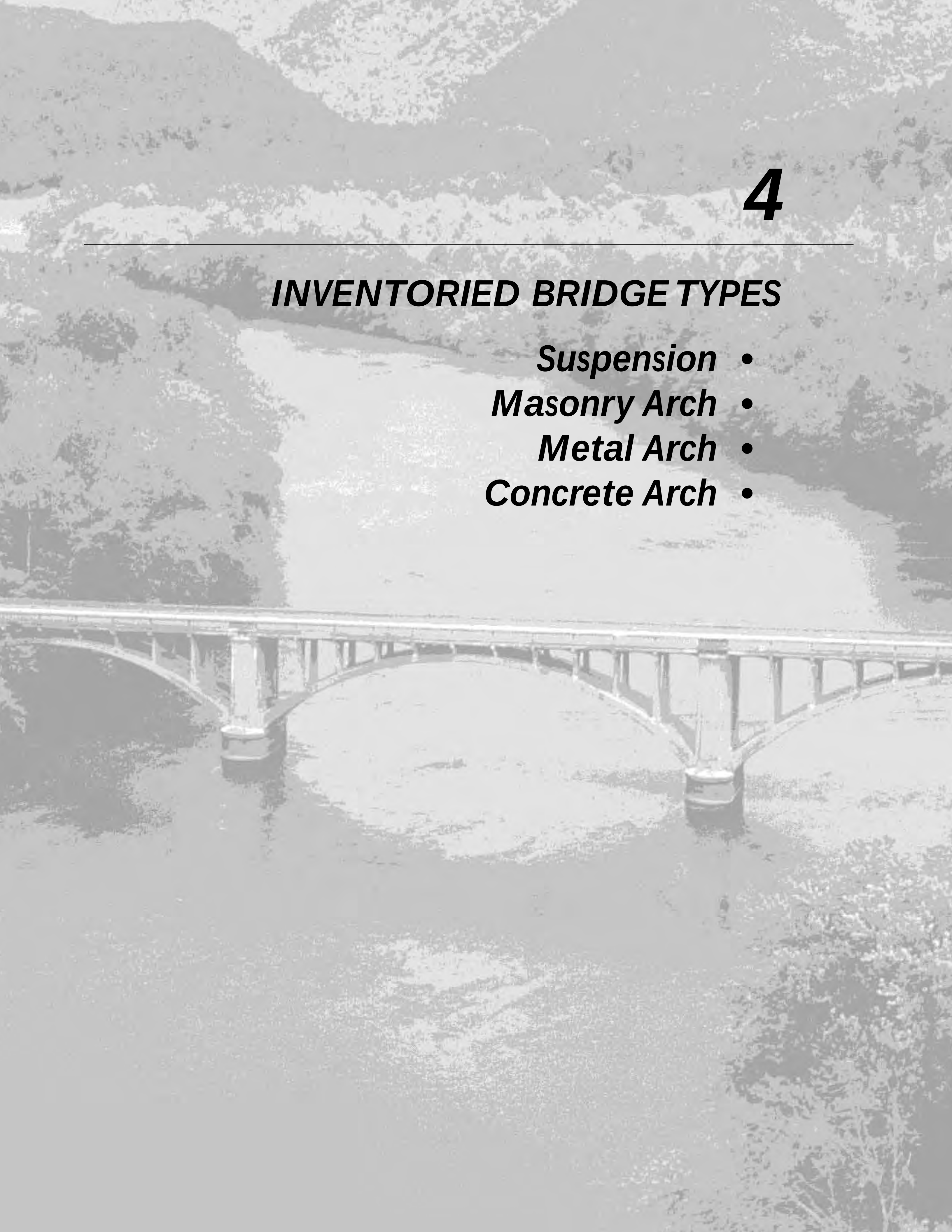


4

INVENTORIED BRIDGE TYPES

- Suspension
- Masonry Arch
- Metal Arch
- Concrete Arch

Henley Street Bridge: Construction scenes of the Henley Street Bridge (#132, 47-SR033-06.72) showing the gantries erecting the centering for the arch ribs as well as the reinforced ribs. In September 1930, when a small advertisement ran in the local newspaper for workers, about 3,000 men appeared the next day, hundreds as early as dawn. Workers were paid 25-30 cents an hour. It is said that contractors during this era expected at least one worker to die in a construction accident for every million dollars the project cost (Photographs courtesy of the McClung Collection, Knoxville).

BRIDGE TYPES INVENTORIED SUSPENSION, MASONRY ARCH, METAL ARCH, AND CONCRETE ARCH BRIDGES

Throughout history, as man needed to cross streams, he attempted to devise some type of bridge. Man probably developed them by trial and error, with most early bridges typically being crude in their simplicity. These early bridges consisted of trees cut to fall across streams as well as stone or wood slabs laid across piles of rocks. However, even in ancient times while not fully understanding how they worked but simply knowing that they did man devised fairly sophisticated bridging systems based on beams, arches, trusses, and suspension. Through the centuries, these same forms evolved into more complex structures.

This bridge survey inventoried six bridge types: suspension, masonry arch, metal arch, concrete arch, timber truss, and metal truss. This chapter, Chapter Four, discusses suspension and arch bridges, and Chapter Five discusses truss bridges. Each bridge type is unique in its own design and place in the development of bridge design in this country. Yet, the evolution of each expanded our understanding of the others. Ultimately, this continuing development resulted in new bridge designs that made these older bridge types generally obsolete. While separate and independent in design, the histories of these bridge types overlap just as their period of use does.

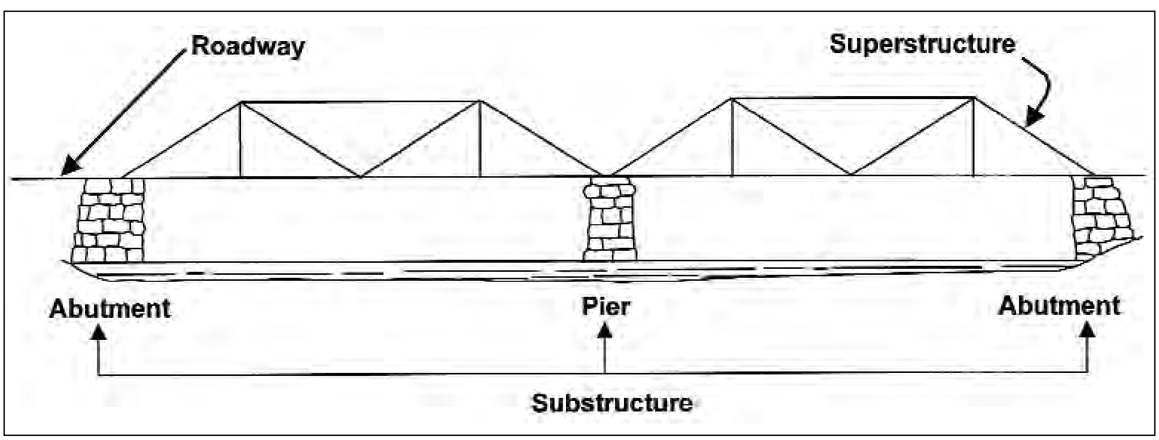


Figure IV-01: Basic Bridge Components.

What is a bridge? A bridge is a structure that provides a means to span an obstacle such as a stream or gully. While bridges vary greatly in function and appearance, several general principles apply to most bridges. (Appendix A is a glossary of bridge terms.)

Bridges carry weights or loads by being able to distribute the stresses caused by those loads. These loads may be "dead loads" (the static weight of the structure itself) or "live loads" (dynamic weight such as moving traffic). The composition of the bridge determines the distribution of these loads. For instance, arch or beam bridges act somewhat as an entity in compression, distributing loads downward and outward while truss bridges contain individual compressive and tensile members that act together to distribute the loads throughout the span.

A bridge usually contains three parts: the superstructure, the substructure, and the roadway. The superstructure is generally categorized, somewhat inaccurately, as the part of a bridge that is above the roadway and the substructure as the part below. The superstructure receives and supports loads and transfers these loads to the substructure. The superstructure can be one or more spans above or below the roadway. In this context, a span refers to the load-carrying structure (arch, truss, beam, etc.) that lies between individual substructure elements (pier to pier, pier to abutment, or abutment to abutment).

The substructure contains the abutments, piers or other features that support the one or more spans that comprise the superstructure. Abutments support each end of the bridge. The breastwall, the main element of an abutment, supports superstructure loads and retains the approach fill. Wingwalls, a continuation of the breastwall, extend at an angle from the breastwall and serve as retaining walls for the slope material. Pier abutments are abutments without wingwalls. Piers, located at intermediate positions between the abutments, support the end of a span of a multi-span structure. Columns placed on top of a solid pier base form pedestal piers. To reduce the obstruction to the flow of water, the upstream side of the pier often contained a sharp or pointed surface, called nosings or cutwaters. Both the upstream and downstream sides of some piers contain nosings, to present a symmetrical appearance and for functional reasons. Bents, another type of substructure element, contain two or more vertical or column-like members.

There are three general structural types of bridges: through, pony, and deck. A through bridge contains structural elements at each side and across the top to provide increased lateral bracing. The roadway lies on top of the deck above the bottom lateral bracing, and traffic goes "through" the inside of the span between the top and bottom of the bridge. A pony bridge does not have a "top" but has side trusses connected with bottom lateral bracing. Again, traffic goes between the sides and immediately atop the deck above the bottom lateral bracing. Advantages of pony trusses include having easily accessible members for repairs and maintenance and an unlimited vertical clearance. However, because pony trusses do not have top lateral bracing, they have less lateral stability than through trusses and cannot be used for longer spans. Although builders could erect multiple pony trusses to achieve a longer bridge length, the increased cost of the substructure typically outweighed the advantages. On a deck bridge, the entire structure (excluding guardrails) lies below the roadway. Disadvantages include difficult accessibility for repairs and maintenance as well as the bridge being more of a waterway obstruction.

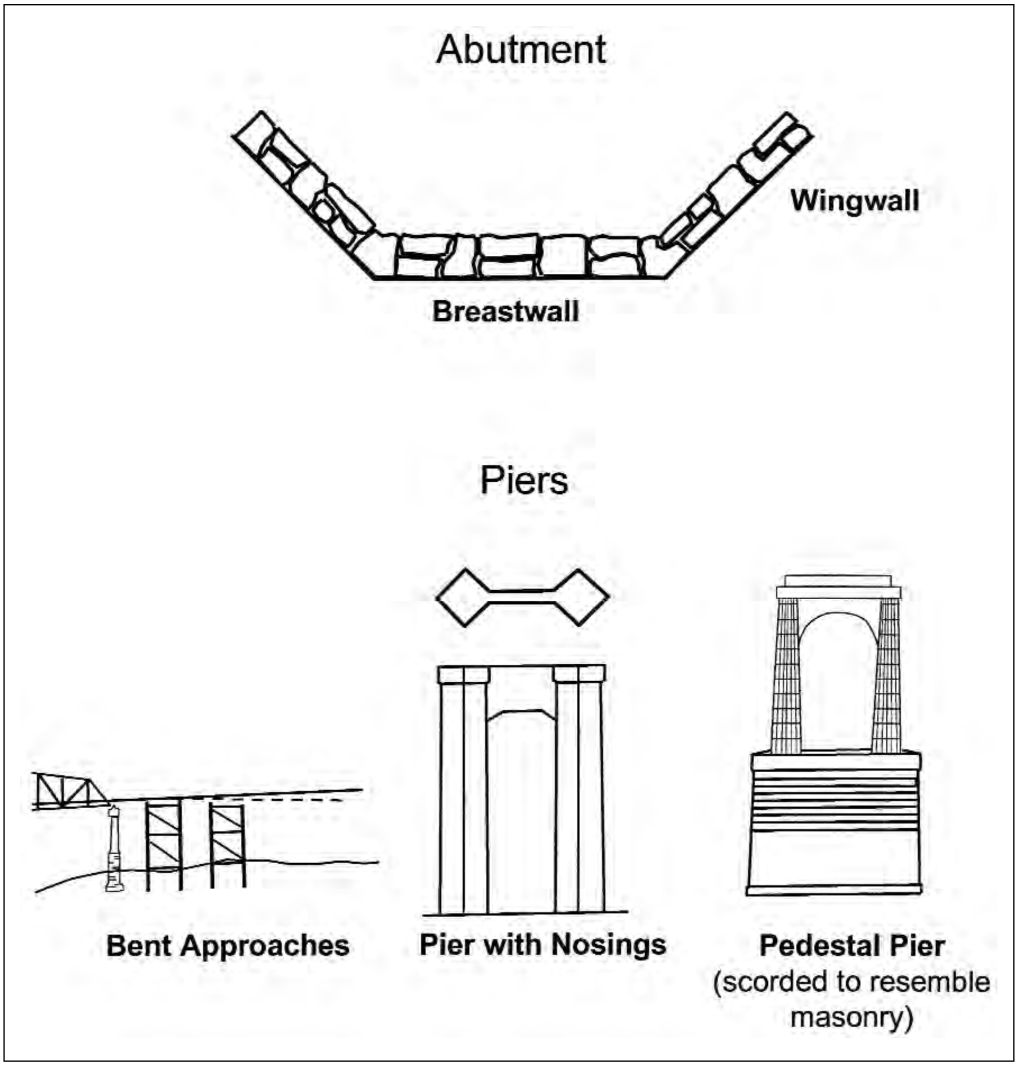


Figure IV-02: Basic Substructure Components.

A semi-deck bridge, a variation of the pony or deck bridge, contains the roadway about half-way (or less) between the bottom and top chords, resulting in neither a deck nor a pony truss. This study did not delineate semi-deck trusses as a separate bridge type but treated them as a sub-type or variation of the pony truss. Builders rarely erected semi-deck through trusses due to the problems with overhead clearances. However, on several 1930s through trusses, the state highway department used a variation in which the bottom chord was a few feet below the deck rather than the standard placement immediately below the deck.

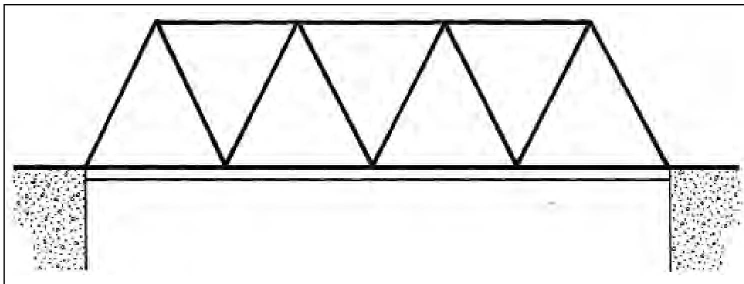
Many bridges contain shorter secondary approach spans such as stringers, girders, beams, or bents. For most pre-World War I bridges, builders tended to use the same material for approach spans as they did for the main spans. For instance, a concrete arch had concrete girder or beam approaches rather than steel I beams, just as a metal truss bridge had steel bent, stringer, or beam approaches. The Market Street Bridge in Chattanooga (#85, 33-SR008 - 09.53), which has a metal arch lift span flanked by concrete arches, is an exception probably due to a change in bridge design. Hamilton County and the designer wanted a concrete bridge, but for clearance reasons, the War Department forced the county to replace an arch span with the lift span. However, beginning in the 1920s, the state highway department typically used concrete approaches with steel trusses. Also, later alterations frequently mixed materials, such as on the 1890 metal truss Sulphur Fork Bridge at Port Royal in Montgomery County (#21, 63-A0456-01.88). A 1950s renovation to this bridge added concrete deck girder approaches.

SUSPENSION BRIDGES: In its most basic form, a suspension bridge is an extremely simple bridge type. Consequently, ancient builders used it around the world in countries such as China, Japan, India, Tibet, Mexico, Peru, and other areas of South America (Tyrrell 1911:202). These ancient suspension bridges typically consisted of rope cables supporting wooden decks without lateral stiffening. Since these bridges swayed in the wind or as loads crossed them, people often called them “swinging bridges,” a name still commonly used for small pedestrian suspension bridges. Although the use of suspension bridges was geographically diverse, builders did not erect them in large numbers.

Many historians consider the Jacob Creek Bridge in Pennsylvania, built in 1801 by James Finley (1756-1828), the first suspension bridge in the United States. Finley, Charles Ellet (1810-1862), and John Roebling (1806-1869) were the United States’s most well known nineteenth century suspension bridge builders. The 1847-1849 Wheeling (West Virginia) Suspension Bridge by Ellet was a significant early design that marked “the beginning of American ascendancy in suspension bridge design and construction which was to last more than a century” (Kemp 1979:261). Roebling designed the 1867 Cincinnati Suspension Bridge but is most famous for the 1867-1883 Brooklyn Bridge in New York, designed by Roebling but finished after his death by his son and daughter-in-law, Washington and Emily Roebling. Although relatively uncommon, the distinctive design of suspension bridges tended to make them local landmarks. One of the most famous twentieth century bridges in the United States is the 1929-1937 Golden Gate Bridge in San Francisco. Suspension bridges in the early nineteenth century typically used wood towers and suspension chains, but by the mid-nineteenth century, Roebling and Ellet had popularized the use of stone towers and iron-wire cables. In the twentieth century, builders used steel towers and cables (Jackson 1988:34).

Although suspension bridges enjoyed a degree of popularity for small vehicular bridges, and several examples remain, especially in the Southwest United States, builders most commonly erected them when a specific design issue precluded the use of other bridge types. These design problems included the length, the topographic features of the crossing, or the need to eliminate piers on a navigable stream. Consequently, suspension bridges tended to be major structures that required engineering expertise and were well-known local features. This put them in marked contrast to the ubiquitous metal truss bridge that dotted the countryside during the late nineteenth century, a design that a large number of contractors of varying skills could erect. Unlike truss bridges which engineers rarely build now, engineers still build suspension bridges under certain circumstances, primarily for aesthetic reasons or due to span length constraints.

A suspension bridge consists of three fundamental parts: the cables, the towers, and the anchorages. The cables, the main members of a suspension bridge, act in tension and pass over the tower and are then anchored on each end of the bridge. The sagging cable out-line forms a “U” shape (or “bowed” effect) in the center of the bridge. From the main cable, tension hangers drop and support the deck. Large suspension bridges usually contain a truss of some



THROUGH

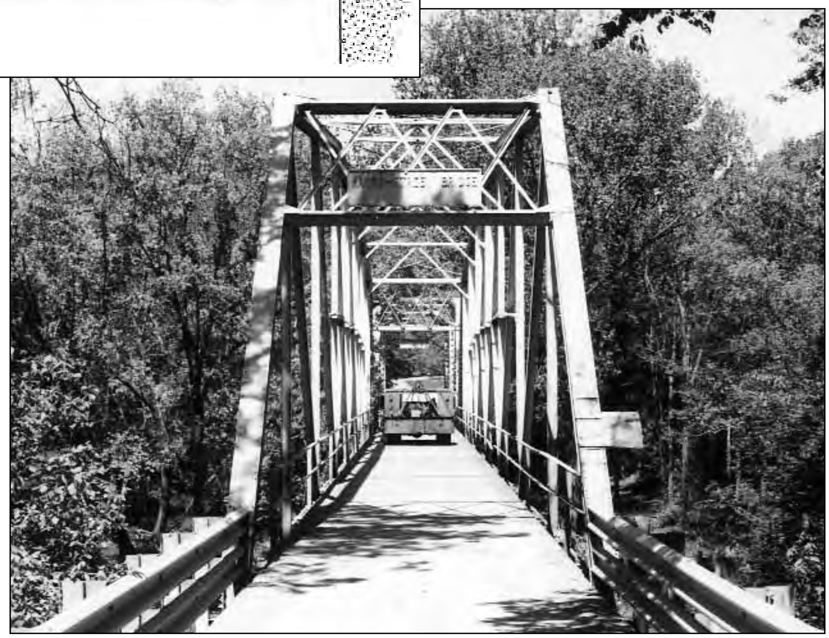
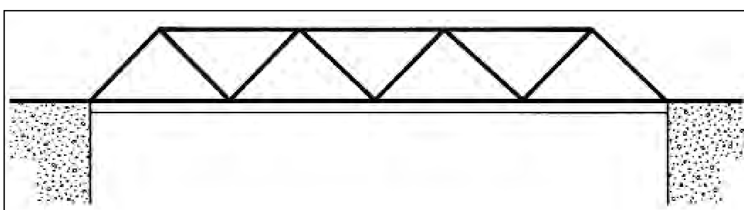
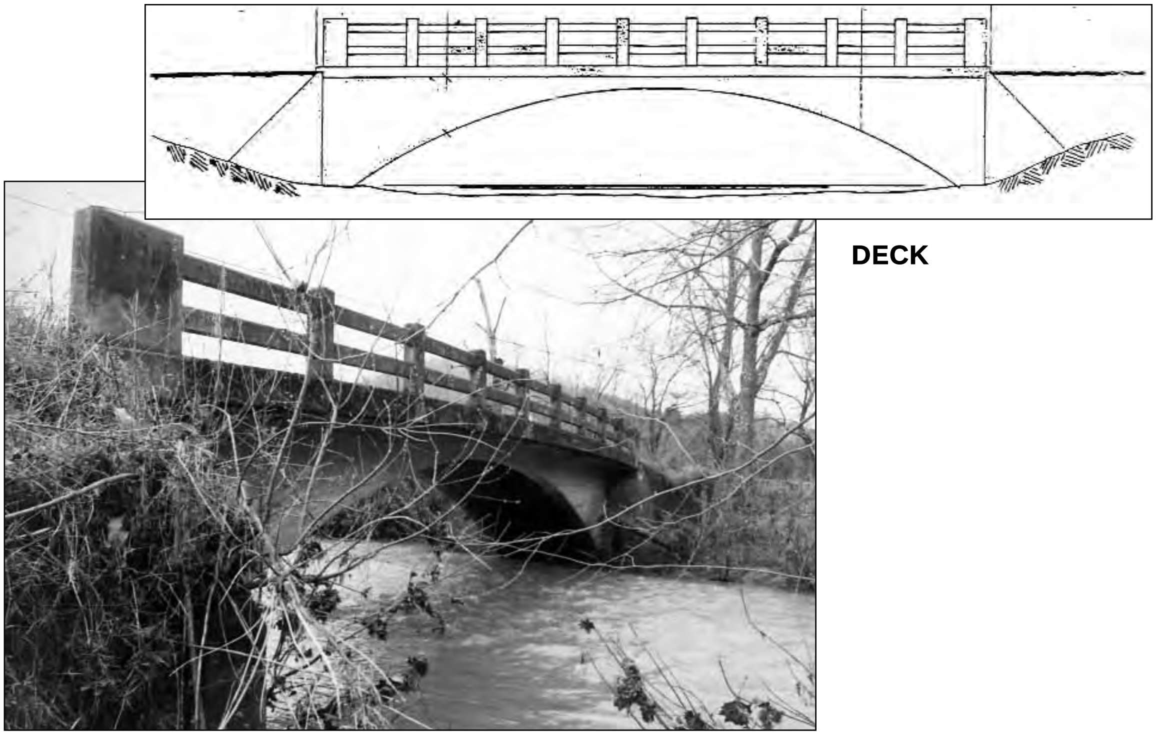


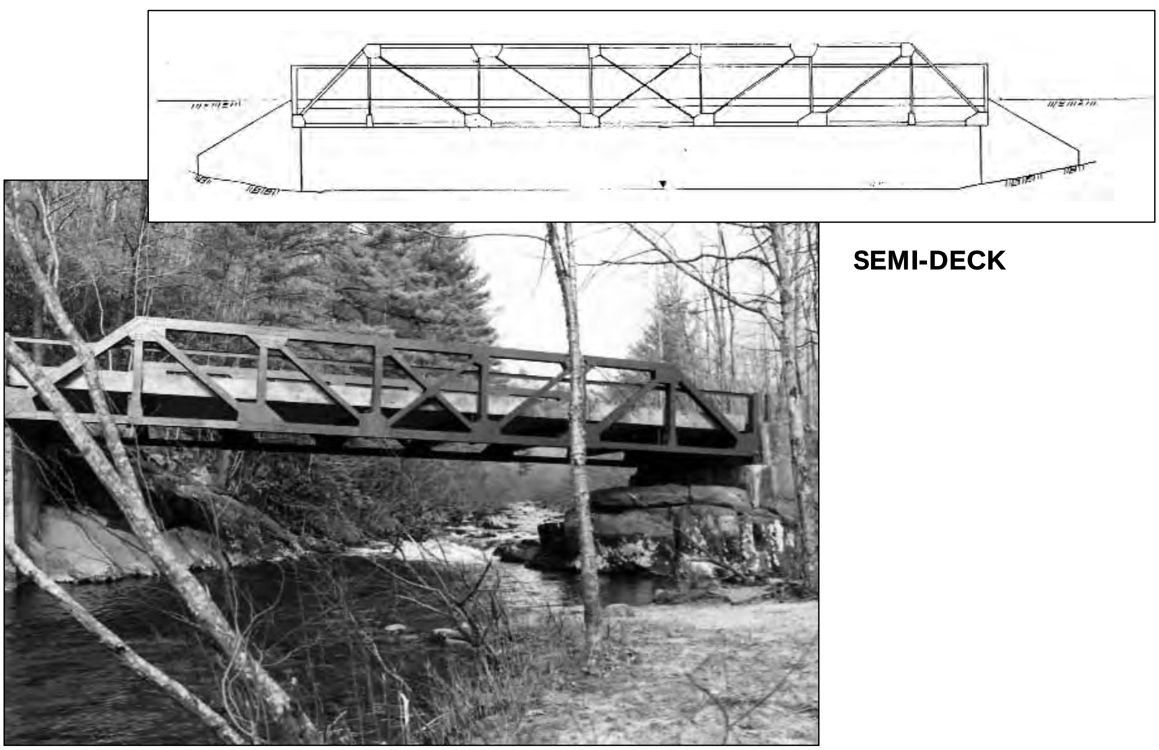
Figure IV-03:
Basic Bridge Types.



PONY



DECK



SEMI-DECK

form on or below the deck to provide lateral stiffening that stabilizes the deck. Secondary benefits of lateral bracing include increased ease in the pouring of concrete during construction and better distribution of loads. The towers, the only members that act in compression, can be built from a variety of materials such as wood, stone, or steel. The depth of the sag for the cables, which is determined by the length of the span it supports and the weight it must carry, dictates the height of the towers. Longer spans required a greater depth of sag and thus taller towers. The towers are usually the most visible element of a suspension bridge, and they frequently contain some form of ornamentation. The third major component of a suspension bridge is the anchorage system. Since the anchorages secure the ends of the cables, weight is a key component and they are generally of masonry or concrete unless the bridge can be anchored in natural rock.

The cable-stayed bridge, a variation of the traditional suspension bridge, is a cross between a suspension bridge and a cantilever bridge in that the roadway is suspended from a cable and cantilevers to both shores from one or more towers in the middle. Cable-stayed bridges are self-anchored within the bridge itself while traditional suspension bridges have an external anchorage system with the backstays anchored into abutments or the ground itself. Another difference is that, unlike the traditional "bowed" cable system, the cable-stayed suspension bridge creates a triangular appearance by having cables extend diagonally from the towers to the deck. Modern cable-stayed bridges generally feature one of four general cable configurations or patterns: the star pattern in which cables are attached from one point on the roadway to several points on the towers; the harp pattern in which parallel cables are attached from several points on the roadway to several points on the towers; the fan pattern in which cables that are not parallel are attached from several points on the roadway to several points on the towers; and the radiating or converging pattern in which cables are attached from several points on the roadway to the top of the towers (Podolny and Fleming 1972:2089).

Builders proposed cable-stayed bridges as early as 1784 and built a few in the early 1800s. However, the collapse of at least two major structures by the mid-1820s contributed to a decline in their popularity. John Roebling used cable-stays as a supplemental support in a few early suspension bridges such as in the Brooklyn Bridge, but builders seldom used this form (Podolny and Fleming 1972:2081). A German engineer "rediscovered" the cable-stayed bridge in 1938. However, engineers did not use it in construction until after World War II when, due to the massive destruction of bridges in Europe during the war, the continent needed numerous bridges and engineers utilized new and often daring design concepts. In this climate, the cable-stayed bridge became somewhat popular, and West Germany built the first modern cable-stayed bridge in 1955. Engineers erected the first modern cable-stayed bridge in the United States in 1972 in Sitka, Alaska (Gute 1973; Podolny 1976). Other examples in the United States include the 2,503-foot Intercity Bridge spanning the Columbia River in Washington completed in 1978 (Grant 1979) and the 1983 Sunshine Skyway Bridge, which is over fifteen miles long, across Tampa Bay in Florida. Currently, engineers consider this type of bridge to be appropriate for intermediate span lengths (about 400-1200 feet), a length not always well suited for either girder bridges or traditional suspension bridges.

Although it is impossible to document the number of suspension bridges erected in Tennessee, it appears that cities and counties rarely built vehicular suspension bridges. Nashville had perhaps the best known suspension bridge in the state, the Woodland Street Bridge. Davidson County built the first suspension bridge over the Cumberland River at this crossing in 1850. It partially collapsed in 1855, and the Confederate Army destroyed it in 1862. The county built a new suspension bridge in 1866 and replaced it in the 1880s. In addition, county court

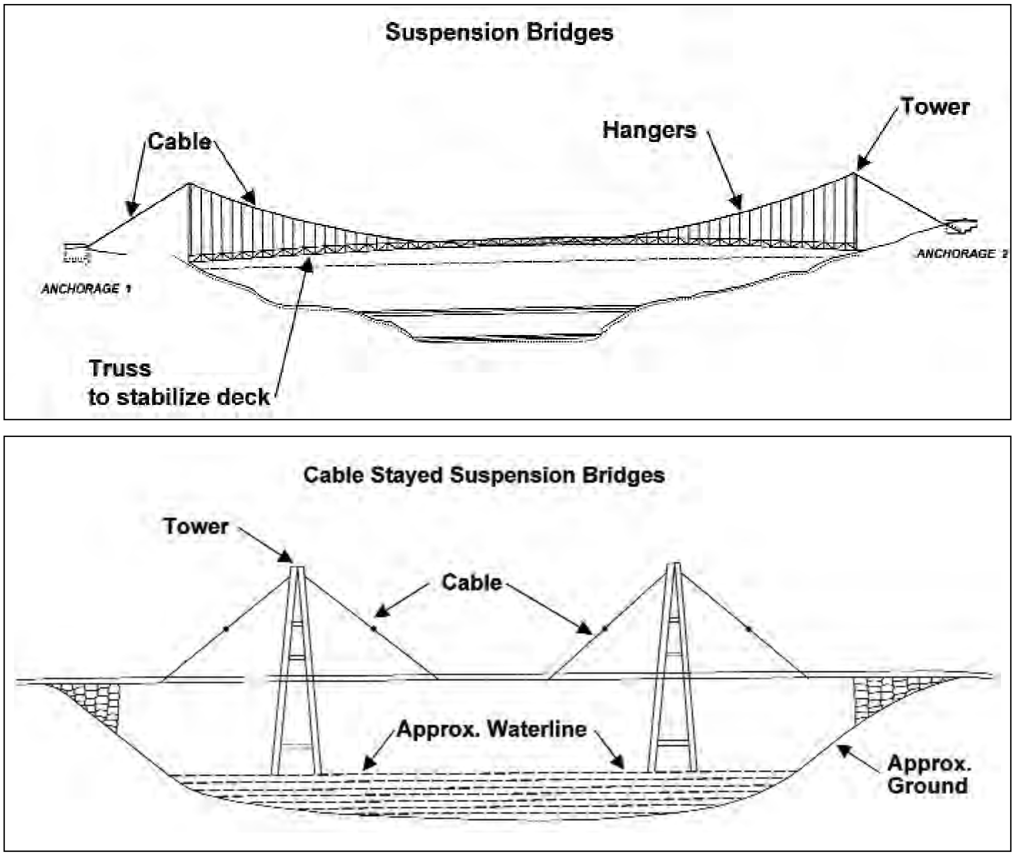


Figure IV-04: Types of Suspension Bridges.

minutes indicate that local governments sometimes built small scale suspension bridges. For instance, in 1889, Montgomery County erected a 120-foot suspension bridge spanning Marshall Creek in a rural area (Montgomery County Court Minutes Volume 31:476).

Pedestrian suspension bridges, that either the counties or private individuals built, were more common than vehicular suspension bridges in Tennessee. These were usually small scale and simple, if not crude, in design. An unusually long pedestrian suspension bridge was located in Davidson County at Old Hickory. The U. S. Government built the 540 by 8 foot bridge in 1918 during World War I to temporarily serve the Old Hickory Powder Plant. When World War I ended the same year, the government closed the bridge. When a new industrial complex opened in this area in 1923, the government gave the bridge to the county. Davidson County used it for light vehicular and pedestrian traffic until replacing it in 1928 with a steel truss (#122, 19-SR045-02.03). Some small scale pedestrian suspension bridges remain in the state, primarily in East Tennessee. Private property owners built most of these to provide access to residences separated from the road by a creek. The Tennessee Valley Authority also built some pedestrian suspension bridges in the 1940s such as the abandoned Cave Bridge at the site of a mill and small village near Doyle in White County. Built about 1944, it is 414 feet long and features steel towers of built-up members and steel cables.

Only one vehicular suspension bridge remains in Tennessee (see Table IV-01). Cheatham County built this fixed cable-stayed wrought iron bridge in 1891 at Sycamore Mills

(#22, 11-NonHighway-1). Unusual even when built, today it is possibly the only extant nineteenth century fixed cable-stayed bridge in the United States (Griffin 1978). Cheatham County awarded the contract to build this bridge in January 1891 to Eugene Castner ("Major") Lewis who had previously submitted plans and specifications for its design to the county court. Lewis apparently completed construction before April 1892, when the county authorized payment of $1,600 to Lewis (Cheatham County Court Minutes Volume F:240, 319). The bridge was located on a county road that bisected Sycamore Mills, a substantial mill community that the DuPonts owned. The county court minutes do not indicate that it was common for Lewis to build bridges for the county, but as president of the surrounding Sycamore Mills complex, his interest in a bridge at this site is obvious, but it does not explain why he chose such an unusual design. None of the typical features including bridge length, topography, or stream conditions indicate a need for a suspension bridge at this site. While there seems to be no way to document why Lewis chose this design, the answer probably lies in his unusual and creative personality.

Figure IV-05: Woodland Street Bridge, Nashville (Courtesy Tennessee State Library and Archives, Conservation Photograph Collection #5328).

TABLE IV-01: PRE-1946 SUSPENSION BRIDGES IN TENNESSEE

ELIGIBLE? # IN CH. 6	COUNTY	BRIDGE NUMBER	CROSSING	DATE BUILT	BRIDGE DESCRIPTION
Yes: #22	Cheatham	11-Non-Highway-1	Sycamore Creek	1891	2 Span Cable-stayed

MASONRY ARCHES: Ancient Romans built arch bridges and aqueducts over two thousand years ago. Since then builders have erected arch bridges of masonry, concrete, or other materials in a variety of building forms. European builders often constructed masonry arch bridges, and early settlers brought the building tradition to the United States. However, masonry arch bridges were comparatively expensive to build, required skilled masons, and were labor intensive to erect. These factors limited their use in the sparsely settled United States. Even so, builders found it practical to erect large scale masonry arch bridges for aqueducts and railroads because the ability of masonry arches to carry heavy loads with relatively low maintenance compensated for any drawbacks. The 1697 Frankford Avenue Bridge near Philadelphia, a 75-foot masonry arch bridge on the old Kings Highway, is the oldest engineered bridge open to vehicular traffic in the United States (Jackson 1988:150). Other early examples from the 1810 to 1830 period remain on the National Road. More substantial masonry arch structures that survive are the 1829 Carrollton Viaduct near Baltimore, the 1835 Thomas Viaduct in Maryland and the 1860 Cabin John Aqueduct in Washington. However, while masonry arch bridges have always been viewed as aesthetically attractive, they represent centuries-old building techniques and have never significantly affected modern bridge technology and its evolution in the United States.

As a building material, stone has little tensile strength. An arch acts in compression, distributing the stresses from loads along the arch line downward and outward into the abutments (or piers). In a masonry arch, the stones press together under the weight of a load in an overlapping diagonal pattern. Thus stone, though poor for designs that rely on tension, possesses adequate strength for arch designs. Since the arch itself carries the weight of the bridge, builders paid careful attention to this element. The spandrel walls serve only to retain the fill, usually gravel or dirt, over which the roadbed lies.

Stone masons typically laid stone in one of three general patterns: rubble, squared stone, or ashlar. Rubble masonry consists of rough unfinished stones laid together in an irregular pattern based on their shape and size. Squared stones have been roughly finished and shaped into a rectilinear form. The ashlar pattern, the most refined stone, uses squared and then fully finished stones. Builders typically placed the largest stones on the bottom with the courses laid staggered and parallel to the roadway (and thus perpendicular to the pressures exerted by passing loads) and staggered the vertical mortar joints to avoid a solid joint line running consistent with those pressures.

Some of Tennessee's masonry arch bridges were large scale, such as the Fayetteville Stone Arch Bridge. However, few of the early major bridges in the state were masonry arches, probably because most of these early bridges spanned streams that were navigable. On navigable streams, the piers and arches in the water would have been a deterrent to steamboats and other crafts. The piers and arches also impeded the stream flow. Builders erected numerous small masonry arch spans in the state, a few of which survive.

As bridge building technology improved and the popularity of the metal truss bridge spread in the late nineteenth century, cities and counties rarely built masonry arch bridges. There is no

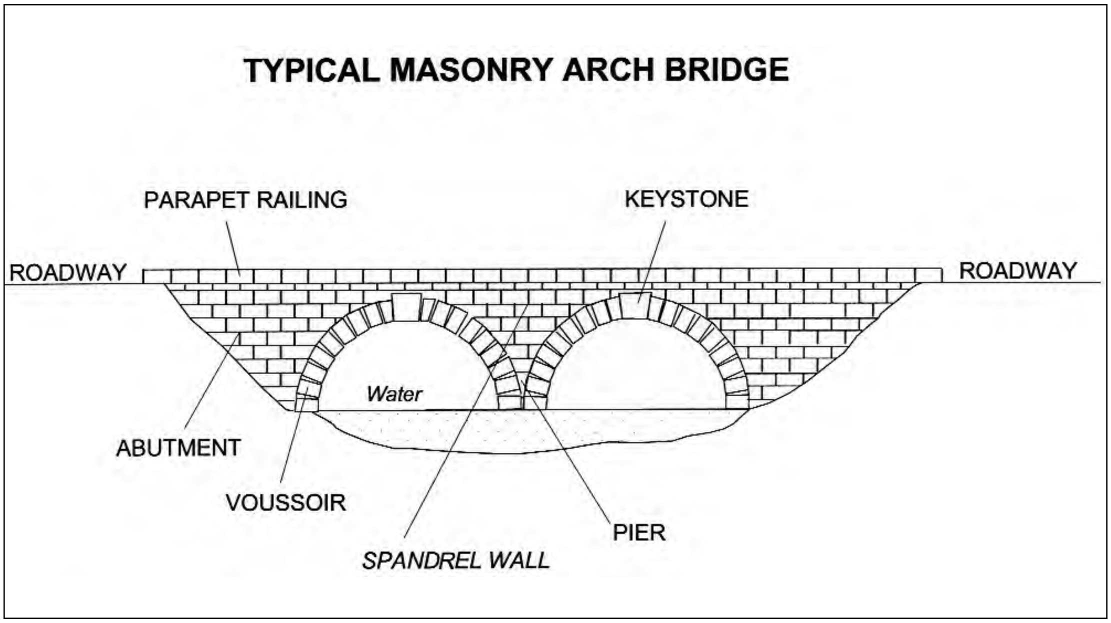


Figure IV-06: Components of a Masonry Arch Bridge.

real explanation as to why a few counties, such as Grundy County, chose to build masonry arch bridges well into the twentieth century. Quite often, people assume the Swiss settlement in Grundy County, which began in 1869 and which peaked in the 1880s (after which out-migration greatly reduced the number of Swiss colonists), resulted in the construction of these masonry arch bridges. However, historical records do not support this folklore. Perhaps the continued use of masonry arch bridges is more indicative of the county's isolated geographic situation in the mountains and a generally conservative tendency. On the other hand, Lincoln County, which was progressive in its bridge building practices, also erected masonry arches into the 1920s.

In the 1930s, masonry arch (or masonry faced) bridges enjoyed a resurgence of popularity as a part of New Deal construction programs. The state and federal governments often used masonry on bridges in parks such as the Old Mail Road Bridge (#149, 18-A0939-01.00) in the Cumberland Mountain State Park in Cumberland County. By this period, aesthetics or a desire to use local labor and materials influenced the selection of masonry arch bridges since their construction was normally uneconomical in comparison to other bridge types.

All of Tennessee's twenty-one masonry arch bridges, except for the two 1930s Cumberland Homestead Bridges (#137, 18-01168-03.76 and #149, 18-A0939-01.00), contain squared and (to varying degrees) dressed stones, usually limestone (see Table IV-02). The two Homestead Bridges use Crab Orchard sandstone in a coursed rubble pattern. The three 1830s bridges use elliptical arches. The remaining bridges use either a variation of the elliptical (segmental) arch or a semi-circular arch.

STEEL ARCHES: Builders have used the arch as a bridge form, in which compressive forces press downward and outward, since ancient times. Until the 1830s, masonry and timber were the most common building materials. However, at that point, engineers and builders began to erect metal arch bridges to a limited extent in the United States, first on the National Road in southwestern Pennsylvania (Jackson 1988:33). The Eads Bridge, the first major steel bridge in the world, spans the Mississippi River at St. Louis. Designed by James B. Eads and built between 1869 and 1874, the Eads Bridge is the country's most famous nineteenth-century metal arch bridge. By the late nineteenth century, steel, which resisted compressive forces better than iron and was thus better suited for arch construction, was widely available and had replaced iron as the primary bridge building material. The widespread availability of steel was in part responsible for the modern era of steel arch construction that began around 1900.

The arch on a metal arch bridge can be formed by a girder or by a truss as in the Market Street Bridge (#85, 33-SR008-09.53), the only steel arch bridge inventoried in Tennessee (see Table IV-03). Top and bottom chords, both parabolic in shape and acting in compression, form the trussed arch. Verticals acting in compression and diagonals acting in tension connect these chords. The deck is suspended from hangers. The connections are riveted. The Market Street

TABLE IV-02: PRE-1946 MASONRY ARCH BRIDGES IN TENNESSEE

ELIGIBLE? # IN CH. 6	COUNTY	BRIDGE NUMBER	CROSSING	DATE BUILT	BRIDGE DESCRIPTION
Yes: #1	Davidson	19-E0224-00.07	Manskers Creek	1841 ca	2 Elliptical Arches
Yes: #2	Robertson	74-NonHighway-1	Red River	1841 ca	2 Elliptical Arches
Yes: #3	Sumner	83-A0884-00.35	Slaters Creek	1841 ca	1 Elliptical Arch
No	Sumner	83-01073-06.72	Bledsoe Creek	1850 est	1 Round Arch
Yes: #13	Davidson	19-NonHighway-8	Browns Creek	1888	1 Elliptical Arch
No	Knox	47-C0199-01.93	Beaver Creek	1894-95	1 Elliptical Arch
Yes: #28	Grundy	31-NonHighway-3	Scott Creek	1898	2 Round Arches
Yes: #30	Sevier	78-00496-07.09	Boyd's Creek	1898	1 Elliptical Arch
No	Knox	47-01281-00.10	Ten Mile Branch	1900 est	1 Round Arch
No	Madison	57-03043-01.05	Branch	1900 est	1 Round Arch
No	Grundy	31-A0078-02.14	Ranger Creek	1905	2 Round Arches
Yes: #52	Grundy	31-NonHighway-2	Firescald Creek	1906	1 Round Arch
No	Coffee	16-02110-00.20	Noah Fork Creek	1908	1 Round Arch
No	Grundy	31-A0023-02.58	Hickory Creek	1910	2 Round Arches
Yes: #71	Grundy	31-A0022-02.49	Hickory Creek	1912	2 Round Arches
Yes: #78	Franklin	26-NonHighway-1	Factory Creek	1914 ca	2 Round Arches
No	Lincoln	52-A0399-02.37	McCullough Branch	1924	2 Elliptical Arches
Yes: #116	Lincoln	52-A0147-03.89	Lane Branch	1926	2 Elliptical Arches
Yes: #137	Cumberland	18-01168-03.76	Byrds Creek	1934	1 Elliptical Arch
Yes: #149	Cumberland	18-A0939-01.00	Byrds Creek	1937 est	1 Round Arch

Bridge's metal arch span is a double leaf bascule rolling lift. Only one other vehicular bridge in Tennessee, the Lenox Bridge (#92, 23-NonHighway-1), which contains a swing span, is a movable bridge.

Interestingly, the Market Street Bridge was under construction at the same time as the Hell's Gate Bridge in New York, one of the best examples of this type and, at 977 feet, the longest example in the world until 1931. At 310 feet, the Market Street Bridge as a steel arch does not compare in length to this bridge. However, in 1916, the Market Street Bridge was the longest double leaf bascule lift bridge in the world, a distinction it held until 1940 when a 333-foot double leaf bascule lift bridge was built in Ohio and the following year a 336-foot example was built in Michigan (Encyclopedia 1979).

TABLE IV-03: PRE-1946 METAL ARCH BRIDGES IN TENNESSEE

ELIGIBLE? # IN CH. 6	COUNTY	BRIDGE NUMBER	CROSSING	DATE BUILT	BRIDGE DESCRIPTION
Yes: #85	Hamilton	33-SR008-09.53	Tennessee River	1917	1 Double Leaf Bascule Arch and 6 Filled Spandrel Arches

GENERAL CHARACTERISTICS AND HISTORY OF CONCRETE BRIDGES: Concrete, which is formed of natural products, is a malleable compound of an aggregate such as rock or gravel bound together by water and cement. Cement, a powder of limestone and clay, is the bonding component of concrete although the terms "concrete" and "cement" are often erroneously used interchangeably. Another misconception is that concrete hardens by drying, but it hardens through a chemical process called hydration in which the cement and water form hydrates that bind the concrete package together. These hydrates grow over time and actually increase the strength of concrete.

Examples of concrete construction date at least to early Roman times when Roman builders used it extensively in structures such as the Pantheon, the Coliseum, and in bridges. However, builders apparently ceased to use it again until the Middle Ages when it appeared in both Spain and Africa. In the 1500s, Spanish settlers introduced to the New World a form of concrete known as tabby, of which examples still exist in coastal areas.

Early builders used lime mortar, which initially hampered the widespread use of concrete because lime mortar, while a good binding material, often deteriorated under water. Natural cement rock was superior as a binding material, and even gained strength under water, but locating natural deposits limited its use. This limitation ended in the 1820s when an English bricklayer, Joseph Aspdin, developed an artificial cement mixture known as Portland cement. Aspdin named his mixture Portland Cement to capitalize on the popularity of limestone found on the isle of Portland. At that time, builders considered Portland limestone the best limestone in England. [The term "portland cement" has come to be viewed as a generic term used interchangeably with any type of cement and is now typically not capitalized.] Artificial cement proved superior to natural cement because builders could form concrete anywhere, without the additional cost of importing natural cement or depending on finding a deposit of it. It also enabled builders to produce concrete more consistently, thereby improving its quality. The government in 1871 granted a patent in the United States for this artificial or portland cement to David O. Taylor. With the development of an artificial cement as a binding agent, the availability and applicability of concrete in bridge construction increased. However, unreinforced concrete is relatively a weak building material and not appropriate for many structural applications.

In the United States in the latter half of the nineteenth century, Ernest Ransome and S.T. Fowler popularized the use of concrete, then known as "artificial stone" (Sedgwick 1991:70). Fowler laid the groundwork for extending its use when he patented a reinforced concrete wall in 1860. Strengthening concrete with the inclusion of metal bars greatly increased its tensile strength. However, Ransome, who formed a company in 1868 in San Francisco to manufacture concrete blocks, deserves much of the credit for its subsequent popularity (Condit 1960:226 227). Another factor that decreased the cost of concrete, and thus increased its availability, was the realization in the mid 1870s that builders could use blast-furnace slag, a by-product for which the iron and steel industries had a disposal problem, as an aggregate in cement. At first used for buildings, the use of concrete for other structures soon followed.

Concrete has compressive strength but low tensile strength that limited its usefulness for construction purposes. However, reinforcing concrete with imbedded steel members, which have high tensile strengths but are weak in compression, can alleviate this problem. Together, the steel strengthens the concrete and the concrete stiffens the steel. The increased strength of reinforced concrete eventually allowed engineers to develop innovative and aesthetically attractive designs for concrete bridges rather than simply replicating the form of masonry arch bridges or facing concrete arch bridges with masonry as many builders often did in the incipiency of concrete arch design.

French gardener Jean Monier, who in the 1860s used concrete reinforced with wire mesh for urns and flower pots, first patented a reinforcing system for concrete. While Monier was not a bridge builder, builders erected over two hundred bridges based on his patent (Plowden 1974:298). A variety of other patents followed, but the Austrian engineer Joseph Melan's patent had the most impact. In 1893 he introduced in the United States a new system that used parallel metal I beams embedded in concrete, somewhat like a metal arch with concrete covering (Plowden 1974:299).

The Cliftridge Bridge in New York, built in 1871-1872, is the first documented concrete arch bridge in the United States. Ransome built the country's first reinforced concrete arch bridge, scored and roughened to imitate stone, in 1879 in San Francisco's Golden Gate Park. However, reinforced concrete arch bridges were not immediately popular. Engineer Henry Tyrrell estimates that builders erected only about one hundred reinforced concrete bridges in this country before 1900 (Tyrrell 1909:104). Tyrrell argued that at this stage few engineers fully understood concrete designs, a problem that persisted until the Austrian government sponsored extensive experimentation on concrete arches between 1890 and 1895. American and European engineering journals published the reports from these experiments. About 1893-1894 the German born Fritz Von Emperger introduced to American builders the Melan reinforcing system that received considerable attention. Noted bridge engineer Edwin Thacher erected a number of major bridges based on this system around the turn of the century. In 1897 Thacher built the first large multispan concrete bridge in the United States, which spanned the Kansas River at Topeka, which for a time was the largest bridge of its type in the world (Plowden 1974:298).

The popularity of concrete greatly increased as builders publicized its advantages (Tyrrell 1909:1-2). For example, in 1907, Daniel Luten published a description of several concrete arch bridges he had built and listed several advantages of concrete arch bridges:

ADVANTAGE OF REINFORCED CONCRETE BRIDGES

A properly constructed concrete bridge is absolutely indestructible.
A concrete bridge is the only bridge that grows stronger with age.
As time passes, traffic on our highways grows heavier; steel and wooden bridges grow weaker; concrete bridges grow stronger. To build a concrete bridge then, is just plain common sense.
Portland Cement is the most perfect coating known for the protection of steel.
A concrete bridge provides a continuous gravel roadway. Wooden floors for bridges are an expensive nuisance. Concrete bridges require no floor renewals.
Concrete bridges are rust proof, frost proof, flood proof and fire proof.
Concrete bridges require neither painting nor repairs.
Concrete bridges are permanent improvements.
A concrete bridge can be widened at any time without re building.
To make a bridge flood proof, pave the bed of the stream to prevent scour, and then build the bridge in a solid monolithic mass so that it will stay.
A concrete bridge once built, is built for all time.
Concrete bridges are built with labor hired from the immediate vicinity of the bridge; with gravel or stone purchased in the immediate locality, and with cement secured from local agents. The greater part of the expense for such a bridge is thus returned to the county.
The money that tax payers expend for a concrete bridge is returned to the tax payers for labor and materials.
The beauty of horse shoe concrete arches lies in their common sense.
Concrete bridges are the handsomest for park bridges, the most durable for highway bridges, the most serviceable for railway bridges.

Bridges built of concrete will endure as monuments for all time (Luten 1907:92 93).

Publications such as Luten's convinced many people that concrete arch bridges were sturdier and more resistant to flood damage than truss bridges whose members were often damaged by floating debris. Many engineers also thought that concrete bridges could function more as low water bridges with the water flow just passing over them. Builders claimed that concrete was less expensive and required less skilled labor to erect than steel or masonry, and builders could hire local laborers rather than importing skilled masons. The materials to make concrete were readily available at nearly any site, bringing more profits to local suppliers than an out of state steel producer. Builders could easily mold concrete into any shape, from functional piers to elaborate decorative designs. Builders could pour and mold concrete in the air as well as under water, minimizing or eliminating the very dangerous underwater work in caissons. Builders claimed that concrete would harden with age, and thus the older the bridge, the stronger it would become, unlike steel bridges that would weaken with age and use. They claimed that concrete bridges required less maintenance and that municipalities would not have to paint concrete bridges as they did steel bridges. Since the deck was a continuous roadway above the arch, the bridges did not need wooden decks that the owner had to replace frequently. References in some of Tennessee's county court minutes indicate that the commissioners believed that concrete arch bridges would last a hundred years--far longer than the expected life span of a truss bridge.

The shape of these early concrete arch bridges replicated the form of masonry arch bridges, a logical design since both concrete and masonry are low in tensile strength but adequate for compressive stresses when used in an arch design. These early concrete arches, termed filled spandrel or barrel arches, had a solid barrel arch topped with vertical side walls (solid spandrel

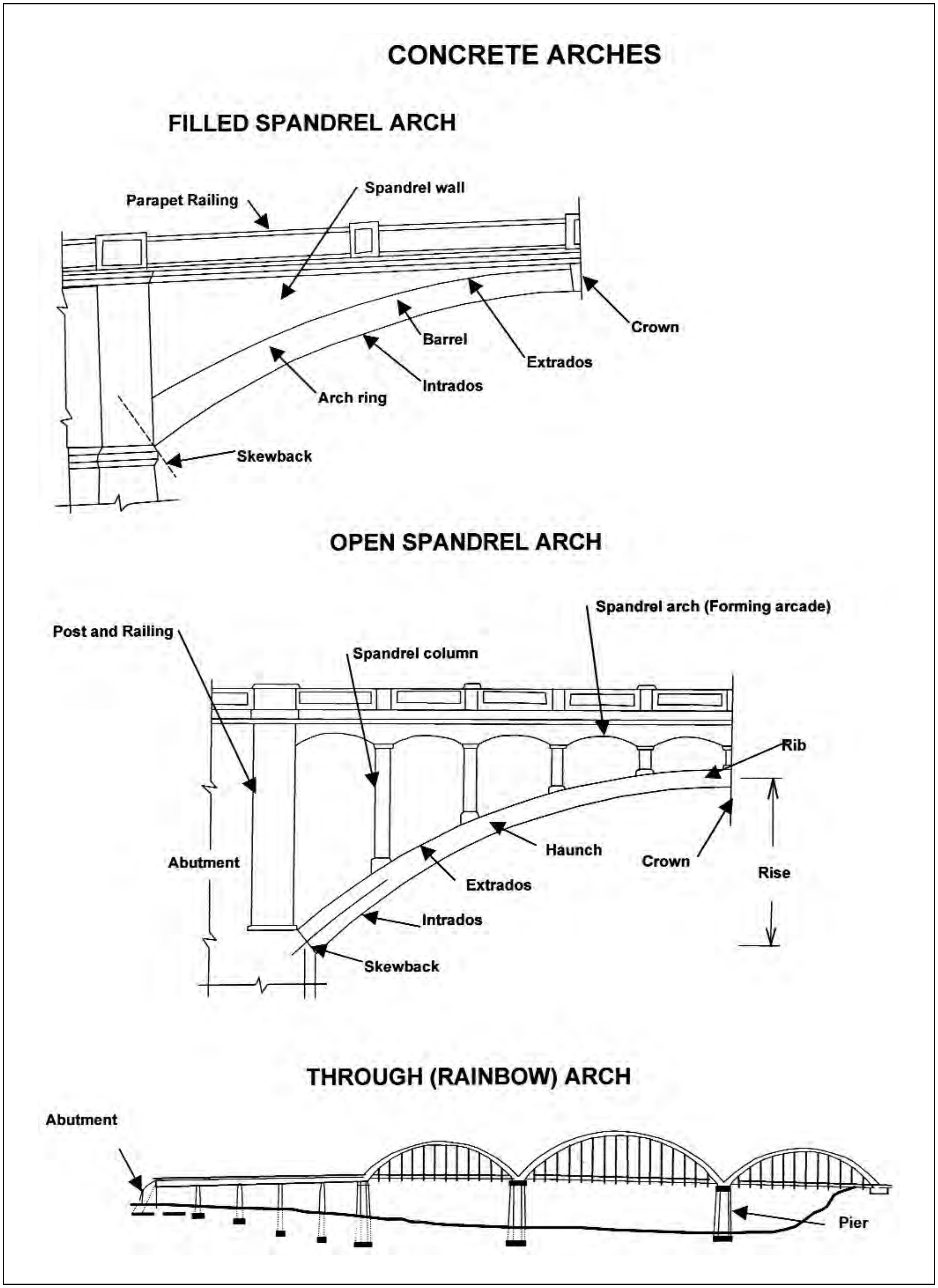


Figure IV-07: Types of Concrete Arch Bridges.

walls). This form created a cavity, and the spandrel walls basically served as retaining walls for a partial or total fill of earth or rocks. Small spans generally used solid earth filling. The spandrel walls and fill served as the foundation for the roadbed (driving surface) which crossed over the bridge. To support the roadbed, some arches contain a series of interior walls and arches, which might not be visible on the exterior, instead of fill.

In an arch bridge, the stresses are distributed throughout the bridge with only a minimal deflection of its deck (unlike a beam bridge that must deflect to distribute the load stresses). From the load crossing the deck, stresses are transferred down through the spandrel walls where they spread outward following the line of the arch. The forces then spread into the abutment where they are absorbed. Therefore, the abutments must be a solid foundation, preferably rock. For this reason, builders erected few concrete arches in West Tennessee where soils are not stable.

Builders can either pour concrete at a building site within falsework or framing, which is removed after the concrete hardens (cast in place), or builders can place concrete in molds off site and later erect the concrete forms at the site (pre cast).

Daniel Luten, the founder of the Luten Company of Indianapolis, took out many patents between 1900 and 1906 relating to concrete arch bridges. Although many national leaders such as Thacher built visible and monumental bridges, Luten's firm dominated the field of small scale bridges from about 1900-1920. During this period, many people used the term Luten Arch for any filled spandrel concrete arch. When competitors copied his designs, Luten frequently filed lawsuits which judges consistently settled in his favor that forced many other concrete arch builders to pay him royalties. However, James Marsh, an Iowa bridge builder challenged Luten in court in 1918 and an Iowa judge ruled Luten's patents invalid, saying that they were too broadly worded (Herbst and Rottman 1986:10). This ruling opened the field for numerous competitors with various concrete arch designs, and the construction of concrete arch bridges greatly expanded.

During the time Luten's company held a virtual monopoly on concrete arch designs, some philosophical changes occurred within the industry. Within the 1900-1910 period, engineers began to recognize concrete's great versatility and potential attractiveness as a building material itself and began experimenting with the form and appearance of concrete bridges. As historian Carl Condit wrote, "By 1910, however, the main line of evolution was moving away from massive construction, with its echoes of the masonry tradition, toward the flattened parabolic curves of narrow ribs, the slender spandrel posts, and the minimal piers that scientific reinforcing was to make possible" (Condit 1968:257).

In the early twentieth century, engineers achieved major advances in both the aesthetic design and technology of concrete bridge design. European engineers led in experimentation in both research and in construction of new and different bridge designs. However, due to the complexity of the research, most Americans did not pursue research in this field that resulted in "an arrested growth in structural art for American concrete bridges" (TRB 1991:74). Even so, while not daring, American concrete arches became more attenuated and slender, further differentiating the look of concrete arch bridges from masonry arch bridges.

Accordingly, two other early twentieth century types of concrete arches began to appear in Tennessee in the early 1920s: the open spandrel arch and the filled spandrel-ribbed arch. The open spandrel design dates to at least 1896 when Edwin Thacher patented such a bridge design. The open spandrel arch functioned similarly to a filled spandrel or barrel arch and carried the deck above the arch as did a barrel arch, but visually, the designs were substantially different. Rather than having a solid spandrel wall, this arch design contained an open spandrel area with vertical columns. These columns could either be straight or arched forming a small arcade. Although the barrel of the arch could be solid, the design typically contained two parallel ribs along the outside edges of the arch, usually connected with bracing. For more support, such as on wider bridges, the arch contained additional ribs. All of the open spandrel arches in Tennessee have the typical ribbed barrel; none use a solid barrel.

Filled spandrel and open spandrel arches also differed in how they distributed stresses. A filled spandrel arch uniformly distributes the load throughout the spandrel wall before it spreads along the arch line. An open spandrel arch distributes the load downward through the vertical spandrel column over which it passed and not throughout all the columns. Open spandrel arches, which eliminated roadway fill and required smaller footings, used less material but were more labor intensive to build than filled spandrel arches. Therefore, filled spandrel or barrel arches were more economical for shorter spans, and open spandrel arches were better for longer spans or high crossings.

Filled spandrel arches originally had solid parapet rails, but with the open spandrel arch, an open rail of posts or balusters became common. Only one of Tennessee's extant open spandrel arches has a parapet rail. However, builders used both types on filled spandrel arches throughout the 1920s and 1930s in Tennessee. Interestingly, the parapet railing could be a functional member sharing the load with the arch, but the open rail merely served as a railing for pedestrians or vehicles. Its primary advantage was that it weighed less and thus reduced the dead load.

A variation of the open spandrel arch was a through (or pony) arch, which located the arch above the roadway and placed the roadway within the arch rather than on top of it, as is common on a deck arch. James Marsh of Des Moines, who patented his design, popularized this arch form. Marsh's design was essentially a steel bridge encased in concrete. Comparatively expensive, few builders used this design outside the Iowa region (Herbst and Rottman 1984:10). Although Marsh's patents termed his design a "Marsh Rainbow Arch," the term Rainbow Arch has come to be used generically for any through concrete arch bridge such as the McBee or Mascot Bridge (#133, 47-01262-04.68). The through arch basically functioned the same as an open spandrel arch

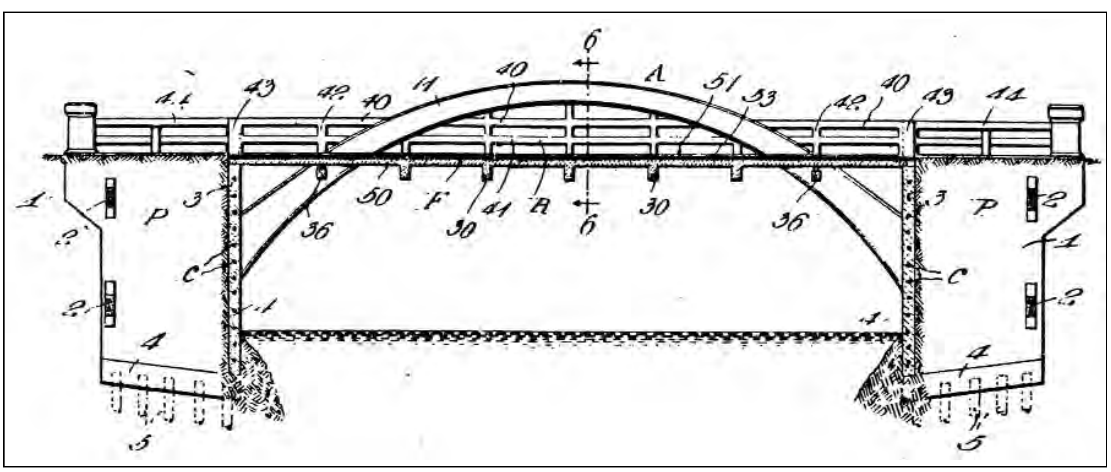


Figure IV-08: James B. Marsh's Patent for his "Rainbow Arch" bridge, 1912, Patent # 1,035,026.

Figure IV-09: Photograph of a Filled Spandrel-Ribbed Arch Bridge in Wilson County; #124, 95-A0392-02.12, Built by Bell and Bell in 1928.

except that it contained an inverted arch that carried the deck along the bottom of the arch rather than on top of it. Some engineers such as Henry Tyrrell strongly opposed pony or through designs. Tyrrell felt the side supports were "a danger and menace to travel" and that builders should use them only when "the underneath clearance or structural requirements positively prohibit the rise of a deck bridge" (Tyrrell 1909:108). Builders rarely erected pony or through ("Rainbow") concrete arches in Tennessee. One example is known to have been built by John Steel in Lawrence County (see Figure III-12, not extant). Knox County chose a through arch design for the McBee Bridge in order to maintain the existing grade with nearby railroad tracks that would not have been possible with a deck arch.

A third major variation of the concrete arch, the filled spandrel ribbed arch, appeared in Tennessee in the early 1920s. Historians generally date this form to 1898 and attribute it to Pennsylvania Public Works Department Engineer F. W. Patterson (Spero 1984:5). From the side elevation, this variation appeared to have a filled spandrel and a solid barrel arch. On closer inspection, the design contained parallel ribbed arches below a filled spandrel creating a "hollow" look. None of Tennessee's examples contain a delineated arch ring along the ribs, but neither do many of the state's barrel arches. Usually, the arch contained two ribs along the outer edges that were flush with the spandrel walls, but for a wide bridge such as the Elizabethton Bridge in Carter County (#115, 10-03939-00.10), builders often used more ribs. This type of arch required less concrete material than a barrel arch but used more reinforcing materials and probably required more labor.

The haunched girder, a hybrid blending of the arch and girder, also reflected this change in design philosophy. Roughly a dozen examples built in the 1920s and 1930s remain in Tennessee. Still built today, but typically for comparatively short spans, haunched girder spans serve as a transitional design between the concrete arch bridges of the early twentieth century and modern bridges.

In assessing the significance of concrete arch bridges, one major difference between concrete arches and metal truss bridges is important to note. Historians can readily identify unique design features or patented elements on truss bridges as the entire truss is visible to the eye. While there are different types of concrete arch bridges (for example, open and filled spandrel), many unique identifying features are not visible. For instance, various bridge companies acquired a wide variety

Figure IV-10: Photograph of a Haunched Girder Bridge in Bradley County, Erected in the 1920s by Steel and Lebby.

of patents dealing with abutments, ties, hinges, and especially the steel reinforcing. None of these features are normally visible, and thus the only way to determine if a concrete arch bridge contains a patented feature (other than an on site inspection during demolition) is through research, or if the bridge plaque identifies it. It is possible that some of the early Luten bridges in Tennessee could be considered patented, but county court minutes or newspaper articles contain no specific references to them as patented bridges. The only concrete arch bridge in Tennessee known to have patented features is the Clinch Avenue Viaduct in Knoxville (#48, 47-A0135-00.42). Nationally recognized Edwin Thacher prepared the plans for this bridge, and the bridge plaques identify specific patents by Thacher and Melan.

Builders could easily form concrete into a variety of shapes, and concrete was thus readily adaptable to decoration either through the surface finish or the inclusion of decorative motifs. Builders could, and often did, face concrete bridges with stone, brick, or plaster, especially during concrete's early use. One example is the stone faced Belle Meade Bridge in Nashville (#51, 19-B0983-01.61) which a landscape architectural firm included in exclusive residential development in 1906. Stone facing served two purposes. First, it reinforced the similarity of the forms of concrete arches and masonry arches while providing a reassuring transition to a new design. It was also a response to the City Beautiful Movement of the 1890s and early twentieth century that encouraged aesthetically attractive urban areas. For many people, only stone bridges were aesthetically attractive.

Builders could create other finishes from concrete itself with such methods as "cement washing, tooling, sandblasting, rough casting or slap dashing, scrubbing, cold water painting, and acid treating" (Tyrrell 1909:60). For instance, the 1925 Indian Creek Bridge in rural Hardin County (#114, 36-A0446-00.04) has bush hammered depressed panels in the spandrels as a decorative feature. The Chickasaw Gardens Bridge in Memphis (#117, 79-B0741-00.01), which a developer built in 1926 for an exclusive subdivision, has a washed rock finish that creates a rough exposed aggregate appearance.

In addition to the type of finish, concrete bridges often contained some type of decorative motif. The railing usually featured on both sides an incised decorative design, most commonly rectangular

Figure IV-11, Various Decorative Treatments on Concrete Arch Bridges: *Top*, urn shaped balusters on the rail, (#103, 95-02036-01.51, Main Street in Watertown), built by Luten in 1921; *below*, modillions, incised lines in a chevron pattern, and a band along the arch; on a few bridges, this line was scored to imitate masonry, (#118, 15-SR009-21.60, built 1928, east of Newport;

right, incised star and rectangular designs (#98, 05-NonHighway-1, the Walland Bridge east of Maryville in Blount County), built by Luten in 1918; and *bottom*, incised rectangular, diamond, and triangular designs; (#79, 28-01891-04.77, northwest of Pulaski in Giles County), built by Luten in 1914.

in shape. Other shapes included diamond, hexagonal, and star patterns or a combination. The Clinch Avenue Viaduct in Knoxville (#48, 47-A0135-00.42) contained an unusually elaborate rail treatment, a fleur-de-lis design. Builders occasionally used urn shaped balusters rather than a plain post and rail railing. All of Tennessee's extant examples are located in towns, and a possible conclusion is that builders or cities perceived this feature as an urban amenity, related to the City Beautiful movement. Some builders placed elaborate light fixtures such as Ionic columns on rails. Again, all of Tennessee's extant examples are located in urban areas. Many builders defined the barrel of the arch with a single incised line along the curve of the arch, delineating the extrados. This decorative feature resembled a ring-course of voussoirs on a masonry arch. From a practical standpoint, it may also have allowed additional room for the metal reinforcing rods within the arch. Occasionally, builders delineated an incised triangle in the spandrel area or added a string course at road level. Arched columns that created a colonnade effect formed another decorative feature.

Possibly because concrete itself was so easy to form into decorative shapes, bridge plaques on these bridges are normally quite plain. However, another factor may have been the post-Victorian time period when even truss plaques were relatively simple. Another difference is that builders normally placed plaques on concrete arch bridges on the inside of the railing (rather than at the portal). Plaques located on the inside of the rail, either at the end posts or at mid point of the bridge, are not as readily visible as plaques on most trusses.

In the 1930s, it was common for many New Deal projects to face concrete structures for aesthetic appearances. An example is the 1936-1938 Cumberland Mountain State Park Dam in Cumberland

Figure IV-12: 1930s Photograph of the Loop Bridge on State Route 71, Great Smoky Mountains National Park, Sevier County (#141, 78-SR071-05.85) (Author's Collection).

County (#147, 18-01166-03.59), a concrete arch structure faced with stone. The "Parkitecture" movement in the 1920s and 1930s expanded on the judgmental view that masonry was more attractive than concrete and espoused stone as an ideal finishing material that blended man made structures with the natural environment. The seven concrete and stone bridges on Newfound Highway in Sevier County within the Smoky Mountain State Park (#s141-146, 148; 78-SR71), built through the National Park Service as New Deal projects in 1937, are an excellent example of this movement. The bridges, culverts, tunnels, curbs, and retaining walls along the highway form a cohesive unit through the use of natural stone materials that blend the roadway with the surrounding terrain. Of note is the "Loop Bridge" (or "pig-tail" bridge) that crosses over and under itself. This bridge replaced two steep switchbacks (or "hair-pin" curves) which Park Service philosophy deemed as unsightly and, from a practical standpoint, allowed the motorist to easily navigate a steep slope.

However, notwithstanding the Parkitecture movement, an understanding and appreciation of concrete's building potential and aesthetic value evolved. This trend became evident in both the graceful and soaring arch designs, which clearly proclaimed that the bridges were concrete, as well as in the finishing touches of decorative details.

From a technological standpoint, engineers began to experiment with pre-stressing concrete in the early twentieth century although they did not widely use this method until the 1940s. Pre-stressing is a method to introduce internal stresses, such as with steel reinforcing bars stretched or stressed while curing within concrete, which counteract any external loading stresses and thus compensate for the low tensile strength of concrete. Prior to pre-stressing, the weight of concrete limited its use for long spans. With this innovation, concrete became even more widely used leading to its popularity today.

Although concrete arch bridges originally imitated the shape and appearance of masonry arch bridges, they gradually found their own identity, first as veneered or unfaced barrel arches and later as open spandrel arches and ribbed arches. As experimentation and technological advances continued in concrete, this evolution resulted in the increased use of concrete for long and short girder spans. These new forms of concrete bridges were more economical and practical for substantially longer spans and soon replaced concrete arches of any style. Thus, the experimentation that brought concrete arches into their own as a form paradoxically led to their demise as more efficient and cost effective concrete designs replaced them.

CONCRETE ARCHES IN TENNESSEE: Tennessee builders were slow to adapt the use of concrete arches for vehicular bridges. Other than several railroad overpasses, the survey inventoried only five pre-1910 concrete arch bridges in Tennessee. The 1903-1905 Evergreen Cemetery Bridge in Memphis (#44, 79-E0578-00.21), built as a cooperative project by several railroads, contains one unique 100-foot span. The 1905 Clinch Avenue Viaduct in Knoxville (#48, 47-A0135-00.42), built by the railroads and the city, is a fifteen span viaduct with an elaborately decorated railing. Landscape gardeners O. G. Simonds and Company of Chicago designed the 1906 Belle Meade Bridge in Nashville (#51, 19-B0983-01.61), a one span bridge faced with masonry, located at the entrance to an exclusive residential development. The Dixie Portland Cement Company built the Cumberland Avenue Bridge in Richard City in Marion County (#53, 58-A0443-00.50) in 1906 as part of a planned town designed by an engineering firm. The Centennial Park Bridge in Nashville (#66, 19-NonHighway-4) is a small one span structure built in 1909. No city or county government built these bridges as a typical vehicular bridge. In each case, atypical building circumstances (a railroad as the lead agency, a landscaping or engineering firm's involvement, or the location in a major urban park) influenced the innovative design.

One noteworthy experiment in concrete is the concrete deck trusses on the 1909 Shelby Street Bridge in Nashville (#58, 19-03245-01.47). Designed by local engineer Howard Jones, the bridge's two approach spans each contained three parallel arched deck trusses. While arched in appearance, each functions as a concrete truss; the concrete only acts as a stiffener and as protection for the steel rods within the concrete that comprise one tenth of the arch area. As one engineering publication explained, the "bottom chords act as ties to take the horizontal components of the end thrusts of the arched top chords" (Creighton 1909:200). Thus, while the spans are trusses and partially function as trusses, they also distribute the forces or stresses within the span similar to the way an arch does.

The novel design caused some local engineers to question its stability. To test his design, (and, hopefully, to quieten his critics), Jones built an eleven-foot model, one-tenth the size of the longest truss. He planned to load it with bricks until it collapsed. However, after the load reached 17,000 pounds it became too top heavy to continue loading. His design was obviously structurally sound (Nolen 1983:20). Even so, skepticism remained, and when the county opened the bids for the contract, one firm had bid $100 per cubic yard as opposed to the $17.25 bid by the Foster-Creighton firm that received the contract.

Wilbur Creighton of the Foster-Creighton Company wrote that while he was outwardly confident about building these spans, he was somewhat worried since he knew of nothing else similar to them. By trial and error, he developed a system to pour the "bowstring" upper chord. One morning during their construction, as Creighton traveled to work, he heard a thunderous crash from the bridge site. Believing that the trusses had collapsed he hurried to the site only to discover, to his relief, that a water tank from a nearby building had fallen to the ground (Nolen 1983:1-2).

Research by Canadian historians indicates that a 1909 bridge in Ontario and the Shelby Street Bridge are the two oldest extant tied concrete trusses in North America (Morrison 1985:1). It is possible that these two bridges were the first of this type built, or at least among the earliest built. While builders never extensively erected the concrete arched truss, its design is significant as an innovative experiment in concrete that broke with the traditional imitation of masonry arch bridges.

Not until the 1910s did concrete arch bridges become widespread in Tennessee. About 1912 the national leader in concrete arch bridges, the Luten Company of Indianapolis, briefly opened a branch office in Nashville before moving it to Knoxville where it operated under the supervision of George Daugherty until 1946. With Luten's arrival in Tennessee, many counties began to contract for concrete arch bridges and a few local builders copied Luten's designs. Some counties even passed resolutions in their county court minutes stipulating a preference for concrete over steel truss bridges. Although concrete arch bridges became popular in Tennessee, they did not dominate the bridge industry, and most counties continued to primarily build steel truss bridges. Prior to 1920 in Tennessee, builders erected only the filled spandrel design, which duplicated the form of masonry arch bridges. Examples of the filled spandrel arch, the most prevalent concrete arch design in Tennessee, date from 1903 through 1951. Of Tennessee's 307 pre-1946 concrete arch bridges, 256 or 83% are filled spandrel arches. See Table IV-04. Three post 1945 concrete arch bridges remain in Tennessee and all are filled spandrel arches; see Appendix A. Railroads introduced the filled barrel arch to Tennessee around the turn of the century. In the 1910s the Luten Bridge Company dominated the field in Tennessee, but from about 1920 until the early 1930s, Luten shared the field with the Steel-Roehl-Lebby firm. A variety of other firms practiced to a lesser extent in the state. Twenty-nine of these 256 bridges (11%) are eligible for the National Register.

Table IV-04: Pre-1946 Filled Spandrel Arches in Tennessee

ELIGIBLE? # in CH. 6	COUNTY	BRIDGE NUMBER	CROSSING	DATE BUILT and BUILDER	# ARCH SPANS and RAIL
Yes: #44	Shelby	79-E0578-00.21	Railroads	1903-1905 Frisco RR	1-Parapet
No	Humphreys	43-A0195-00.63	Roads	1905 L& N RR	1-None
Yes: #48	Knox	47-A0135-00.42	Railroads	1905 Edwin Thacher	10-Parapet
No	Hawkins	37-A0337-00.24	Road	1905 est; Southern RR	1-None
No	Hawkins	37-A0461-00.05	Road	1905 est; Southern RR	1-None
No	Hawkins	37-A0830-00.06	Road	1905 est; Southern RR	1-None
Yes: #51	Davidson	19-B0983-01.61	Richland Creek	1906	1-Parapet
Yes: #53	Marion	58-A0443-00.50	Poplar Springs Branch	1906	1-Parapet
No	Polk	70-A0356-02.40	Road & Mason Branch	1906 est; L & N RR	1-None
No	Hamilton	33-A0838-00.41	Road	1907 Southern RR	1-None
No	Hamilton	33-A0851-00.29	Road	1907 Southern RR	1-None
No	Sullivan	82-B0194-00.38	Road	1907 Clinchfield RR	1-None
No	Washington	90-03964-03.95	Road	1907 Clinchfield RR	1-None
No	Washington	90-04237-04.23	Road	1907 Clinchfield RR	1-None
No	Washington	90-04242-00.48	Road	1907 Clinchfield RR	1-None
No	Hamilton	33-E0068-01.54	Road	1909 est; Southern RR	1-None
No	Hamilton	33-E0073-00.87	Road	1909 est; Southern RR	1-None
Yes: #66	Davidson	19-NonHighway-4	Duck Pond	1910 Foster-Creighton	1-Parapet
No	Davidson	19-B0269-01.17	Hogan Road	1910 est; L & N RR	1-None
No	Hawkins	37-A0603-02.92	Road	1910 est; Clinchfield RR	1-None
No	Lauderdale	49-01482-00.04	Road	1910 est; ICG RR	1-None
No	Lauderdale	49-A0485-01.85	Road	1910 est; ICG RR	1-None
No	Monroe	62-A0384-01.77	Road	1910 est; L & N RR	1-None
No	Monroe	62-A0810-00.18	Road	1910 est; L & N RR	1-None
No	Bedford	02-A0260-00.36	Flat Creek	1913 Luten	2-Parapet
No	Davidson	19-F0209-00.18	Branch	1913 Luten	1-Parapet
No	Grundy	31-A0249-01.03	Little Fiery Gizzard	1913 Silica	3-Curb
No	Maury	60-B0021-01.59	Snow Creek	1913	2-Parapet
No	Maury	60-A0424-00.04	Curry Branch	1913 est	1-Parapet
Yes: #79	Giles	28-01891-04.77	Big Creek	1914 Luten	2-Parapet
No	Loudon	53-SR072-03.01	Fork Creek	1914 Luten	1-Parapet
No	Loudon	53-SR072-08.78	Clear Creek	1914 Luten	1-Parapet
Yes: #80	Loudon	53-02507-08.23	Pond Creek	1914 Luten	1-Parapet

No	Wilson	95-A0328-00.12	Beech Log Creek	1914 Luten	2-Parapet
No	Wilson	95-A0731-00.02	Branch	1914 Luten	2-Parapet
No	Wilson	95-A0328-01.25	Branch	1914 est	1-Parapet
No	Blount	05-A0004-00.51	Baker Creek	1915 Luten	1-Parapet
No	Blount	05-A0782-00.05	Little Nine Mile Creek	1915	1-Parapet
No	Blount	05-A0863-01.30	Nine Mile Creek	1915 Sullinger-Ferris	2-Parapet
No	Knox	47-02407-05.46	Stock Creek	1915 Luten	1-Parapet
No	Knox	47-03771-00.34	Fourth Creek	1915 Luten	1-Parapet
No	Knox	47-A0040-01.43	Stock Creek	1915 Luten	1-Parapet
No	Knox	47-D0841-00.61	Roseberry Creek	1915 Luten	2-Parapet
No	Knox	47-D0959-01.98	Stock Creek	1915 Luten	1-Parapet
No	Maury	60-SR247-02.50	Turkey Creek	1915	1-Parapet
No	Sevier	78-02421-09.85	Birds Creek	1915 Luten	1-Parapet
No	Sevier	78-A0491-00.56	W Prong Little Pigeon	1915 Luten	3-Parapet
No	Shelby	79-J0125-00.26	Gayoso Bayou	1915	1-Curb
No	Wilson	95-A0265-01.33	Round Lick Creek	1915 Luten	3-Parapet
No	Wilson	95-A0282-00.23	Neal Branch	1915 Luten	1-Parapet
No	Blount	05-A0024-02.39	Floyd Creek	1915 est	1-Gone
No	Blount	05-A0770-00.40	Centenary Creek	1915 est	1-Parapet
No	Carter	10-A0273-00.13	Little Doe Creek	1915 est	3-Parapet
No	Carter	10-A0327-00.02	Doyle Creek	1915 est	4-Parapet
No	Carter	10-A06242-01.44	Doe River	1915 est	3-Parapet
No	Cocke	15-NonHighway-1	Branch	1915 est	1-Parapet
No	Davidson	19-D0480-00.20	Litton Street	1915 est; L & N RR	1-Parapet
No	Grainger	29-SR092-09.16	Richland Creek	1915 est	2-Parapet
No	Hawkins	37-SR066-01.76	Walkers Creek	1915 est	1-Gone
No	Hawkins	37-SR066-02.60	Branch	1915 est	1-Gone
No	Knox	47-A0122-01.33	Road	1915 est; Southern RR	1-None
No	Knox	47-NonHighway-1	Roseberry Creek	1915 est	1-None
No	Maury	60-A0200-00.01	Silver Creek	1915 est	2-Parapet
No	Maury	60-NonHighway-8	Beech Creek	1915 est	1-Parapet
No	Roane	73-A0017-00.45	Branch	1915 est	1-Parapet
No	Sevier	78-B0006-00.07	W Prong Little Pigeon	1915 est	3-Urn/Gone
No	Williamson	94-A0054-00.00	Road	1915 est; L & N RR	1-Parapet
No	Maury	60-A0224-02.16	Hurricane Creek	1915-1916	1-Parapet
Yes: #86	Roane	73-01226-00.50	Emory River	1915-1918 Luten	7-Parapet
No	Carter	10-A0273-03.15	Doe River	1916 Luten	4-Parapet

No	Carter	10-A0702-00.81	Buck Creek	1916 Luten	2-Parapet
No	Maury	60-A0008-00.83	Greenlick Creek	1916	1-Parapet
No	Maury	60-A0116-00.44	McCutcheon Creek	1916	1-Parapet
No	Maury	60-A0116-00.98	McCutcheon Creek	1916	2-Parapet
No	Maury	60-A0230-00.01	Fountain Creek	1916	2-Parapet
Yes: #88	Maury	60-A0358-00.42	Big Bigby Creek	1916 W. B. King	5-Parapet
No	Maury	60-A0392-00.08	Scotts Creek	1916	2-Curb
Yes: #89	Unicoi	86-A0068-00.89	Nolichucky River	1916 Luten	5-Parapet
No	Blount	05-A0545-01.17	Ellejoy Creek	1916 est	1-Parapet
No	Carter	10-NonHighway-1	Doe River	1916 est	3-Parapet
No	Carter	10-NonHighway-2	Doe River	1916 est	3-Parapet
No	Sumner	83-A0086-00.01	Station Camp Creek	1916-1917 Luten	3-Parapet
No	Cocke	15-SR160-05.04	Dry Fork Creek	1917 Luten	1-Parapet
No	Grainger	29-01213-02.49	Richland Creek	1917 Luten	1-Parapet
Yes: #94	Maury	60-NonHighway-4	Beard Creek	1917	1-Parapet
No	Roane	73-03698-00.10	Black Creek	1917 Luten	1-Urn
No	Unicoi	86-SR107-03.27	Indian Creek	1917 Luten	1-Parapet
No	Unicoi	86-A0020-00.17	South Indian Creek	1917 ca.	2-Parapet
No	Unicoi	86-A0038-00.10	Rocky Fork Creek	1917 ca.	1-Parapet
No	Maury	60-SR247-15.76	Carter's Creek	1917 est	2-Parapet
No	Cocke	15-SR160-09.00	Slate Creek	1917-1919 Luten	1-Parapet
Yes: #98	Blount	05-NonHighway-1	Little River	1918 Luten	3-Parapet
No	Cocke	15-SR160-03.50	Clay Creek	1918 Luten	2-Parapet
No	Giles	28-A0057-01.43	Big Creek	1918 Luten	2-Parapet
No	Maury	60-01905-07.40	Knox Creek	1918	3-Parapet
No	Unicoi	86-A0049-00.02	South Indian Creek	1918 Luten	2-Parapet
No	Knox	47-D0982-00.87	Stock Creek	1918 est	1-Parapet
No	Maury	60-A0171-01.48	Hurricane Creek	1918 est	2-Post
No	Maury	60-A0171-03.33	Goose Creek	1918 est	1-Par/Gone
No	Maury	60-A0378-00.19	Sugar Creek	1918 est	1-Parapet
No	Cocke	15-SR035-08.17	Clear Creek	1919 Luten	1-Parapet
No	Cocke	15-SR035-09.65	Clear Creek	1919 Luten	1-Parapet
No	Rutherford	75-A0195-02.19	Fall Creek	1919 Luten	1-Parapet
No	Blount	05-A0003-00.91	Baker Creek	1920 Luten	2-Parapet
No	Giles	28-A0401-00.03	W Fork Shoals Creek	1920 Luten	1-Parapet
Yes: #100	Smith	80-01068-03.16	Hickman Creek	1920 Luten	4-Parapet
No	Wilson	95-A0727-00.03	Stoners Creek	1920 Luten	1-Parapet

No	Benton	03-A0275-04.01	Road	1920 est; L & N RR	1-None
No	Benton	03-A0439-01.25	Road	1920 est; L & N RR	1-None
No	Blount	05-NonHighway-2	Nine Mile Creek	1920 est	1-Parapet
No	Cocke	15-SR032-21.47	English Creek	1920 est	1-Gone
No	Dickson	22-A0338-00.02	Road	1920 est; L & N RR	1-None
No	Dyer	23-SR020-14.49	Branch	1920 est	1-Parapet
No	Greene	30-02578-03.13	Meadow Creek	1920 est	1-None
No	Greene	30-A0486-01.86	Road	1920 est; Southern RR	1-None
No	Greene	30-A0824-01.25	Richland Creek	1920 est	1-Post
No	Hamilton	33-B0515-00.66	Road	1920 est; Southern RR	1-None
No	Knox	47-01124-00.94	Williams Creek	1920 est	1-Parapet
No	Knox	47-02424-04.42	Tuckahoe Creek	1920 est	1-Parapet
No	Knox	47-A0106-01.01	First Creek	1920 est	1-Parapet
No	Knox	47-C0491-00.01	Love Creek	1920 est	2-Parapet
No	Knox	47-E0582-00.30	First Creek	1920 est	2-Post
No	Loudon	53-02362-01.45	Muddy Creek	1920 est	1-Parapet
No	Maury	60-A0446-00.90	Kettle Branch	1920 est	1-Parapet
No	Maury	60-NonHighway-4	Beard Branch	1920 est	1-Parapet
No	Monroe	62-A0033-00.22	Sweetwater Creek	1920 est	1-Parapet
No	Monroe	62-A0081-01.20	Sweetwater Creek	1920 est	1-Parapet
No	Sevier	78-B0271-00.77	E Prong Little Pigeon	1920 est	1-Parapet
No	Shelby	79-J0126-00.10	Bayou	1920 est	1-Curb
No	Union	87-A0317-02.46	Flat Creek	1920 est	1-Post
No	Wilson	95-01950-02.99	North Creek	1920 est	1-Gone
No	Wilson	95-A0213-04.17	Jennings Creek	1920 est	3-Parapet
No	Wilson	95-NonHighway-1	Cedar Creek	1920 est	1-Parapet
No	Wilson	95-NonHighway-2	Spencer Creek	1920 est	2-Parapet
No	Wilson	95-NonHighway-3	Spencer Creek	1920 est	4-Parapet
No	Blount	05-A0551-00.05	Little River	1920-1921	1-Parapet
No	Hawkins	37-A0355-00.18	Bradley Creek	1920-1922 State	1-Gone
No	Campbell	07-SR009-24.12	Big Creek	1921 Luten	1-Parapet
No	Giles	28-01902-03.23	Little Bradshaw Creek	1921 Nashville Bridge	1-Parapet
No	Giles	28-A0218-00.15	Little Creek	1921	1-Parapet
No	Greene	30-02592-05.86	Guest Creek	1921 Steel & Roehl	1-Post
No	Greene	30-A0988-01.21	Little Chucky Creek	1921 Steel & Roehl	1-Post
No	Jefferson	45-A0145-00.01	Lost Creek	1921 Luten	1-Parapet
No	Perry	68-A0302-03.85	Poole Lake	1921 Nashville Bridge	2-Parapet

No	Van Buren	88-A0015-01.75	Laurel Creek	1921 Concrete	1-Post
Yes: #103	Wilson	95-02036-01.51	Round Lick Creek	1921 Luten	2-Urn
No	Wilson	95-NonHighway-5	Spring Creek	1921	1-Parapet
No	Greene	30-02521-00.36	College Creek	1921 ca.	1-Gone
No	Maury	60-A0424-02.16	Baptist Creek	1921 est.	2-Parapet
Yes: #104	Giles	28-A0334-00.33	Jenkins Branch	1921-22; Nashville Bridge	1-Parapet
No	Campbell	07-02425-03.64	Cove Creek	1922	1-Parapet
No	Campbell	07-02425-06.24	Cove Creek	1922	1-Parapet
No	Greene	30-02391-16.03	Union Temple Creek	1922 Steel & Roehl	1-Post
No	Greene	30-A0163-03.17	Hoover Creek	1922 Steel & Roehl	1-Post
No	Greene	30-A0653-05.20	Mud Creek	1922	1-Post
No	Knox	47-C0590-00.66	First Creek	1922	1-Parapet
Yes: #106	Sevier	78-01284-00.56	Birds Creek	1922 Steel & Roehl	1-Post
No	Sevier	78-01284-00.89	Birds Creek	1922 Steel & Roehl	1-Post
No	Warren	89-A0425-00.86	W Fork Hickory Creek	1922 Nashville Bridge	2-Parapet
No	Grainger	29-01213-11.98	Bethel Branch	1923 Steel & Roehl	1-Post
No	Grainger	29-01328-00.91	Branch	1923 Steel & Roehl	1-Post
No	Grainger	29-02473-00.24	Richland Creek	1923 Steel & Roehl	1-Post
No	Grainger	29-02473-00.38	Rocky Creek	1923	1-Gone
No	Grainger	29-A0412-00.22	Branch	1923 Steel & Roehl	1-Post
No	Greene	30-A0309-01.23	Lick Creek	1923 Steel & Roehl	1-Post
No	Greene	30-A0309-02.19	Lick Creek	1923 Steel & Roehl	1-Post
No	Greene	30-A0949-01.50	Little Chucky Creek	1923 Steel & Roehl	1-Post
No	Wilson	95-01067-14.07	Lick Creek	1923 Luten	1-Parapet
No	Blount	05-SR035-05.34	Little River	1924 Luten	3-Parapet
No	Greene	30-A0309-00.62	Lick Creek	1924 Steel & Lebby	1-Post
No	Maury	60-A061-02.91	Duck Creek	1925 Luten	3-Parapet
No	Montgomery	63-00973-02.06	Branch	1925 State	1-Spindle
No	Smith	80-A0174-03.05	Hickman Creek	1925 Bell & Bell	2-Parapet
No	Campbell	07-2425-05.60	Cove Creek	1925 est	1-Parapet
No	Davidson	19-C0300-00.14	Road	1925 est; L & N RR	1-None
No	Davidson	19-C0301-00.18	Road	1925 est; L & N RR	1-None
No	Giles	28-01875-02.72	E Fork Shoals Creek	1925 est	1-Parapet
No	Giles	28-A0302-00.05	Blue Creek	1925 est	1-Parapet
No	Polk	70-SR030-08.09	Branch	1925 est	1-Parapet
No	Polk	70-SR030-08.24	June Bug Creek	1925 est	1-Parapet
No	Roane	73-A0069-01.12	Hurricane Creek	1925 est	1-Parapet

No	Wilson	95-A0320-05.89	Rocky Branch	1925 est	1-Parapet
Yes: #114	Hardin	36-A0446-00.43	Indian Creek	1925-1926 State	1-Parapet
No	Davidson	19-SR006-20.11	Dry Creek	1926 State	2-Gone
No	Maury	60-01916-00.09	Little Bigby Creek	1926	1-Post
Yes: #117	Shelby	79-B0741-00.01	Cypress Creek	1926	3-Post
No	Sullivan	82-A0456-01.50	Beaver Creek	1926 est	1-Gone
No	Maury	60-B0029-00.01	Little Bigby Creek	1926-1927	1-Parapet
No	Morgan	65-SR029-19.94	Rock Creek	1926-1928	2-Curb
No	Carter	10-A0317-00.01	Doe River	1927	2-Post
No	Knox	47-01262-01.99	Flat Creek	1927	1-Gone
No	Maury	60-SR245-09.92	Little Bigby Creek	1927	2-Parapet
No	Wilson	95-A0725-00.29	Branch	1927 Luten	1-Post
No	Wilson	95-SR141-00.89	Branch	1927 est	1-Post
No	Wilson	95-02038-01.91	Spring Creek	1927 est	3-Parapet
No	Dickson	22-00967-05.11	Branch	1928 est	2-Curb
No	Greene	30-02590-05.30	Gap Creek	1928 est	1-None
No	Roane	73-02366-05.52	Paw Paw Branch	1928 est	1-Post
No	Davidson	19-SR024-16.34	Mill Creek	1928-1929 State	1-Parapet
No	Giles	28-SR015-09.71	Branch	1928-1929 State	1-Curb
Yes: #126	Campbell	07-A0080-00.49	Stinking Creek	1929 Steel & Lebby	2-Post
No	Campbell	07-A0080-00.80	Stinking Creek	1929 Steel & Lebby	2-Post
No	Maury	60-01903-00.03	Bear Creek	1929	2-Parapet
No	Dickson	22-SR048-24.06	Furnace Creek	1929-1930 State	2-None
No	Maury	60-A0433-00.01	Catheys Creek	1930	2-Parapet
No	Maury	60-B0027-00.01	Little Bigby Creek	1930	1-Parapet
No	Williamson	94-SR011-07.73	Wilson Branch	1930 State	1-None
No	Carter	10-03990-00.34	Buffalo Creek	1930 est	1-Parapet
No	DeKalb	21-02148-02.30	Smith Fork Creek	1930 est	3-Parapet
No	Franklin	26-A0589-00.10	Crow Creek	1930 est	1-Post
No	Giles	28-A0116-00.09	Robertson Fork Creek	1930 est	1-Parapet
No	Greene	30-02527-01.27	Sinking Creek	1930 est	1-Post
No	Greene	30-B0059-00.15	Gap Creek	1930 est	1-Parapet
No	Knox	47-SR001-17.64	Third Creek	1930 est	1-Gone
No	Knox	47-C0199-01.42	Beaver Creek	1930 est; Steel & Lebby	1-Post
No	Maury	60-A0229-00.05	Fountain Creek	1930 est	1-Parapet
No	Maury	60-A0229-01.50	S Fork Fountain Creek	1930 est	1-Parapet
No	Maury	60-A0418-01.77	Dog Branch	1930 est	1-Parapet

No	Monroe	62-SR072-05.17	Branch	1930 est	1-Parapet
No	Sumner	83-A0616-00.09	Donaho Branch	1930 est	3-Curb
No	Warren	89-02171-05.90	Hickory Creek	1930 est	2-Post
Yes: #134	Anderson	01-A0136-01.96	Hinds Creek	1931 Luten	1-Post
No	Maury	60-A0091-02.00	Fountain Creek	1931	1-Parapet
No	Shelby	79-SR057-02.72	Cypress Creek	1931 State	1-Spindel
No	Maury	60-A0089-03.18	Terrell Branch	1932	1-Parapet
No	Shelby	79-SR003-12.73	Gayoso Branch	1932-1933 State	1-Curb
No	Hamilton	33-SR002-03.33	Wauhatchie Pike	1933 est; Southern RR	1-None
No	Scott	76-A0063-00.84	Roaring Paunch Creek	1933 est	1-Spindle
Yes: #136	Anderson	01-SR071-04.79	Hinds Creek	1934 TVA	1-None
Yes: #141	Sevier	78-SR071-05.85	State Route 71	1935 NPS	1-Parapet
No	Campbell	07-A0090-00.01	Terry Creek	1935 est	1-Parapet
Yes: #142	Sevier	78-SR071-08.54	W Prong Little Pigeon	1936 NPS	1-Parapet
Yes: #143	Sevier	78-SR071-05.65	Cole Branch	1936-1937 NPS	1-Parapet
Yes: #144	Sevier	78-SR071-05.23	Walker Camp Prong	1936-1937 NPS	2-Parapet
Yes: #145	Sevier	78-SR071-02.83	W Prong Little Pigeon	1936-1937 NPS	1-Parapet
Yes: #146	Sevier	78-SR071-01.98	Walker Camp Prong	1936-1937 NPS	1-Parapet
Yes: #147	Cumberland	18-01166-03.59	Byrds Creek & Lake	1936-1938 CCC	15-Parapet
No	Bedford	02-SR016-13.08	Dry Creek	1937 State	1-Curb
Yes: #148	Sevier	78-SR071-13.31	W Prong Little Pigeon	1937 NPS	3-Parapet
No	Sevier	78-SR071-15.85	Roaring Fork Creek	1938 State	1-Spindle
No	Dickson	22-SR001-15.42	Wildcat Branch	1939 State	1-None
No	Dickson	22-SR001-15.64	Branch	1939 State	1-None
No	Hickman	41-SR050-29.62	Boat Branch	1939 State	1-None
No	Knox	47-SR001-04.10	N Fork Turkey Creek	1939 State	1-Spindle
No	Dyer	23-A0282-00.85	Branch	1940 est	1-Curb
No	Madison	57-03046-01.29	Sandy Branch	1940 est	1-None
No	Madison	57-03047-01.28	Sandy Branch	1940 est	1-Curb
No	Madison	57-B0145-00.63	Sandy Branch	1940 est	1-Curb
No	Marshall	59-SR106-03.22	Wrights Branch	1940 est	1-Post
No	Maury	60-SR247-18.46	Branch	1940 est	1-Gone
No	Shelby	79-04386-00.30	Ditch	1940 est	1-None
No	Shelby	79-B0594-02.91	Cypress Creek	1940 est	3-Post
No	Tipton	84-01476-00.28	Road	1940 est; ICG RR	1-None
No	Tipton	84-A0252-01.33	Road	1940 est; ICG RR	1-None
No	Sumner	83-SR109-14.96	Tuckers Creek	1941 State	1-Curb
No	Davidson	19-SR001-19.20	Browns Creek	1942	1-Spindle

After World War I, a variety of factors changed concrete arch building in Tennessee. By the late 1910s, concrete arch bridges were becoming increasingly popular. A lawsuit in 1918, which largely negated Luten's patents, made it easier for other companies to compete with Luten. Also engineers had developed new designs for concrete arches that did not rely on the traditional barrel arch. Tennessee native John Steel took full advantage of this new development. Steel returned to Knoxville about 1919 after serving in World War I and after briefly studying bridge design at France's Ecole des Ponts et Chausses, a school that promoted concrete arch designs. Steel worked with Otto Roehl from about 1919 to 1924 as a specialist in concrete design but then formed a partnership with Thomas Lebby and established the Steel and Lebby Company. Steel advocated concrete arch designs, and over the next decade, his firm built few truss bridges.

The Luten Bridge Company and the Steel-Roehl-and-Lebby firm dominated the construction of concrete arch bridges in Tennessee. Yet, their influence took quite different directions. Luten, who in its early years specialized in the filled spandrel design, was the first to build concrete arches on a statewide basis, which introduced the arch to a broad audience, enhancing its popularity and its replication by other builders. Small local contractors, many who probably could not even be termed bridge companies, built a few concrete arch bridges. The work of W. B. King of Maury County (see #88, 60-A0358-00.42) illustrates this trend. Some larger out of state companies such as the Concrete Steel Bridge Company of West Virginia executed some contracts in Tennessee but not to any great extent. Even the Nashville Bridge Company, which had a regional reputation in building steel truss bridges, erected only a few concrete arch bridges (for example #104, 28-A0334-00.33). The State Highway Department built several concrete arch bridges of different designs in the 1920s and 1930s (for example: #114, 36-A0446-00.43, a filled spandrel or #107, 89-A0278-00.31, an open spandrel). Yet, in sheer number and in name recognition, Luten dominated the field in Tennessee.

While smaller in both the region it served and the number of bridges it built, the Steel and Lebby Company was more influential from a design standpoint. Luten chose more traditional concrete arch designs, probably due to its established reputation based on early patents. On the other hand, Steel-Roehl-and-Lebby chose newer variations and more experimental designs, probably in an effort to attract attention and establish its own reputation. Although the firm built filled spandrel arches, it also built open spandrel and ribbed arch designs that were markedly different from Luten's trademark solid barrel arch. Steel-Roehl-and-Lebby played a major role in the break from traditional designs that imitated masonry arches and significantly expanded the range of concrete arch design in Tennessee.

The open spandrel arch is the first clear break with traditional barrel arches. Steel and Roehl built the oldest known extant open spandrel arch in Tennessee, the 1921 Rainbow Bridge in Greene County (#102, 30-NonHighway-1). The survey inventoried twenty-two open spandrel arches that comprise 7% of the total 307 concrete arches. Constructed between 1921 and 1936, the Steel-Roehl-Lebby Company, the State Highway Department, and the Luten Bridge Company built most of these bridges. See Table IV-05. One of these open spandrel arches, the Mascot/McBee Ferry Bridge (47-01262-04.68), is a "Rainbow" through arch. Eight of these 22 bridges (36%) are eligible for the National Register.

The ribbed spandrel arch, the third type of concrete arch bridge to be built in Tennessee, is a variation of the traditional barrel arch. Builders erected Tennessee's extant 30 ribbed spandrel arches between 1921 and 1934. Of the 307 concrete arch bridges, these 30 bridges comprise 10% of the total. The Luten Bridge Company erected most of these bridges (see Table IV-06). Five of the 30 (17%) are eligible for the National Register.

Table IV-05: Pre-1946 Open Spandrel Arches in Tennessee

ELIGIBLE? # IN CH. 6	COUNTY and NUMBER	CROSSING	DATE BUILT	BUILDER	ARCH SPANS and RAILING
Yes: #102	Greene 30-NonHighway-1	Camp Creek	1921	Steel & Roehl	1 deck arch with 2 arched spandrel ribs; post rail
Yes: #107	Warren 89-A0278-00.31	Rocky River	1922-23	State	1 deck arch with 2 straight spandrel ribs; parapet railing
No	Morgan 65-02378-12.80	Branch	1923	Steel & Lebby	1 deck arch with 2 straight spandrel ribs; post railing
Yes: #110	Polk 70-02268-01.51	Conasauga River	1923	Steel & Roehl	1 deck arch with 2 straight spandrel ribs; post railing
No	Campbell 07-SR116-00.04	New River	1924	Luten	1 deck arch with 2 straight spandrel ribs; post railing
No	Greene 30-A0202-00.06	Lick Creek	1924 est	Steel & Lebby	1 deck arch with 2 straight spandrel ribs; post (gone) railing
No	Greene 30-A0303-00.74	Lick Creek	1925 est		1 deck arch & 2 straight spandrel ribs; railing unknown (gone)
No	Greene 30-A0879-01.69	Branch	1925 est		1 deck arch with 2 straight spandrel ribs; post railing
No	Sevier 78-02421-12.51	Little Pigeon River	1925 est		1 deck arch with 2 straight spandrel ribs; post railing
No	Sevier 78-A0580-00.27	Waldens Creek	1925 est		1 deck arch with 2 straight spandrel ribs; post railing
No	Sevier 78-NonHighway-1	Waldens Creek	1925 est		1 deck arch with 2 straight spandrel ribs; post railing
No	Cheatham 11-01948-00.45	Big Turnbull Creek	1926-27	State	3 deck arches with 2 straight spandrel ribs; post (gone) railing
Yes #118	Cocke 15-SR009-21.60	French Broad River	1926-28	State	3 deck and two filled spandrel arches with 2 arched spandrel ribs; spindle railing
Yes: #121	Knox 47-01262-01.16	Roseberry Creek	1927	Steel & Lebby	1 deck arch with 2 straight spandrel ribs; post railing
No	Hamilton 33-SR148-00.99	Branch	1928	Steel & Lebby	3 deck arches with 3 straight spandrel ribs; post railing
No	Wilson 95-01058-05.56	Bartons Creek	1928	Luten	3 deck arches with 2 straight spandrel ribs; post railing
Yes: #128	Stewart 81-A0330-01.41	Standing Rock Creek	1929	Luten	1 deck arch with 2 straight spandrel ribs; post railing
No	Sullivan 82-SR036-05.01	Holston River	1929-30	State	3 deck arches with 2 straight spandrel ribs; spindle railing
No	Cumberland 18-SR001-34.20	Piney Creek	1929-31	State	1 deck arch with 2 straight spandrel ribs; spindle railing
Yes: #132	Knox 47-SR033-06.72	Tennessee River	1930-31	Marsh	6 deck arches with 2 straight spandrel ribs; spindle railing
Yes: #133	Knox 47-01262-04.68	Holston River	1930-31	Freeland Roberts	3 through arches with 2 straight spandrel ribs; post railing
No	Knox 47-A0129-00.08	Roads	1936	Luten	5 deck arches with 2 straight spandrel ribs; spindle railing

Table IV-06: Pre-1946 Ribbed Spandrel Bridges in Tennessee

ELIGIBLE? # IN CH. 6	COUNTY	BRIDGE NUMBER	CROSSING	DATE BUILT & BUILDER	ARCH SPANS	RAIL
No	DeKalb	21-A0278-03.69	Dry Creek	1922 Luten	2	Parapet
No	DeKalb	21-A0312-00.41	Clear Fork Creek	1922 Luten	2	Parapet
Yes: #105	Giles	28-A0002-00.23	Factory Creek	1922 Luten	1	Parapet
No	Wilson	95-A0197-03.48	Cedar Creek	1922 Luten	2	Parapet
Yes: #113	Greene	30-A0909-00.21	Nolichucky River	1925 Steel-Lebby	4	Post
No	Maury	60-01920-02.72	Loves Branch	1925	1	Gone
No	Sevier	78-02421-03.50	Little Pigeon River	1925 est	1	Post
Yes: #115**	Carter	10-03939-00.11	Doe River	1926 Luten	3	Post
No	Rutherford	75-B0084-00.09	Lytle Creek	1927 Luten	2	Post
No	Warren	89-A0419-01.40	Hickory Creek	1927 Luten	1	Post
No	Wilson	95-02032-07.54	Smith Fork Creek	1927 Luten	2	Post
No	Wilson	95-A0318-00.01	Rocky Branch	1927 Luten	2	Post
No	Wilson	95-A0470-01.04	Bartons Creek	1927 Luten	1	Post
No	Wilson	95-A0499-02.87	Cedar Creek	1927 Luten	1	Post
No	Wilson	95-A0519-01.53	Cedar Creek	1927 Luten	1	Post
No	Wilson	95-A0717-00.29	Spring Creek	1927 Luten	2	Post
No	Wilson	95-A0305-00.08	Smith Fork Creek	1927 est	1	Post
No	Humphreys	43-01781-04.15	White Oak Creek	1928 Luten	2	Post
No	Loudon	53-02551-03.67	Sweetwater Creek	1928 Luten	2	Post
No	Wilson	95-02032-07.53	Smith Fork Creek	1928 Luten	2	Post
Yes: #124	Wilson	95-A0392-02.12	Fall Creek	1928 Bell & Bell	3	Post
No	Wilson	95-SR141-17.81	Jennings Fork Cr	1928 est	1	Parapet
No**	Carter	10-SR037-22.33	Doe River	1929 Luten	5	Post
No	Grainger	29-A0096-00.08	Indian Creek	1930 Luten	1	Post
No	Franklin	26-A0123-00.78	Rock Creek	1930 est	1	Gone
No	Greene	30-01329-04.91	Richland Creek	1930 est	1	Parapet
No	Lawrence	50-A0521-04.54	Shoal Creek	1930 est	3	Post
No	Warren	89-04398-02.75	Cove Creek	1930 est	2	Parapet
Yes: #134	Anderson	01-A0136-01.96	Hinds Creek	1931 Luten	1	Post
No	DeKalb	21-A0050-04.20	Smith Fork Creek	1934 Luten	3	Post

Unless otherwise noted, all arches contain two ribs.
** Seven ribs