges built after 1895, basic open hearth process steel replaced wrought iron and Bessemer process steel as the material.

Discussion of standardized detailing of members and how common they became based on field inspection findings. Emphasis will be placed on identifying innovative or retardataire details that add significance, like cast connections for end posts and top chords, unusual bearings, or panel point connections.

The Pratt truss designs emerged as the most popular of the myriad of pin connected truss configurations because of its simplicity of design and economy of fabrication and erection, especially the use of eye bars to facilitate field connections. In addition to providing the long-sought after "stiff truss," composed of standardized members, made by building up standard shapes like rolled plate, angle, and or channels, eliminated the need for expensive custom cast iron components.

From the perspectives of quantity and variety of truss designs, Pennsylvania possesses an exceptionally rich and well preserved assemblage of 19th century, pin connected, metal truss through or "high" truss highway bridges. Those that exhibit innovative or distinctive detailing and are thus significant in the evolution of truss bridge technology include **Totals by type and design will be followed by specific examples.**

Pony truss bridges, those with shallower truss depths for shorter spans and thus no upper bracing between the top chords, were common by 1890. The standardization of truss members and the proliferation of bridge fabricating companies in Pennsylvania and throughout the northeastern portion of the United States, especially Ohio, made these bridges readily available. The bridge type was wholeheartedly embraced by county officials in the mid 1880s as an economical and low maintenance alternative to masonry arch and timber spans, and they were built in great numbers. As with thru truss spans, the Pratt design proved to be the design of preference, and over 150 Pratt pony truss bridges survive.

Several of the more noteworthy examples of the pony truss type in Pennsylvania have distinctive details that reflect the experimentation inherent in some early bridges... .

Most metal truss bridges built before 1895, from light Pratt pony trusses to heavier Parker through truss railroad spans, were assembled in the field (at the site) with pinned connections. The reasons for the use of the pins (circular bars with threaded ends which were passed through the individual components) were several including the ease of erection and the use of forged wrought-iron eyebar diagonals and bottom chords in Pratt-design trusses until nearly the end of the century.

In the mid- to late-1890s better knowledge of the strength of materials and metallurgy combined with the improvement of field pneumatic riveting led to the transition from pinned to riveted connections. The adoption of riveted field connections resulted in a rapid shift from the Pratt to almost exclusive use of the Warren truss design by the 1910s. Patented in 1848 by British engineers James Warren and Willoughby Monzani, the straightforward truss is particularly well suited for rigid connections. It is distinguished by its simplicity of design, ease of construction with equal-sized members, and ability of some of the diagonals to reverse stresses. Capacity could be increased by adding a second set of diagonals (double intersection Warren) or by the addition of verticals.

Warren pony trusses, which came to dominate after 1900, are among the best represented of all the metal truss bridge types and designs in the state. There are over 125 surviving examples with about 12 of the total dating to before 1900.

The construction of metal truss bridges peaked during the first two decades of the 20th century. Their decline in popularity, just like their rise to prominence, was based on technological advances of other bridge types, particularly steel stringers, steel girders, and reinforced concrete spans. Those new technologies proved to be more economical and required less maintenance than metal truss spans. They quickly gained favor during the first two decades of the 20th century when the state was developing and improving both its farm-to-market and rural delivery road systems as well as early state highway systems.

Pony truss bridges using electric arc welding to connect the rolled section members were built on county roads starting in the mid 1930s. Developed in Europe in the 1880s, electric arc welding is thought to have first been done in this country by Baldwin Locomotive (Ridley, Pennsylvania) in 1902. It also became a common repair technique for bridges during the 1930s. Application to other bridge technologies, however, was limited until after World War II, when welded bridges, especially girders and beams, became the rule rather than the exception. **Examples will be cited and explained.**

Deck Truss Bridges

Although not nearly as common as the thru and pony types of truss bridges, the deck truss, where the roadway is supported on top of the truss, is represented within the state's population of metal truss spans. Deck trusses are used when clear spans exceed 80'-100' when there is sufficient vertical clearance to allow the bridge to be below the roadway elevation. In the 20th century, the deck truss type was commonly used for approach spans for major crossings. It is also not uncommon to have cantilevered deck truss approach spans.

Examples and significant detailing will be described, starting with pin-connected examples.

Cantilever Truss Bridges

A significant 20th-century innovation in truss bridges is the design and construction of cantilever spans, epitomized by the **example(s) to be identified**. The development and refinement of the cantilever span type as represented by the ? reflects the late-19th and early 20th centuries as both understanding of materials and empirical formulae.

Rather than each span resting or bearing independently on its piers or abutments, the cantilever truss is continuous over its supports, where it is deeper to resist bending stresses (moments). The cantilever truss thus provides for longer clear spans between supports and at the same time ease of construction as the span between the cantilevered sections is "dropped in". While the cantilever truss bridge was known in the late-19th century (1895-1896 Northampton Street Bridge over the Delaware River between Phillipsburg, NJ and Easton, PA owned by the Delaware River Joint Toll Bridge Commission), it was not until after World War I that the long-span thru and deck cantilever truss bridges came into their own.

Based on field inspection findings, the section will be expanded and examples will be used to bring use of the design up to 1956. The type was used with great frequency in Allegheny County.

III. METAL ARCH BRIDGES

Contemporary with the advent and refinement of the metal truss bridge was the metal arch bridge. In fact, the oldest metal bridge in the country, the Cumberland Road over Dunlap's Creek at Brownsville, is a cast iron deck arch dating to 1839. The design of the bridge, composed of over 500 individual castings, was expensive in comparison with other period technology and was not used for short span bridges.

Metal arch bridges can be deck arches or thru arches. Thru arches can have the thrusts countered by the abutments/piers, or they can be tied. In a tied arch, the horizontal thrust is taken by longitudinal beams, which are in tension. Vertical thrust is carried by the abutment/pier. The advantage of the tied arch is that the abutment/pier is smaller, which was a consideration when the 1930-1932 West End-North Side Ohio River bridge at Pittsburgh was designed. The McKees Rocks Ohio River steel arch bridge, also designed by V.R. Covell of the Allegheny County Department of Public Works and built at the same time, is not tied and is based on Gustave Lindenthal's 1914-1916 Hell Gate bridge over the East River at New York. The deck of the two-hinge arch is suspended from the lower arch rib that takes the full compressive stress.

The advantages of metal arch bridge technology for long span bridges was dramatically and elegantly illustrated by James B. Eads 1868-1874 Mississippi River bridge at St Louis. Each of the three hingeless arches has a 500' clear span, and although the bridge established the technology as viable, it was the three hinge (at the end points and in the middle to accommodate rotation) design introduced in this country by Pennsylvania Railroad engineer Joseph Wilson that led to its widespread adoption. The hingeless metal

arch is statically indeterminate while the 3-hinge arch is determinate. This meant that the arch could be less deep and could be asymmetrical if needed.

The three hinge steel arch offered greater and more aesthetic possibilities than the hingeless arch bridge. A classic example of the technology is H. B. Rust's 1896-1897 Panther Hollow Bridge at Pittsburgh. It is located in the National Register-listed Schenley Park Historic District. The parabolic arches have trussed webs and have a lightness and unobtrusive quality that is characteristic of the "superior appearance" of the bridge type. To Carl Condit, the Panther Hollow bridge represents "the culmination of thirty years of progressive development in the arch, and there are few structures of this kind that can match it." The technology was used through the 1950s in Allegheny County.

The 1986 survey includes bowstring arch-truss bridges under the metal arch category. This context will do the same. It is assumed (hoped) that examples will be identified.

Description of the evolution of the type and various designs. Narrative will emphasize their contribution to the evolution of metal bridge technology and why they were eclipsed in popularity by other designs.

IV. CONCRETE BRIDGES

Concrete, composed of sand, gravel, or other aggregate held together by a hardened paste of natural cement and water, has been known since Roman times, but it was the 1813 perfection of Portland cement, an artificial hydraulic cement, that helped concrete come to the fore as a modern building material. Portland cement, noted for its strength and abrasion resistance, was developed in England. Initially it was very expensive, and as result of the cost, its use in this country was limited. In 1871, David O. Saylor was granted a United States patent for the manufacture of artificial cement, and this breakthrough gave great impetus to the experimentation and usage of the material in a variety of building applications. The earliest use of the material, which has good compressive strength but little tensile strength, was for building footings and walls (Condit, pp. 224-227).

Reinforcing plain concrete with internal metal (either rods or mesh) was developed in Europe in the mid-19th century and then experimented with in this country by farsighted engineers like Ernest L. Ransome and Edwin Thacher. While most American engineers were familiar with a combination of concrete and reinforcing by about 1870, it took another 30 years of experimentation and theoretical and empirical investigations before engineers and builders had a mature understanding of the capabilities and versatility of the material (Condit, p. 232). During this period of experimentation, types of reinforcing systems and designs of reinforcing bars were developed. Engineers were even uncertain what to call the new hybrid. Names included ferro-concrete, concrete-steel, and armed-concrete before reinforced concrete became the standardized terminology about 1905.

Several types of bridges can be built with concrete; T beams, channel beams, slabs, thru girders, through

arches, open spandrel arches and closed spandrel filled arches. T beam, channel beam and slab bridges can be both cast-in-place or precast and then assembled at the site.

The earliest reinforced concrete bridges built in this country were closed spandrel, earth-filled arches dating to around 1890. It was also used for bridge substructures. The technology did not begin to seriously challenge metal truss bridges in Pennsylvania until the very end of the 19th century with the earliest in-state example being the ???.

Any identified applications of unreinforced concrete will be described.

Early Reinforced Concrete Bridge Technology

One of the earliest reinforcing systems applied to arch bridges was developed in 1861 by a Parisian gardener named Jean Monier, who used wire mesh nets embedded in the concrete for making stronger pots and tubs. His single-net concept proved insufficient for handling the tensile stress introduced by live loads, so a second net near the surface of the extrados was added to provide the tensile capacity needed at the outer limits of the arch ring. Over time this system proved less than satisfactory as the mesh was difficult to work with, and the transverse wires of the mesh took no stress making them an expensive but useless detail. Despite these and other weaknesses, the detail was successfully employed in early concrete arch bridges in Europe and this country.

The Monier system was used in Pennsylvania through at least 19??. **Examples and descriptions to be cited.**

Of greater influence in promulgating reinforced concrete arch technology is the Melan design. Invented in 1892 by Austrian engineer Josef Melan and patented in this country in 1893, the design utilizes steel beams (bowed I-beams for shorter spans and bowed lattice web girders for longer ones) embedded in concrete. Really more a steel arch with concrete encasing than a true reinforced concrete structure, the Melan system was able to support greater capacity for longer span lengths than the Monier system. **Examples and descriptions to be cited.**

By 1906, the reinforcing system had been eclipsed by designs based on Ernest Ransome's late 1880s scheme of using reinforcing bars distributed only in the tension zones (Ransome received a patent for the commonly used square twisted reinforcing rod in 1884) (Loov, p.68). After 1905, reinforced concrete arch technology became commonplace **totals will be added**. They are primarily spans of less than 60' long and finished with concrete spandrel walls and parapets. Reinforced concrete arches proved to be an economical, more rigid, and relatively low maintenance alternative to metal truss spans.

Part of the reason for the rapid acceptance and application of the technology is that the material was also being used for a variety of structure types, like buildings, railroad ties, piers and bulkheads, and even ships, and the knowledge transfer benefitted all. Additionally, individual promoters and companies such as Daniel Luten and the Corrugated Bar Company published "how-to" brochures on reinforced concrete bridges using

their designs, calculations, or reinforcing bars. In the era before the consulting engineer and a professionally trained county engineer and staff, such promotional literature did much to spread information about the advantages of reinforced concrete bridges.

Significance of Daniel Luten and his companies and successors in building reinforced concrete bridges in the state. Diehl and Whittaker, who built many bridges in the eastern part of the state in the 1910s and 1920s were once associated with Luten. Early examples of their work have been identified, and the findings/conclusions of Luten's significance will be summarized.

Evolution and significance of deck arch type and identification of details/features that are technologically significant. Specific examples will be cited and described.

The state highway department favored the semicircular arch for both culverts (less than 20' clear span) and bridges because of its adaptability to differing field conditions and loading" (ENR, 1944). It was also economical to maintain and provided a pleasing appearance. Adopted as a standard design in the late 1910s, the semicircular arch was used for clear spans from 6' to over 69' and was finished with just a head wall -- no railings. The roadway could be carried near the crown of the arch, in the deck arch design, or on fill well above the crown. The design was used by the Department with virtually no changes into the 1950s.

Open Spandrel Arch Bridges

The development of reinforced concrete technology came to a graceful yet powerful culmination about 1907 in the open-spandrel arch bridge, which efficiently combines the compressive ability of concrete with the tensile capacity of steel reinforcing. The type can have a continuous arch ring across the width of the bridge or individual ribs, which results in further economy of material. Both designs are finished with spandrel columns to support the deck. Open spandrel arch bridges were used throughout Pennsylvania for long-span crossings and viaducts with great frequency during the 1920s-1950s. There are over 75 surviving examples in the state.

Examples from Walnut Street in Philadelphia and Campbell's bridge in Bucks County will be described to illustrate the application of the technology to short and long spans in the state.

Description of how post-World War II applications of the technology are different. At this point, they do not appear to be different.

Slab

Late 1890s advancement in the understanding of reinforcing placement to accommodate tension and shear forces resulted in reinforced concrete being used more frequently for slab, T beams and girder bridges early at the turn of the 20th century. The appropriateness of one bridge type over another was predicated on several

factors, such as length of span, roadway profile, and economical use of steel. While all four reinforced concrete bridge types are represented in the state, the T beam and slab types were the most popular. Both were adopted as early state standard designs and were used with great frequency in the 1920s and 1930s all across the state.

The State Highway Department and county engineers used the slab bridge type for spans up to about 35', and the bridge type is present in nearly every county in the state. An early state standard design, examples from the 1910s and 1920 are generally finished with paneled parapets and flared lower parapets that protect the blunt ends of the bridge from impact. Slab bridges generally have a concrete substructure.

World War II proved to be a watershed in precast concrete bridge construction. The desirability of using precast concrete over structural steel or cast-in-place concrete construction for short-span bridges became by the mid-20th century a matter of economics rather than technological development. Following the war, the federal and state government redoubled their efforts to improve the nation's highways with massive infusions of aid, not only for state and federal highways as had been the practice in the past, but also for secondary and local road systems. The expanded highway program in combination with rising costs and shortages of structural steel, as well as increasing labor costs, prompted state highway departments to seek out the most economical means of building large numbers of bridges for small streams on secondary roads. In 1953 Mr. E. L. Erickson, Chief of the Bridge Branch of the Bureau of Public Roads (BPR), came out in favor of expanded use of precast concrete because of the savings in forms and falsework, elimination of on-the-job labor, speed of construction, better maintenance of traffic flow, and closer control of concrete mix, placing, and curing obtained through factory operation. The large federal and state contracts encouraged the establishment and growth of concrete casting companies with investment in the types of equipment such as heavy-duty rubber tired truck cranes necessary for precast bridge construction (Erickson 1953: 40-43; Fraser 1957: 27-37).

Several precast designs were developed and used extensively by the counties and the state immediately following the war. Some of the designs such as the precast channel beam are still being used. The precast designs illustrate that Pennsylvania was very much in step with national trends in the late 1940s and early 1950s. One of the salient characteristics of concrete is its moldable qualities, and this stimulated thinking about precast bridge components that could be fabricated off site under controlled conditions, shipped to the site, and then quickly hoisted into place.

Channel Beam

Channel beams are precast members consisting of a three to four feet wide slab between two legs. The channel section resembles a T beam bridge because the legs of adjacent channel beams are connected and appear as a single stem. The primary reinforcing steel is located in the bottom of the channel leg and is placed longitudinally, and both sides of the leg have stirrups. Curbs are cast integral into the exterior units, and any additional railings are attached to them.

The panels are suitable for spans up to 35' in length, and the individual beams are bolted together to act as a unit. The diaphragms provide lateral bracing for each beam with a full-depth diaphragm generally used for H-20 loading and a half depth diaphragm used for H-15. The advantages of the design are common with other precast structures; economical to produce, economy of material, and ease of erection. The design is still being used, but its heyday was the 1950s and 1960s.

T Beam

The T beam, where the cast-in-place longitudinal beam and deck section are integrally connected, is a more efficient use of material than the slab design. T beam design proportions the deck thickness and longitudinal beam size and spacing to achieve a lighter, stronger, and more economical section. Basically the same T beam technology was used extensively by both the State Highway Department, which developed standard designs for T beam bridges, and the counties from the late 1910s through the 1950s, making it one of the most common bridge types in the state. T beam bridges are supported on both ashlar and concrete substructures and are usually finished with concrete balustrades or parapets. There are over 2,300 T beam bridges in the state with the vast majority of them being simply supported.

Thru Girder

Another common 1910s and 1920s reinforced concrete bridge type is the through girder. It is composed of cast-in-place longitudinal beams and transverse floor beams that are connected by the arrangement of the steel reinforcing wires. The concrete deck is poured separately. Reinforced concrete thru girder bridges are finished with paneled parapets similar to those used on early slab bridges. While scattered throughout the state, they were commonly used in Lancaster County where over 26 examples built before 1925 survive. The bridge type represents the experimentation that characterizes the early days of reinforced concrete bridges. Since the railings are cast integral with the superstructure, it is not possible to widen the bridge.

Rigid Frame

The rigid frame bridge, where the top member and the verticals are integral, remains one of the most efficient uses of both steel and concrete. The monolithic construction was initially applied to short-span slab-like bridges with a low rise in the 1920s. The larger examples, like those used by the Pennsylvania Turnpike Authority for overpass bridges, shares the efficiency of the smaller examples, but they require expensive and restrictive form work to erect. The bridge type is capable of spanning greater lengths than a slab bridge. The telltale detail that usually distinguishes a rigid frame span from a slab is the arch soffit of the rigid frame that provides strength at the knees. The rigid frame bridge type was developed in Europe during the last part of the 19th century, but it was not utilized in this country for overpasses until the 1920s on the Westchester County (New York) parkways.

Prestressed and Post Tensioned Concrete Beam Bridges

Pennsylvania was the national leader in the bridge application of the European-developed prestressed concrete, a reinforced concrete that is internally stressed to overcome the tensile stresses from bending caused by load. Two methods are used to produce prestressed concrete; pretensioning and post-tensioning steel strands. Pretensioning is the application of a controlled force to the concrete member through its reinforcing before the concrete has set, and the set concrete hold the tensioning. Post-tensioning means that the load is applied by stretching (done by jacking) the reinforcement after it has set.

Post-tensioning was popularized by French engineer Eugene Freyssinet, who began using high-strength steel wires for reinforcement in 1928 and is considered the father of modern prestressed concrete. The advantage of prestressing is that it addresses the inherent weakness of concrete, which is poor in tension, and produces a substantial increase in the strength of the concrete member as compared to that of a similar non-prestressed member thus resulting in a smaller member. By combining the precompression of the concrete with pretensioning and predeflection of the steel, it is sometimes possible to reduce the weight of a member to little more than half that of its standard reinforced equivalent (Condit, p. 188). Additionally, pretensioning of the steel means that it cannot elongate under normal loads and the concrete is thus immune to cracking and to secondary stresses.

Although prestressing was first used in this country by the Preload Corporation, who used specially design equipment to impose tension for large circular tanks and pipes, it was Philadelphia's 1949-1951 Walnut Street bridge that inaugurated the modern prestressed concrete industry in the United States (Jester, p. 115). The bridge was the first linearly prestressed structure in the country. Interestingly, the 160'-long beams were fabricated by the Preload Corporation, and Prof. Gustave Magnel of the University of Ghent in Belgium, originator of the post-tensioning system with saddles to separate and carry the wires and wedges to anchor them, was hired by Preload Corporation as the consulting engineer. The Walnut Street bridge, removed in 1985 because the concrete, not the post-tensioning had failed, gave credibility to prestressed concrete as a viable technology for bridge construction.

In 1950, while the Walnut Lane Bridge was under construction for the City of Philadelphia, the Concrete Products Company of America, located in Pottstown, actually produced the first post-tensioned bridge beam in this country. It was a hollow box beam. The state had built 47 bridges with Concrete Products Company's prestressed beams, and several short, pre-1954 examples have been identified in District 10-0. Field findings about early applications of the technology will be summarized.

The use of prestressed technology spread rapidly in the 1950s due to (1) a steel shortage as a result of the Korean conflict, the unprecedented construction activity after World War II, and, after 1956, the building the interstate highways. The technology's application was related to resolution of a number of technical problems, principally the production of high-strength, low-slump concrete and methods for consolidating and curing the concrete to achieve the needed transfer strength for pretensioning.

More information on this company and its influence in the state, as well as other Pennsylvania fabricators will be added.

IV. METAL GIRDER BRIDGES

Contemporary with the development of metal truss bridges during the middle of the 19th century was the origin of the girder span, which takes advantage of the tensile strength of wrought iron.

Built-up girders, composed of rivet-connected plate for the web and angles for the flanges to make a I-beam section of sufficient depth to span greater distances than possible with the available rolled beams, were used by the railroads as early as 1847, and they proved to be the only serious competitor to the metal truss for railroad use in the 19th century. Noted bridge engineer and author J.A.L. Waddell states that while "plate girders are as unscientific structures as a bridge specialist ever has to design, they are without doubt the most satisfactory type of construction possible for short spans [up to 100']" (Waddell, p. 408).

By the 20th century, the built-up girder bridge was steel rather than wrought iron. It proved to be the most efficient and economical railroad bridge type for shorter crossings as evidenced by the hundreds of pre-1940 examples in the state. Another reason for the popularity of the bridge type is its ease of installation. Since the girders were almost completely assembled in fabricating shops, conveniently located on rail lines, the bridges could easily be loaded onto flatbed cars. Once at the erection site, cranes quickly hoisted them into position, often on earlier abutments, with minimal traffic interruption. The ability to transport girders was often the factor limiting their length.

The most common girder bridge type in Pennsylvania is the thru girder where the floor beams are placed in line with the bottom flange of a pair of girders with the roadway passing between the paired girders. The depth of the girders is determined by its span length. In railroad applications, both rail over road and road over rail, the 3-span arrangement is common with two short, and thus shallow, girders supported on the abutments and built-up curb columns flanking the longer and deeper main span. The single span thru girder is also very common, especially in urban areas where aesthetics (curb columns were not considered a civic amenity) and/or vertical clearance were considerations.

Built-up thru girder bridges were used on non-railroad related highways **will be added as will the State Highway Department's usage of the bridge type on its early state routes.**

The deck girder bridge, with the floor beams placed near the top flanges of the girders and the roadway located at the top of the girders, was used when vertical clearance and grade considerations permitted. The technological development and application of the deck girder bridge in Pennsylvania is similar to that of the thru girder span; it was developed and used extensively by the railroads in the 19th century. Among the most interesting of early deck girders are the wrought-iron lattice web girders. **Examples will be cited.**

Prior to the development of the rolled deep web I beam and its application for mid-length spans slightly later in the century, the built-up girder span served as a longitudinal metal beam for longitudinal beam or stringer bridges. **Examples will be cited and described.**

Simply supported built-up deck girders are frequently used as approach spans for long spans or viaducts where vertical clearance is not a limitation. Both the simply supported and the continuous form of the deck girder are well represented **examples will be cited.**

V. STRINGER BRIDGES

The stringer, or longitudinal beam, bridge represents the oldest bridge technology, dating to time immemorial when felled trees were laid across streams. It is the best represented bridge technology in the state. Whether the material is wood or metal, the principle behind the stringer bridge is the same; it relies on the bending strength of the material to resist the loads.

Timber stringers bridges were built from the earliest days of settlement and are still being constructed. Also, timber stringers have historically been used in conjunction with bridge types, especially truss bridges, as part of the flooring system.

The wrought iron and later steel I-beam bridge, or stringer, came into common use in the years just before the first world war. By the end of the 1920s, it had surpassed all other bridge types for spans up to about 35 feet in length, and it went on to become by far the most common, mid-20th century bridge type. **Totals by number and by percentage of total population.**

Although structural wrought iron I beams had been rolled in this country since the early 1850s (wrought iron I beams are thought to have first been rolled by Peter Cooper at his Trenton Iron Works in the Chambersburg section of Trenton), and steel since the early 1870s, several technological and financial hurdles prevented their widespread use for short-span bridges (20'-35') until immediately before World War I. By the end of the 19th century, civil engineers were well aware of the potential application for metal beams in bridge construction, but they were generally employed for components, particularly the flooring, of truss bridges. J.A.L. Waddell commented in his 1884 The Designing of Ordinary Iron Highway Bridges that in most cases built-up members were far stronger and stiffer than wrought iron I beams, and he limited his recommended use of rolled beams for stringer spans of less than 20'.

The introduction of steel I beams for stringer bridges appears to have been related to improvements of the open-hearth steel making process that resulted in larger quantities at lower prices. The Pencoyd Iron Works (established in Philadelphia in 1852) advertised their steel I beams in Engineering News beginning in April, 1896, noting their progress in the production of beams of greater depth and strength (April 23, 1896, p. 279). Despite the claims of the trade, the inability to roll steel beams of sufficient length and depth at a competitive price remained a technological limitation into the early 20th century.

A major technological breakthrough that affected bridge building in Pennsylvania occurred in 1908 when the Bethlehem Steel Company began producing wide-flange steel beams on the Grey Mill (used in Germany since 1902). The mill rolled beams at greater speed with greater depths and at an approximately 10% savings in material with no reduction in strength (Misa, pp. 247-272). Although the company first met difficulties producing and marketing the new 26-, 28-, and 30-inch deep beams, by the early 1910s, it had overcome the problems. In his 1916 edition of Bridge Engineering, J.A.L. Waddell now touted the superiority of steel stringers, calling them "a great boon to bridge designers and builders" because of their simplicity, compactness and lower price (Waddell, 1916, p. 47, 411). The 30-inch beam was suitable for spans up to 35',

according to Waddell.

The earliest metal stringer bridges and how the beams were used will be described. Many of the early examples have encasement and a concrete jack arch deck system.

Steel stringer bridges without jack arches dating from the first decade of the 20th century are not uncommon. Their use on the county level was promoted by state Public Roads Commission and the federal Office of Public Roads through "how-to" pamphlets. The stringers were used plain, completely encased in concrete as a composite member of the slab deck, like the **examples will be cited**.

Encasement of steel stringers in concrete to protect them from corrosion was a known technique since the late 1890s, and it is a common detail in Pennsylvania. Encased steel stringer bridges were built and survive in great numbers on the state's highways because of the measure of protection the concrete added.

Steel stringer bridges, like reinforced concrete spans, were historically finished with reinforced concrete balustrades or parapets that were successfully designed to be both safe and attractive. Aesthetics was always an important consideration to state bridge designers, and that emphasis on appearance is well reflected in the large population of handsome, well-proportioned bridge railings and corresponding abutment and pier detailing from the 1920s, 1930s, and 1940s throughout the state.

A stringer design that was used with great frequency in the 1930s was for upgrading bridges on former secondary roads that were legislated into the state system was one where welded angle cross bracing was used. The rigid cross braces stiffened the bridge and help hold the beams in place. This design was used for span lengths up to 76' with a 22'-wide roadway (ENR, July 1, 1933, pp. 709-710).

VI. MOVABLE SPAN BRIDGES

With the exception of the University Avenue (previously determined eligible) and Passayunk Avenue (altered in early 1980s) bridges at Philadelphia, Pennsylvania does not appear to have movable bridges in the survey population. This section will be completed as needed for any identified movable bridge types/designs.