Property Type: Concrete Arch Bridges

Description: Concrete arches are generally defined as one of two structural types: closed spandrel and open spandrel arches. The older and more common of the two, closed spandrel arches feature solid concrete walls between the deck and the arch ring. These sidewalls act as spandrels to help support the deck's outer edges, and they also act as retaining walls to hold in the load-bearing fill material (e.g., earth, rubble, sand) between the deck and ring. The spandrels may be poured integrally with the arch rings or as separate members. In their massive profiles, closed spandrel arches resemble traditional stone arches, and some have been sided with stone veneers or formed with faux stone faces. They are typically used for relatively short span lengths, ranging from less than 20 feet up to over 200 feet. The longest closed spandrel arch known to have been constructed in Arizona is the Holbrook Arch Bridge [**abd.**], a Luten arch with a span of 174 feet.

In contrast with the closed spandrel arch, open spandrel arches feature pierced or open spandrel walls with no fill material. The live and dead loads of the deck is transferred to the arch ring by means of concrete columns or, in some cases, secondary arches. The arch ring may extend continuously over the width of the bridge or may be subdivided into separate ribs. Although open spandrel arches require more intricate formwork than closed spandrels, they consume less concrete material, and their lighter weight allows for greater span lengths.

With either open or closed spandrels, the concrete arch is a structural type that traces its origins to Roman precedents. Although the Romans had developed a form of hydraulic cement, there is no evidence to suggest that they used it for bridge construction. After Rome fell, concrete technology was lost to the Western world for over a thousand years, until it later reappeared in England. British engineer George Semple was apparently the first to use hydraulic cement for bridge construction, on pier foundations for the Essex Bridge in Dublin, built in the mid-16th century. In 1824 Englishman Joseph Aspdin developed an artificial cement composed of a calcinate mixture of limestone and clay. Aspdin called his concoction Portland cement after Portland on Devonshire, the source for his limestone. Almost 50 years later, American David O. Saylor patented his own type of Portland cement and built the country's first cement manufacturing plant near Copely, Pennsylvania.

The first documented use of concrete on an American bridge, like Semple's Essex Bridge, was not for a superstructure at all, but for the foundations of the Erie Railroad's Starrucca Viaduct, completed in 1848. John Goodrich was probably the first in this country to use concrete as the principal material for the spans of a bridge. A modest 31-foot structure built in 1871, his Cleft Ridge Park Bridge in Brooklyn's Prospect Park used concrete because it was intended to be an ornamental structure and concrete was cheaper than stone. Soon other concrete spans began to appear in this country. From 1890 to 1900, over 150 reinforced concrete spans were built on scales ranging from minimal to monumental.

see continuation sheet

These early structures were built of unreinforced, or mass, concrete, which has the same structural properties as stone. Although far stronger than either iron or wood in compression, unreinforced concrete has virtually no tensile strength. Its use in bridge work was therefore limited to an ancient structural form derived from stonemasonry—the arch. The arch rib or ring functioned essentially as an extended curved column, under compression over its entire length. Further, as a beam it had to resist the bending and shear stresses caused by shifting live loads applied to the bridge deck and differential expansion and contraction caused by weather. "It was a comparatively easy change from the stone voussoir arch to the concrete monolithic or voussoir construction," engineer Frank Barber stated in 1911.[78]

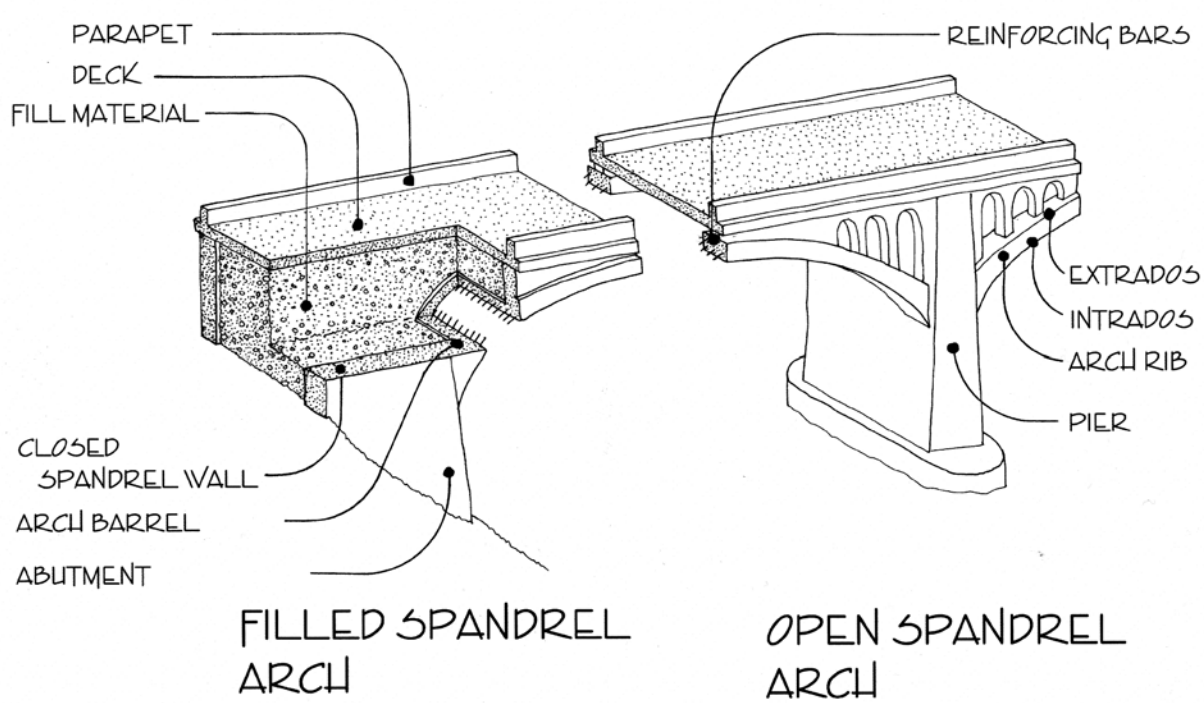

Figure 49. Concrete arch diagram.

[78]Frank Barber, "Characteristics of Long-Span Concrete Bridges," *Engineering Record* (8 April 1911): 397.

see continuation sheet

It would not be until the end of the 19th century that engineers would begin to understand and develop the plastic properties of concrete and use it as something more than just a cheap imitation of stone. To address concrete's inherent tensile shortcoming, American engineer W.E. Ward demonstrated in 1871 that the material could be strengthened to resist tension by embedding iron bars in it. Such a composite configuration would combine the compressive strength of concrete with the tensile properties of steel. The concrete would thus protect the reinforcing from corrosion and would provide an economical technological alternative to an all-metal solution by reducing the amount of steel needed to bear the weight. The application of this discovery to large-scale bridge construction should have been immediately apparent. It was not until ten years later, however, that S. Bissel received the first American patent for concrete reinforcing. The first reinforced concrete bridge built in this country was the Alvord Lake Bridge in San Francisco's Golden Gate Park, designed by Ernest Ransome and completed in 1889.

It was only after the turn of the 20th century that concrete began to rival stone for long-span archbuilding. Engineers by then had begun to stretch the technological limits of concrete construction dramatically with new methods of forming, centering and reinforcing the arches. In 1908 American engineer George Webster completed the Walnut Lane Bridge in Philadelphia. Called the largest concrete arch in the world at its completion, it featured an unreinforced 233-foot main arch. By the end of 1910, nineteen concrete arches had been built in the world with spans in excess of 150 feet. *Engineering Record* described the progress that American engineers had made in concrete bridge construction:

> When it is considered that the first reinforced concrete arch bridge in the United States was built only 21 years ago, the development which has taken place in the design and construction of bridges of this type seems very remarkable. Moreover the greater part of this growth has been brought about in the last decade. That this movement is still going on is shown by the fact that at frequent intervals descriptions appear in the engineering press of structures which embody new ideas or material modifications of old ones. It is interesting to watch this progress, and especially to see the influence which the materials used have had on the development.[79]

Despite this auspicious beginning, American bridge engineers soon lagged behind their European peers. The principal reason for this lay in the differences in engineering standards between the two continents. Traditionally more conservative than their European counterparts, U.S. engineers in the 1880s labored under more restrictive structural rules that called for lower working stresses and higher loading conditions for railroads. Initially these standards left little room for the graceful concrete spans that characterized European bridge building at the time. It would not be until highway bridge construction eclipsed railroad work in the 1890s that the long-span concrete arch would come to the fore in America.

One aspect that all long-span concrete arches shared was their open spandrel design. For shorter spans, engineers typically employed filled spandrel arches, with the roadway supported by earth fill poured over the continuous arch ring. But these would be inordinately heavy over long spans, so engineers used open

[79] "The Present Status of Reinforced Concrete Bridges," *Engineering Record* (13 August 1910), 169-170

spandrel arches, which substituted a series of concrete columns for the earth fill, on long spans. The earliest open spandrel arches employed single, relatively thin arch ribs that extended continuously over the width of the bridge. Around 1910 engineers began to experiment with multi-rib arches that used several individual ribs in lieu of continuous ribs. There were several advantages to this new structural form. First, less material was used in the individual ribs. Additionally, the floor of a multi-rib bridge could be supported by a single row of columns on each rib, whereas on a continuous-rib design, several rows of columns or even continuous walls were necessary to distribute the weight of the deck over the arch rib. Finally, on ribbed-arch bridges, the outer edge of the floor could be cantilevered beyond the outside ribs, allowing for narrower sub-deck configurations with narrower, more economical abutments.

After 1905 concrete bridge construction in America experienced a marked increase, due largely to the efforts of one engineer, Daniel B. Luten of Indianapolis. According to bridge historian James L. Cooper, "Daniel B. Luten did more than any other single person to advance the movement from concrete-steel to reinforced concrete bridge design." Patterned loosely after the patented arch reinforcing design of Josef Melan, the Luten arch featured a filled spandrel configuration with a highly elliptical profile [*see Figure 50*]. Luten's arches were clearly innovative. They were sophisticated in their reliance on steel reinforcing and allowed relatively thin concrete sections at midspan. "The Luten System combines numerous improvements in arch reinforcement and construction," Luten stated in a 1908 brochure, "increasing the strength and durability of the structure, and decreasing its cost. Great strength combined with minimum material, resulting in low cost, has been the constant aim in these improvements."[80] In an engineering article Luten explained his arch philosophy:

> An arch of concrete reinforced with embedded steel has all the permanence of stone; in fact it is more permanent than the usual building stones, and has none of the limitations of steel, such as corrosion and crystallization; for concrete is but slightly affected by the elements, and the embedded steel is protected from rust and vibration. No painting or repairs are ordinarily required, and inspection is superfluous. A properly-designed reinforced-concrete arch will be in equilibrium under the fixed load. Reinforcement will be required in the arch ring to resist moving load stresses only, and the moving loads are small in comparison with the fixed load. Such a structure, therefore, displays its material in an efficient form, and because of its useful application presents a beautiful appearance. Everyone knows that concrete is a material strong in compression. Its use in the arch without ornamentation, consequently appeals to the eye. This is wholly apart from the relation of the bridge to its surroundings, in which harmony must be secured ordinarily by ornamentation of spandrels and railings. There is no harmony, for example, in adopting a segmental curve or parabolic arc for an earth-filled arch merely because it carries railway loading, when such curves are not the curves of equilibrium, for the loading.

[80]Topeka Bridge & Iron Company, *Reinforced Concrete Bridges: Luten Patents Owned by National Bridge Company* (Topeka, Kansas: D.B. Luten, 1908), 115.

> Since the concrete arch is of pleasing form when properly designed, all that is necessary to make it harmonize with its surrounding is to limit the design to dignified details for rugged surroundings, and to embellish it with ornamentation for cultivated surroundings. No other bridge structure harmonizes so readily with its surroundings, no matter what they may be. . . For spans of less than 100 ft., dignity of design can usually be best secured for an arch bridge of moderate rise by the use of the earth-filled type with solid spandrels. But a semi-circular arch can hardly be made to present a satisfactory appearance with solid spandrels, unless the depth of load over the crown be proportional to the rise, not an economical arrangement. For spans greater than 100 ft., especially with great rise, the open-spandrel construction is usually to be preferred, and this accords fairly well with economy in this country, at the present cost for labor and materials.[81]

The key to Luten's arches lay in the reinforcing, which he patented. He received his first U.S. patent for steel reinforcing in 1900 and over succeeding years took out a series of wide-ranging patents for reinforced concrete arches. By the 1920s Luten had obtained nearly 50 patents, covering virtually all aspects of concrete arch construction. "The Luten System is the result of eight years of experience in the design and erection of reinforced concrete arches," Luten stated in 1908. "Upwards of forty improvements have been made for the purpose of decreasing its cost and increasing its strength, until now we have a stronger arch by fifty per cent than any other type that can be erected at the same cost. We have been to great expense in developing this structure and in advertising its advantages. We have consequently applied for patents on every improvement, and we now own more cost-saving patents on reinforced concrete arches than all other builders."[82]

Luten's patents were so wide-ranging that it was almost impossible for a contractor to build a reinforced concrete arch without infringing on one of his designs. For several years in the early 20th century, Luten virtually controlled the concrete bridge industry in America. He protected his patents aggressively, demanding royalty payments from companies such as the Pueblo Bridge Company of Colorado, N.M. Stark in Iowa and the Topeka Bridge & Iron Works of Kansas or collecting payments from the raft of lawsuits that his attorneys filed around the country. Luten's grip on the industry became so onerous that many in the engineering, construction and legal professions joined in protest in the 1910s. Finally, in 1918 his dominance of the industry was broken in an Iowa court when many of his patents were ruled invalid. Luten continued designing and building concrete arches into the 1920s, but his dominance in the industry had been broken. As a result, with royalties no longer being paid to Luten by bridge companies, the reinforced concrete arch received increased use as a vehicular bridge type in America.

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[81]Daniel B. Luten, "Arch Design; Specialization And Patents," *Journal of the Western Society of Engineers* XVII: 7 (September 1912), 579-581.

[82]Topeka Bridge & Iron Company, 129. The brochure outlined the royalty procedure:

> The steel reinforcement in our bridges, to be effective, must be of good quality and workmanship and properly placed in the arch. We will furnish the steel as specified, with the working drawings and engineering advice and the license to erect any particular bridge for an agreed amount dependent upon the design, which will be named in the specifications, thus throwing our plans open to general competition. Or we will supply the working drawings and the license for a royalty of ten per cent of the contract.

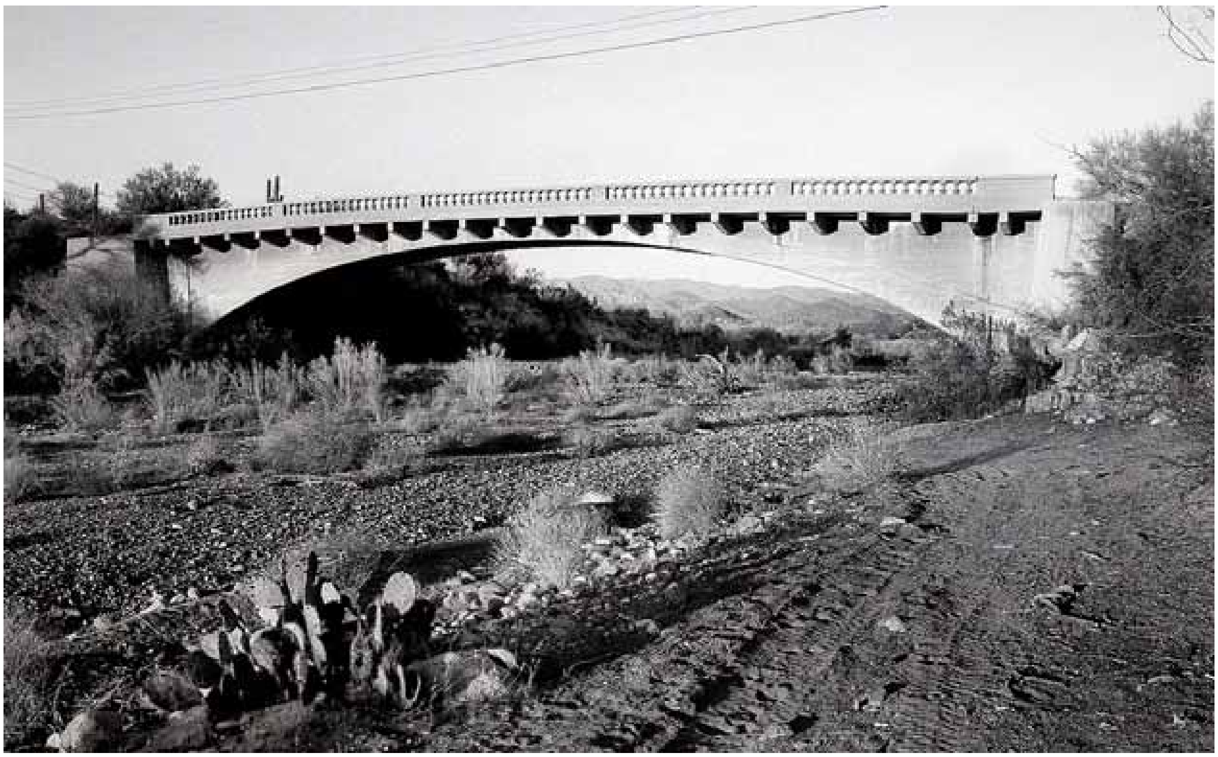

Figure 50. Queen Creek Bridge, 2002.

Arizona followed national trends in the construction of its reinforced concrete arches. The first arches were relatively short-span structures with filled spandrel designs. The three oldest datable vehicular bridges in Arizona (the Alchesay Canyon Bridge [1532] and the Solomonville Road Overpasses [**8150** and 8151]) are concrete arches. The second concrete bridge built by the Territorial Engineer (the Lowell Arch Bridge [**0130**]) was also a filled spandrel arch. The Tempe Bridge, Arizona's first nationally noteworthy concrete arch bridge, involved both filled and open spandrel configurations. "The original plans and specifications called for a nine span solid arch ring bridge 1,225 feet in length," State Engineer Lamar Cobb stated. "Later these plans and specifications were revised to call for an eleven span arch rib type bridge for 18-foot roadway with open spandrel walls."[83]

During the 1910s the State of Arizona contracted for several Luten arches. These structures were built sometimes by the Topeka Bridge and Iron Company and sometimes by local contractors. They ranked among

[83] *Report of the State Engineer*, 155.

the longest Luten arches ever built in the country. In fact the Holbrook Arch Bridge [**abd**.; *see Figure 51*], with a 174-foot span, was probably the longest Luten arch built. The last Luten arch built in Arizona was probably the Mineral Creek Bridge [**abd**.], a 125-foot span built circa 1923.

In an experimental move to provide an alternative to the Luten arch for long-span applications, the AHD bridge department in 1919-1920 designed three almost identical open-spandrel concrete arches. The Cienega Bridge [**8293**], a 146-foot arch with a concrete girder viaduct over a branch of the Southern Pacific Railroad, was built on the Borderland Highway in Pima County. The other bridges were located over Queen Creek in Pinal County and Hell Canyon in Yavapai County. The design of the Hell Canyon Bridge [**abd.**] was later changed to a concrete girder, but the Cienega Bridge and Queen Creek Bridge [**abd.**; *see Figure 52*] were constructed as drawn in 1920-1921. The bridges proved expensive and difficult to erect, however, and the highway department shelved the design permanently. The Mill Avenue Bridge, [**9954**] built in 1930-1931 over the Salt River in Tempe, a special situation, would be the only other open spandrel arch designed by AHD.

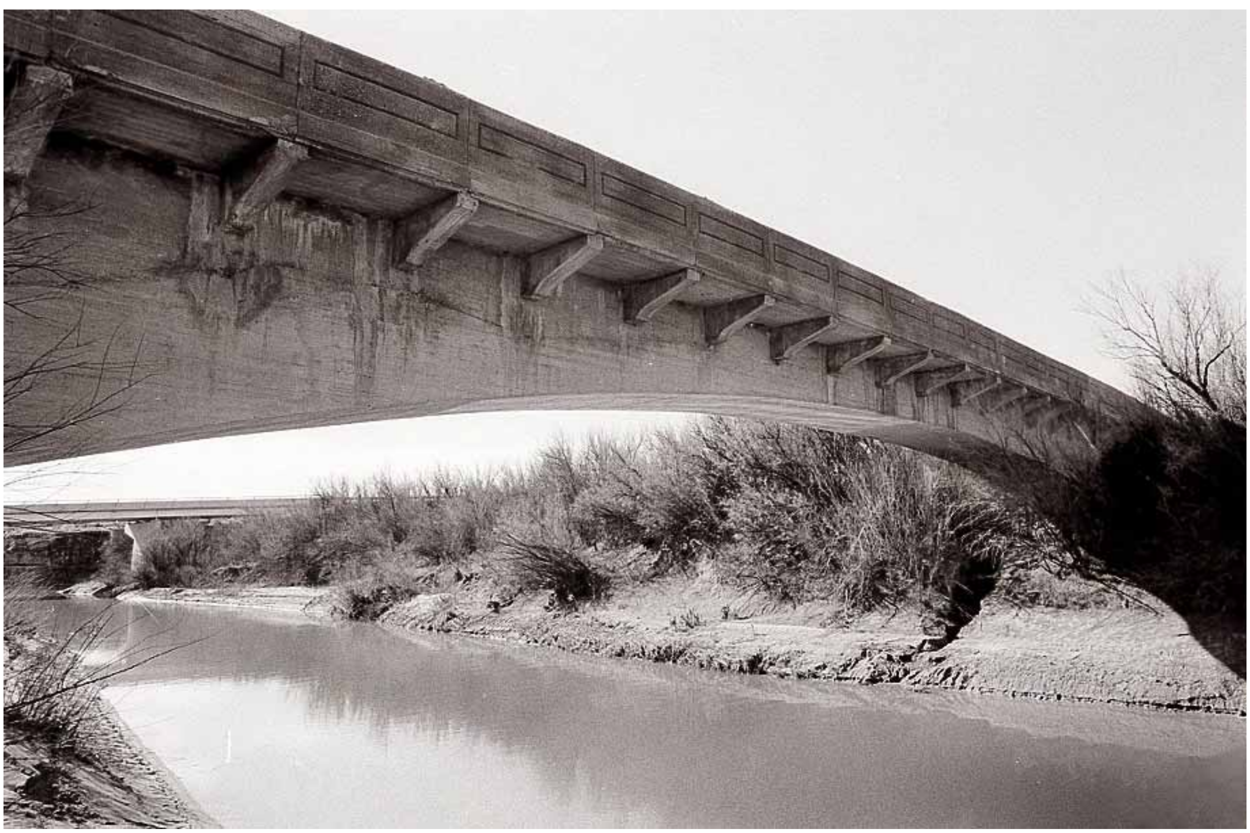

Figure 51. Holbrook Bridge, 2003.

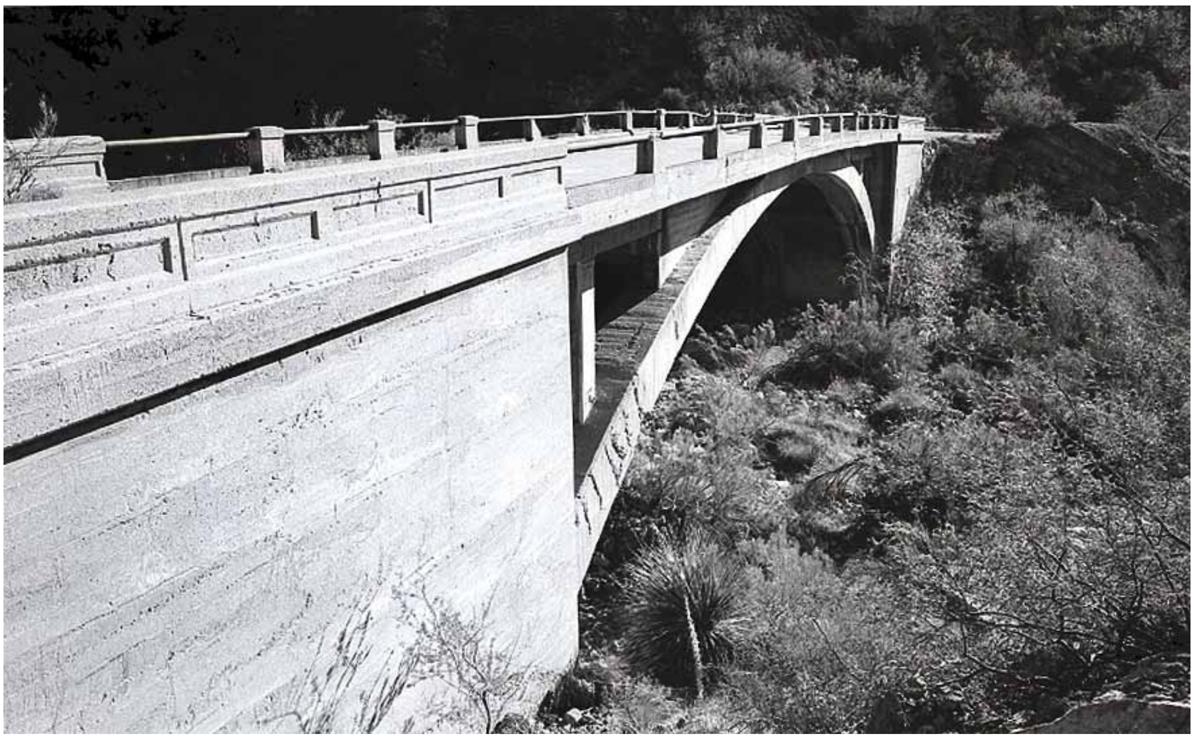

Figure 52. Queen Creek Bridge, 2003.

The Arizona State Engineer's Office used Luten arches and open spandrel arches for long-span applications, but for short- to medium-span concrete arches the engineers developed another standard design. This featured a filled spandrel configuration, with the roadway cantilevered beyond the spandrel walls and reinforcing clustered in a manner noticeably similar to Luten's patent. The major difference between the Luten arch and what the highway department termed as its "common arch" was the arch profile. Luten's bridges were distinguished by their distinctive horseshoe shape. The highway department's common arches were more truly elliptical.

The oldest AHD common arch found in the state is the Devil's Canyon Bridge [**abd.**], a well-proportioned structure built in 1921-1922 on the Miami-Superior Highway. The Devil's Canyon Bridge was soon followed by other common arches, including the Lynx Creek Bridge [**8256**] and the Verde River Bridge [**8236**] in Yavapai County and the Fossil Creek Bridge [**3215**; *see Figure 53*] in Gila County. The concrete arch as a structural type was eventually superceded by other, more efficient concrete bridge designs. Other than the Mill Avenue Bridge [**9954**] and the Arizona Spillway Bridge [**3003**], the latter built as part of the Boulder Dam, only a few concrete arches, all with short spans, were built in Arizona during the 1930s and 1940s.

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Figure 53. Fossil Creek Bridge, 2003.

Significance: For a concrete arch bridge to be considered NRHP eligible, its history and its significance must be definitively documented through archival means. Concrete arch bridges in Arizona may be eligible for listing in the National Register under Criterion A for their association with events that have made a significant contribution to the broad historical patterns of the country, the state or the region. Specifically, this refers to bridges that have played an important role in the development of the state's highway transportation system and, hence, in the settlement of the area. For example, a structure might be significant by its association with a particular route, such as the Borderland Highway, because it was built by the State Highway Department in its formative years, or because it was built by a federal Depression-era relief program.

A bridge may, in addition, be eligible under Criterion B for its association with a significant person, as long as the "significant person" was not the designer or builder of the bridge. A bridge can be eligible by virtue of its designer or builder, but this falls under Criterion C. Indeed, most eligible bridges in Arizona qualify under Criterion C as structures of engineering significance. This can encompass a broad range of considerations. For instance, a bridge can qualify under Criterion C as a well-preserved example of a common type, or as a unique or unusual type.

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The only concrete arch bridge in Arizona that would have been considered nationally significant was the Tempe (Ash Avenue) Bridge, which has subsequently been demolished. Those dateable concrete arches with physical integrity that were built by the territorial or state engineers or the Arizona Highway Department are generally considered to have state-level significance. Most of the locally built concrete arches are also considered eligible on a state level, by virtue of their significant features. Otherwise, small-scale arches built by local entities are considered locally eligible. Superlative concrete arch bridges include:

Lowell Arch Bridge	(Cochise)	earliest territory-built arch
Canyon Padre Bridge	(Coconino)	earliest Luten arch
Solomonville Road Overpasses	(Greenlee)	earliest and only toll-road arches
Gila River Bridge	(Greenlee)	well-preserved two-span Luten arch
Alchesay Canyon Bridge	(Maricopa)	earliest dateable arch
Mill Avenue Bridge	(Maricopa)	longest multiple-span arch
Holbrook Bridge	(Navajo)	longest Luten arch
Cienega Bridge	(Pima)	one of two oldest AHD open-spandrel arches
Winkelman Bridge	(Pinal)	well-preserved, multiple-span Luten arch
Queen Creek Bridge	(Pinal)	one of two oldest AHD open-spandrel arches
Devil's Canyon Bridge	(Pinal)	oldest AHD common arch

Registration Requirements: The general period of significance for concrete arch bridges in Arizona begins in 1905, the date for the state's earliest example of these structural types. Although the functionality of many of the bridges continues to the present—with the majority still in active use—the period of significance generally ends in 1964, the cutoff date for the statewide historic bridge inventory. The period of significance for an individual structure begins with the date that significant activities or events began giving the property its historic significance (typically, initial construction). Once the resource has ceased to serve the function that makes it historically important, its period of significance has ended. Alterations made during the period of significance may be considered part of the bridge's historic fabric, if they are in keeping with the bridge's original design.

Integrity of the structure's historic materials, configuration and setting is essential for a bridge to qualify for the National Register under any criterion. Since none of Arizona's concrete arch bridges has been moved, integrity of location is a given. Integrity of design, materials and workmanship are key to a bridge's eligibility, particularly if that eligibility is stated in Criterion C terms. The principal consideration when evaluating integrity of design and materials is whether the bridge retains the features that defined its character during its historic period. Character-defining features of an arch bridge include the arch ring, spandrels, ribs or barrel, railing or parapet, and abutments, wingwalls and—if present—piers. Alterations to these individual elements have a relative impact on the design integrity of the bridge itself. For instance, widening an arch by adding extensions onto one or both sides impinges more on a bridge's integrity than patching the concrete spandrels or replacing the guardrails. Integrity of workmanship is closely related to design and materials but relates to the skill and craftsmanship involved in a bridge's construction.

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Retaining a sense of setting is an important consideration for a bridge's overall integrity. Setting is defined as the topographic, vegetative and cultural character of the railroad's environs. Cultural character in this case generally delineates the built environment, but it can additionally indicate the socioeconomic or ethnic composition of the bridge's location. The principal consideration of integrity of setting is whether the extent to which the general environment or any particular aspect of that environment that affected the bridge's original design and construction remain intact from the bridge's period of significance. Are the salient features of the structure's environs still discernable and intact? The setting is usually defined as the viewshed from the bridge, which is to say all the natural and cultural features visible from the structure itself.

Integrity of feeling for a bridge is an amalgamation of the integrities of location, design, materials, workmanship and setting. It is a subjective appraisal of the overall experience conveyed by the structure. The principal consideration of integrity of feeling is whether the bridge under consideration and adjacent roadway convey a visceral sense of what it would have been like to travel over it during its historic period. Integrity of association relates to the link between a bridge and the distinctive events or personage that characterize it as historic. The alteration or loss of one or more of these integrities may be mitigated by other aspects of integrity of feeling and association.

Specific requirements under Criterion A:

1. **Early and/or prominent product of the Arizona State Engineer or State Highway Department:** In 1912 the Arizona State Legislature established the State Engineer's Office, and this evolved into the State Highway Department in the 1920s. Several concrete arch bridges were designed by the State Engineer or the Highway Department in the 1910s, 1920s and 1930s, and many remain in place today.

Specific requirements under Criterion C

1. **Early and/or representative concrete arch bridge**: Although they are generally considered among the highest forms of bridge design, concrete arches were never built in abundance in Arizona. Those arch bridges with spans in excess of 30 feet (i.e., true bridges and not arch culverts) that remain with a high degree of structural integrity are sufficiently rare and noteworthy that most are considered significant.

2. **Representative example by an important engineer, architect or bridge company:** Proprietary concrete arches such as those developed by Daniel Luten are considered a significant aspect of bridge design in the early 20^{th} century.

3. **Bridge with exceptional aesthetic merit:** Most bridges built by the state are strictly utilitarian. Occasionally, however, a structure stands out by virtue of its design or because of the quality displayed in its construction. This does not include standard-design concrete guardrails by the Highway Department. The interrelationship of a bridge and its site can also have aesthetic value as well.

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2 Property Type: Concrete Box Culverts and Slab and Girder Bridges

Description: The most common structural type for Arizona highways is the reinforced concrete box culvert. Box culverts are square-barreled spans with integrally cast walls, ceilings, floors and wingwalls. Generally spanning less than 20 feet, concrete box culverts could be built in single-barrel iterations or ganged in multiple-barrel configurations (most of the culverts in the historic bridge inventory feature more than one span, to qualify as bridges under the FHWA's 20-foot minimum structure length requirement). They are bound by angled or straight wingwalls at the upstream and downstream faces and were constructed with the roadway lying directly over the concrete structure or beneath varying-depth layers of earth overburden.

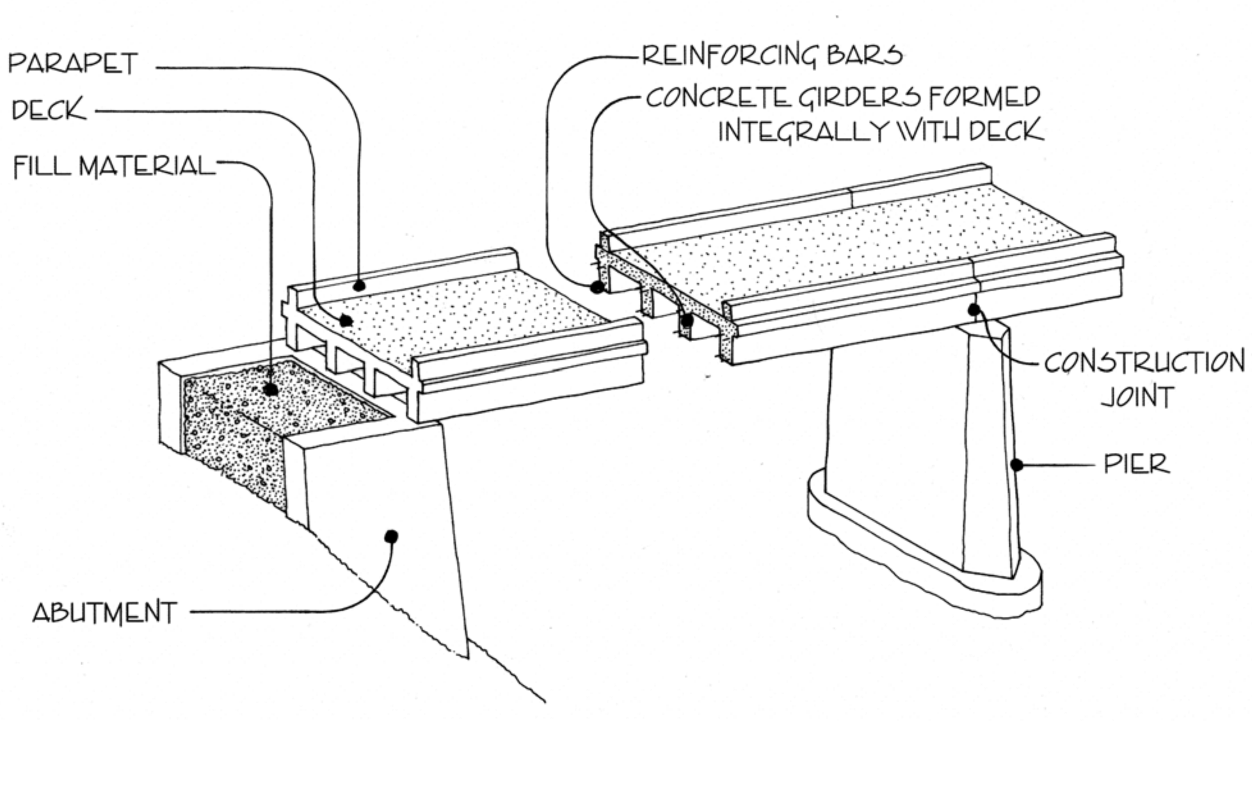

Figure 54. Concrete girder bridge diagram.

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VEHICULAR BRIDGES IN ARIZONA

With its deck and superstructure poured integrally in a single flat sheet over steel reinforcing, the concrete slab is the simplest of the concrete bridge types. The earliest flat slabs in America date to the end of the 19th century. Technology historian Carl Condit attributes the first flat-slab construction to Swiss engineer Robert Maillart in 1900, but American builders had been constructing small-scale slab bridges using empirical methods a few years before that. These short-span structures were built with the steel reinforcement along the bottom edge, in what eventually became a conventional system that acted one way in flexure. This one-way flexure tended to limit the bridges to short-span applications.

Between 1905 and 1909, however, civil engineer C.A.P. Turner experimented with alternative means of reinforcement, creating structures that acted in flexure in both directions. In an article in *Cement Age* in January 1910, Turner described four reinforced concrete bridges built the previous year in Minneapolis, which used his trademark "mushroom head" column design. Turner's work led directly to the advancement of flat-slab technology for longer spans. Reinforced concrete slab bridges—particularly those with one-way flexure systems—gained popularity in the 1910s. Although two-way flat slabs were used frequently in buildings, their use on bridges soon diminished.

With the endorsement of the Bureau of Public Roads and the American Concrete Institute, the highway departments of most states adopted concrete slabs among their standard designs. These structures typically featured relatively short, one-way spans, applicable in two-foot span increments, up to a maximum length of 20 or 30 feet. These were starkly utilitarian structures; architectural detailing, if any, was limited to the concrete parapets or guardrails. When used for short crossings, these bridges proved to be economical and easy to build. Increasing the span length meant increasing the deck thickness, which increased the materials cost. And the relatively short spans meant that supporting piers were necessary for anything beyond the smallest streambed. For these reasons, the standard-design slab bridges of the 1910s and 1920s were generally limited to relatively short, one- or two-span iterations. For any crossing requiring longer spans, concrete girders were typically employed in lieu of slabs.

In Arizona the territorial engineer built several reinforced concrete slabs between 1909 and 1912. After 1912 the state engineer continued using flat slabs for short-span applications, and in 1919 the state engineer's office drafted a set of standard plans for small-scale concrete bridges, to be used on state and county roads. Designed to BPR specifications, these concrete slabs ranged from 6 to 24 feet in span length. One of the state's earliest and most distinguished flat slab bridges is the Broadway Bridge in Clarkdale [**8488**; *see Figure 55*], a five-span structure built in 1917. The state engineer's office experimented briefly in the 1910s with what it called a "rail-top" slab design. Featuring a concrete slab poured in place over a series of parallel steel railroad rails, this represented a classic one-way slab configuration. A handful of rail-top slab bridges, including the Jacks Canyon Bridge [**abd.**] and the Old Trails Wash Bridge [**8594**], remain in place. The experiment lasted only a brief time, however, before the state reverted to more conventional steel reinforcing bars, as illustrated by the Pinal Creek Bridge in Globe [**9711**; *see Figure 56*].

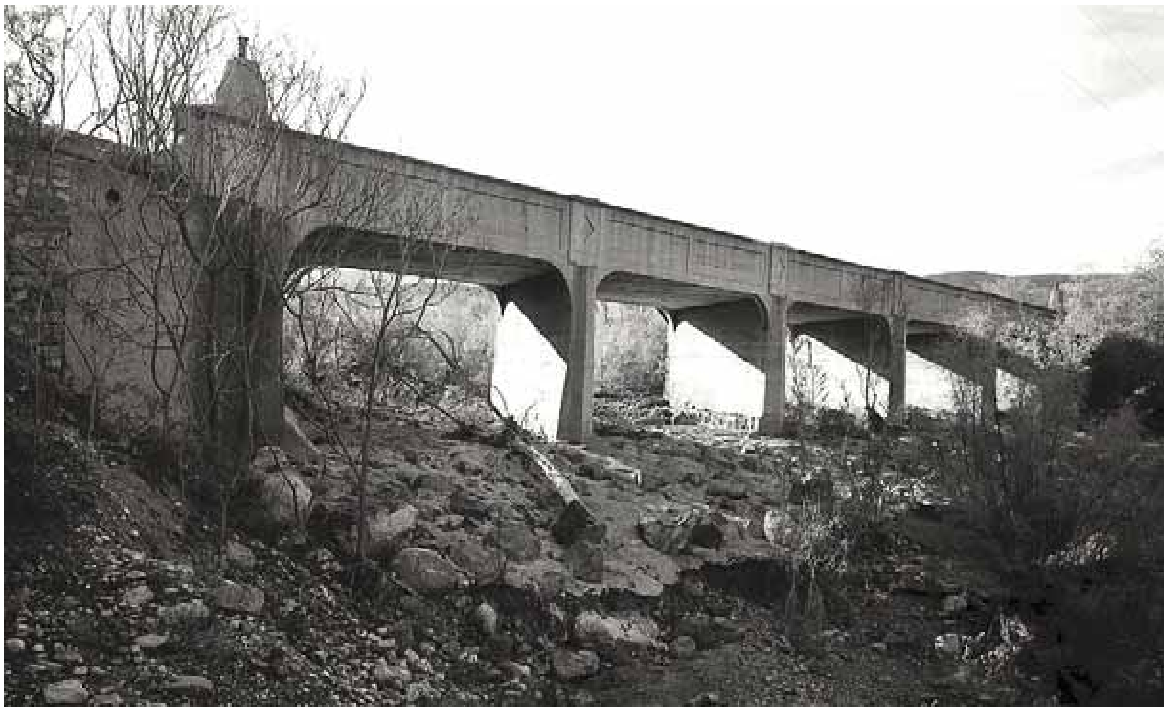

Figure 55. Broadway Bridge, 2003.

During the 1930s and early 1940s, the flat slab received widespread use, both in Arizona and around the country. Standard designs were promulgated by AASHO and various trade organizations, as the slab was perceived as economical bridge type that offered ease of construction, resistance to temperature cycles, stiffness and resistance to shrinkage. The earliest slabs were all simply supported, which is to say, the individual spans were poured and supported by the abutments and piers, independent of adjacent spans. Later advances in engineering sophistication and reinforcing technology allowed the slabs to be poured continuously over the piers, allowing greater span length and materials economy for multiple-span structures. The Arizona Highway Department employed continuous-span slabs on its bridges after World War II, with the slab thickness increased over the supports.

A concrete girder bridge looks something like a slab and features parallel lines of concrete beams poured integrally with the deck slab. Also called concrete tee beams or concrete slab-and-girder bridges, girder structures were generally built with the beams aligned beneath the roadway, but they could be configured with deep girders flanking the roadway on both sides, much like thick guardrails. A step up from the slab in terms of technological advancement, girders in either deck or through

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configurations could economically reach longer spans than slabs. Both structural types were built in single-span iterations with simply supported bearing, or with multiple spans strung together either simply or continuously over concrete piers. Unlike slabs, which could be built in almost any width, concrete girder bridges—and particularly through girders—were generally limited to roadway widths under 24 feet.

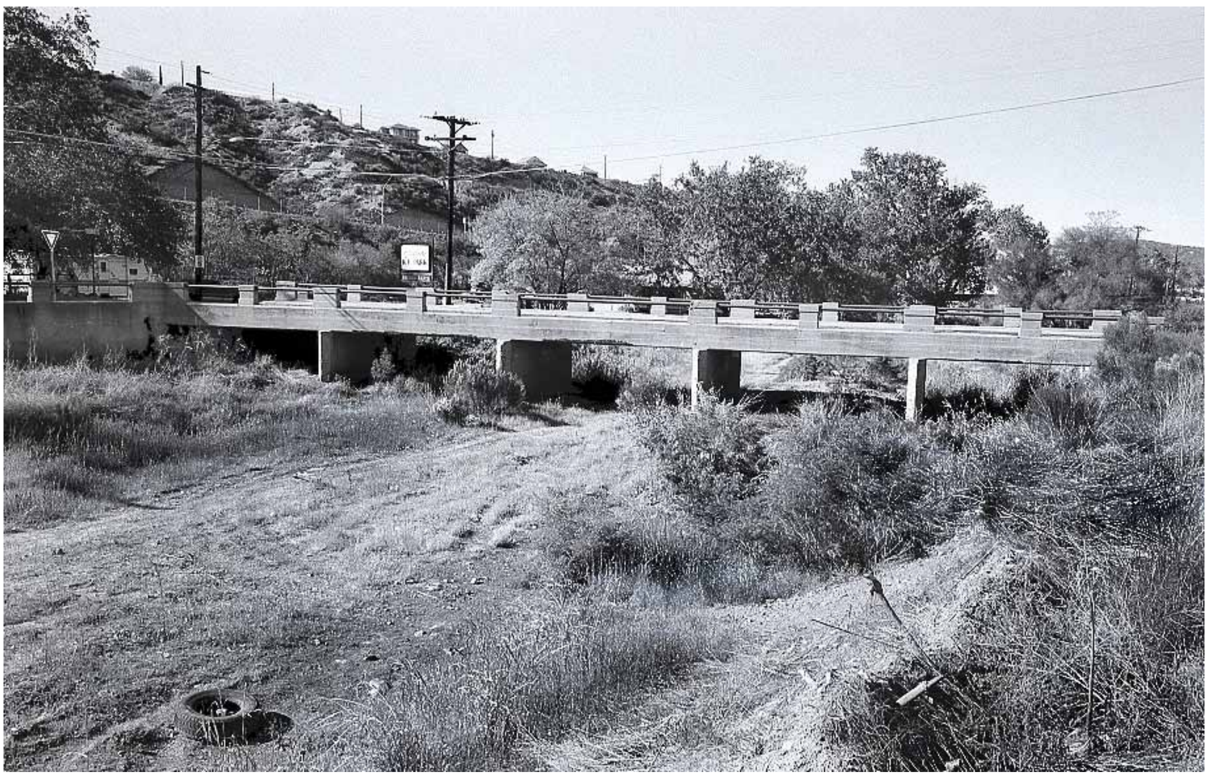

Figure 56. Pinal Creek Bridge, 2003.

Because concrete acts well under compressive loading but poorly under tension, concrete slabs and girders rely heavily on steel reinforcing along their lower surfaces, where the tensile stress is greatest. This reinforcing typically takes the form of square, twisted or deformed reinforcing bars that extend the length of the span. Concrete slabs are generally limited to span lengths of 30 feet or less. Girders can be built with spans in excess of 100 feet, but in Arizona girder bridges built before the 1950s—other than the earliest two-girder structures—rarely exceeded 50 feet.

The first reinforced concrete girder bridge was built in France in 1893. Spans of up to 85 feet appeared by 1904 in Europe, the leader in this design, and in America concrete girders began to receive acceptance for high-

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way use between 1900 and 1910. The first concrete girder bridge of note constructed in Arizona was the multiple-span structure over the Gila River at Florence, built by the Territorial Engineer in 1910. This was followed by immense girder structures over the Gila River at Antelope Hill [**abd.**], over the Agua Fria River at Coldwater [**demolished**] and over the Santa Cruz River near Beyerville [**8166**]. These earliest structures employed two deep girders per span cast integrally with the deck. This allowed relatively long span lengths and thus reduced the number of concrete piers, but the long spans proved uneconomical in their use of concrete and steel. When the highway department developed a set of standard plans for concrete girders in 1919, AHD engineers dropped the two-girder design in favor of a new girder with three somewhat shallower beams. "The slab spans become uneconomical for spans greater than about 24'," State Bridge Engineer Merrill Butler stated in 1920. "For greater spans, the three girder deck is the more economical up to about 50'."[84]

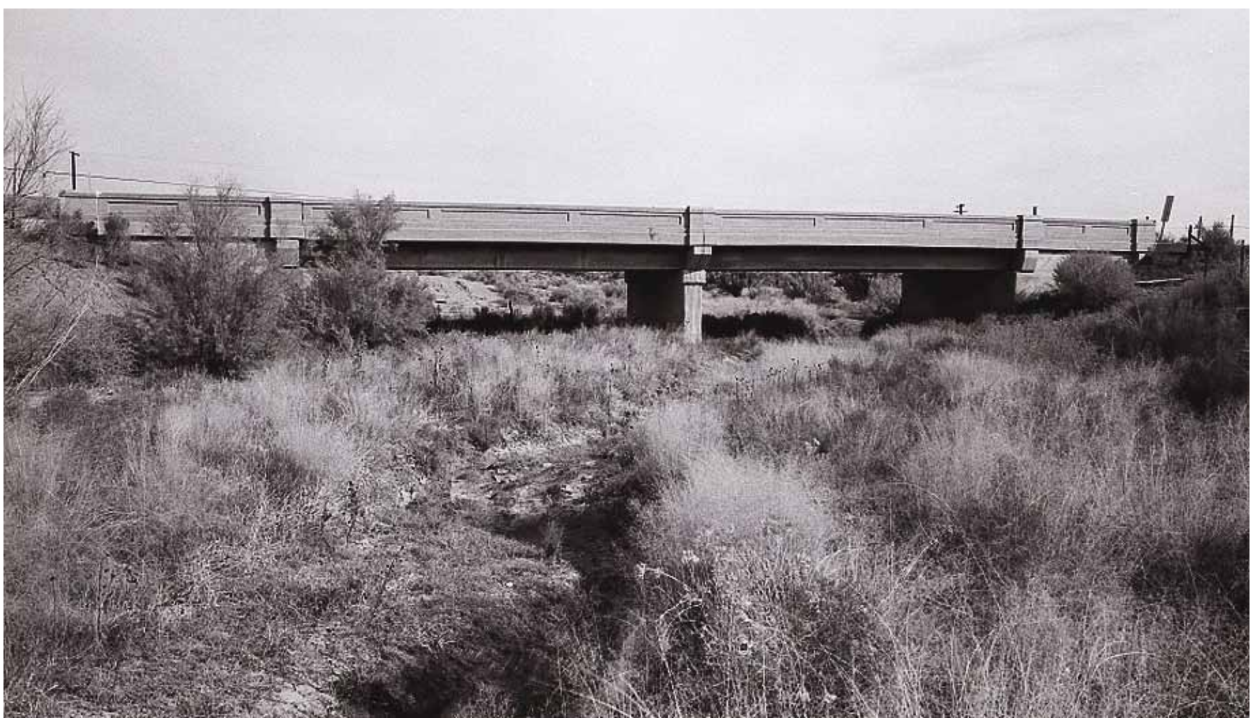

Figure 57. Tanner Wash Bridge, 2002.

The state's implementation of this configuration proved short-lived, however. According to Butler's successor W.C. Lefebvre in 1922, "A set of 4-girder reinforced concrete decks, ranging in span from 20 feet to 40 feet, have been worked up and are being used in the place of the old 3-girder standard plan which has become

[84] *Fourth Biennial Report of the State Engineer*, 65.

obsolete. These new spans, although designed for heavier loads than the old, are more economical in materials and have been used exclusively in the past two years where such spans were required."[85] AHD engineers designed only ten three-girder bridges before shelving this standard, and fewer were actually constructed. Only three are known to have survived—the Cordes Bridge [**8249**] and two bridges over Granite Creek [**1489 and 0042**], both in Yavapai County. The four-girder design, illustrated by the Tanner Wash Bridge [**8160**; *see Figure 57*], became the standard used through the 1920s and 1930s.

Significance: The State Engineer's Office delineated standardized designs for concrete box culverts and slab and girder bridges as early as 1912, updating them occasionally in subsequent years. As the state assumed greater responsibility for bridge design and construction, these structural types received widespread use on Arizona's roads in the 1910s, 1920s and 1930s. There were no noteworthy technological advancements made on these structural types during the 1940s. In the 1950s AHD engineers were able to increase slab span lengths by thickening the slab depth over the piers. During that time the concrete deck girder experienced a notable resurgence in popularity, as the Highway Department employed an AASHTO standard concrete girder design, with the beams arched parabolically over their lengths and supported by concrete spill-through piers. These became the standard design for highway over- and underpasses when Arizona built its interstate highway network in the late 1950s and 1960s.

Concrete box culverts and slab and girder bridges in Arizona may be eligible for listing in the National Register under Criterion A for their association with events that have made a significant contribution to the broad historical patterns of the country, the state or the region. Specifically, bridges that have played an important role in the development of the state's highway transportation system and, hence, in the settlement of the area. For example, a structure might be significant by its association with a particular route, such as the Ocean-to-Ocean Highway, because it was built by the State Highway Department in its formative years, or because it was built by a federal Depression-era relief program. A bridge may, in addition, be eligible under Criterion B for its association with a significant person, as long as the "significant person" was not the designer or builder of the bridge. A bridge can be eligible by virtue of its designer or builder, but this falls under Criterion C. Indeed, most eligible bridges in Arizona qualify under Criterion C as structures of engineering significance. This can encompass a broad range of considerations. For instance, a bridge can qualify under Criterion C as a well-preserved example of a common type, or as a unique or unusual type.

None of Arizona's concrete girder or slab bridges are considered to have national significance. Those dateable concrete girder or slab bridges with physical integrity that were built by the territorial or state engineers or the Arizona Highway Department are generally considered to have state-level significance. Most of the locally built concrete arches are also considered eligible on a state level, by virtue of their significant features. Otherwise, small-scale arches built by local entities are considered locally eligible. Superlative concrete girder and slab bridges include:

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[85] *Fifth Biennial Report of the State Engineer*, 57.

Concho Bridge	(Apache)	earliest and only through girder
Pinal Creek Bridge	(Gila)	well-preserved early AHD multiple-span slab
Negro Canyon Bridge	(Greenlee)	well-preserved prototype of slab design
Rattlesnake Canyon Bridge	(Greenlee)	well-preserved prototype of girder design
Tanner Wash Bridge	(Navajo)	well-preserved early AHD multiple-span girder
Sacaton Dam Bridge	(Pinal)	well-preserved multiple-span girder
Santa Cruz River Bridge	(Santa Cruz)	only intact two-girder bridge
Old Trails Wash Bridge	(Mohave)	well-preserved early example of uncommon slab
Jacks Canyon Bridge	(Navajo)	well-preserved early example of uncommon slab
Side Hill Viaduct	(Navajo)	well-preserved example of singular slab type
Fourth Avenue Underpass	(Pima)	well-preserved, early example of urban girder
Hell Canyon Bridge	(Yavapai)	outstanding early multiple-span example of girder
Granite Creek Bridges	(Yavapai)	well-preserved three-girder bridge
Cordes Bridge	(Yavapai)	well-preserved three girder bridge
Broadway Bridge	(Yavapai)	well-preserved early slab bridge
Antelope Hill Bridge	(Yuma)	earliest girder bridge

Registration Requirements: The general period of significance for concrete slab and girder bridges in Arizona begins in 1909, the date for the state's earliest example of these structural types. Although the functionality of many of the bridges continues to the present—with the majority still in active use—the period of significance generally ends in 1964, the cutoff date for the statewide historic bridge inventory. The period of significance for an individual structure begins with the date that significant activities or events began giving the property its historic significance (typically, initial construction). Once the resource has ceased to serve the function that makes it historically important, its period of significance has ended. Alterations made during the period of significance may be considered part of the bridge's historic fabric, if they are in keeping with the bridge's original design.

Integrity of the structure's historic materials, configuration and setting is essential for a bridge to qualify for the National Register under any criterion. Since none of Arizona's concrete slab or girder bridges has been moved, integrity of location is a given. Integrity of design, materials and workmanship are key to a bridge's eligibility, particularly if that eligibility is stated in Criterion C terms. The principal consideration when evaluating integrity of design and materials is whether the bridge retains the features that defined its character during its historic period. Character-defining features of a girder or slab bridge include the concrete superstructure, deck, railing or parapet, and abutments, wingwalls and—if present—piers. The term "deck" in this instance is defined as the traffic-carrying component of a bridge, which is supported by the bridge's superstructure. In most bridges it is a discreet structural element, built and maintained separately from the superstructural beams or truss. In the case of concrete slabs and concrete girders, however, the deck and the superstructure are one in the same.

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Because of their relative simplicity and below-deck superstructures, slab and girders are generally visually undistinguished, and it is the guardrails that, more than anything, define the character of the bridge from the roadway. Alterations to the individual elements of a slab or girder bridge have a relative impact on the design integrity of the bridge itself. For instance, widening a slab by adding extensions onto one or both sides and replacing the guardrails impinges more on a bridge's integrity than patching the concrete surfaces or repairing the abutments. Integrity of workmanship is closely related to design and materials but relates to the skill and craftsmanship involved in a bridge's construction.

Retaining a sense of setting is an important consideration for a bridge's overall integrity. Setting is defined as the topographic, vegetative and cultural character of the railroad's environs. Cultural character in this case generally delineates the built environment, but it can additionally indicate the socioeconomic or ethnic composition of the bridge's location. The principal consideration of integrity of setting is whether the extent to which the general environment or any particular aspect of that environment that affected the bridge's original design and construction remain intact from the bridge's period of significance. Are the salient features of the structure's environs still discernable and intact? The setting is usually defined as the viewshed from the bridge, which is to say all the natural and cultural features visible from the structure itself.

Integrity of feeling for a bridge is an amalgamation of the integrities of location, design, materials, workmanship and setting. It is a subjective appraisal of the overall experience conveyed by the structure. The principal consideration of integrity of feeling is whether the bridge under consideration and adjacent roadway convey a visceral sense of what it would have been like to travel over it during its historic period. Integrity of association relates to the link between a bridge and the distinctive events or personage that characterize it as historic. The alteration or loss of one or more of these integrities may be mitigated by other aspects of integrity of feeling and association.

Specific requirements under Criterion A:

1. **Early and/or prominent product of the Arizona State Engineer or State Highway Department:** In 1912 the Arizona State Legislature established the State Engineer's Office, and this evolved into the State Highway Department in the 1920s. Numerous concrete slab and girder bridges were designed by the Highway Department in the 1910s, 1920s and 1930s, and many remain in place today.

2. **Outstanding example of federal work relief programs of the Depression era:** Federal work programs in the 1930s and early 1940s, particularly those funded by the Works Progress Administration, led to construction of a number of concrete slab and girder bridges in the state. The most significant display careful craftsmanship and creative design.

Specific requirements under Criterion C

1. **Early and/or representative concrete box culvert or slab and deck girder bridge:** Culverts and slab and girder bridges built before 1925 are sufficiently rare in Arizona that any definitively documented

example that has maintained physical integrity is considered eligible for the National Register. Those built after 1925 with definitive documentation are considered significant on the basis of superlative features (e.g., exceptionally long span length, unusual number of spans, uncommonly good state of preservation). Concrete variable-depth slabs or parabolic girders built after 1950 are considered significant if they were prototypes for these structural configurations.

Concrete box culverts and slab and girder bridges in Arizona tend to have been subsequently widened by adding onto the deck on one or both sides. This widening is considered a serious loss of integrity, especially if it entails the replacement or substantial alteration of one or both guardrails, which are considered character-defining elements. Similarly, the subsequent replacement of one or both guardrails with steel Thrie beams is considered a serious loss of integrity, though the installation of steel beams over original guardrails is considered reversible and represents a less serious alteration.

2. **Example of concrete through girder or two- and three-beam concrete deck girder:** Only one concrete through girder bridge (the Concho Bridge [**8480**]) remains intact in Arizona. It is considered eligible for the National Register as a singular example of its structural type. Similarly, only two two-beam deck girder bridges (the Antelope Hill Bridge [**adb.**] and the Santa Cruz Bridge [**8166**]) and three three-beam deck girder bridges (the Cordes Bridge [**8249**] and the Granite Creek Bridges [**1489 and 0042**]) are still extant. They are all considered eligible for the National Register as the last intact examples of their significant structural types.

3. **Bridge with exceptional aesthetic merit:** Most bridges built by the state are strictly utilitarian. Occasionally, however, a structure stands out by virtue of its design or because of the quality displayed in its construction. This does not include standard-design concrete guardrails by the Highway Department. The interrelationship of a bridge and its site can also have aesthetic value as well.

3 Property Type: Concrete Rigid Frame Bridges

Description: The first concrete rigid frame bridge was designed in 1922 by engineer Arthur G. Hayden for the park commission of Westchester County, New York. It was the last major type of cast-in-place concrete bridge developed. Comprised of a concrete beam superstructure tied rigidly to the abutments with steel reinforcing bars, rigid frame bridges differed materially from conventional simply supported spans. "A clear conception of a typical rigid frame concrete bridge may be obtained by first visualizing an ordinary simple span bridge supported by bearing on two abutments," a 1935 concrete manual stated. "If the bearing is replaced with concrete that continues monolithically from the abutments to the deck, the altered structure becomes a frame with rigid corners—a structure generally called a *rigid frame concrete bridge*."[86]

[86] *Analysis of Rigid Frame Concrete Bridges* (Chicago: Portland Cement Association, 1935), 5.

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Rigid frame bridges were considered an efficient use of material, best suited for spans of between 40 and 120 feet. They were a relatively inexpensive alternative to steel or concrete girder bridges in the 1930s and 1940s. Rigid frame bridges could be built in single-span or multiple-span iterations. The cross section of the beams or vertical sections were usually shaped like I-beams or boxes, but there could be great variety of shape. The horizontal component or slab was often haunched, thicker at the ends than at the middle, presenting the appearance, if not the function, of a shallow arch. Because its construction was relatively labor-intensive, this bridge configuration became popular for federal relief programs in the 1930s. Both picturesque and practical, the flat-arch design appealed to proponents of urban beautification, and rigid frames found widespread use in city parks and landscaped boulevards. By 1935 more than 300 rigid frames had been built in America, most in urban areas. Early rigid frame bridges were limited in span length, but by 1937 the Schmitz Park Bridge in Seattle featured a single 175-foot span.

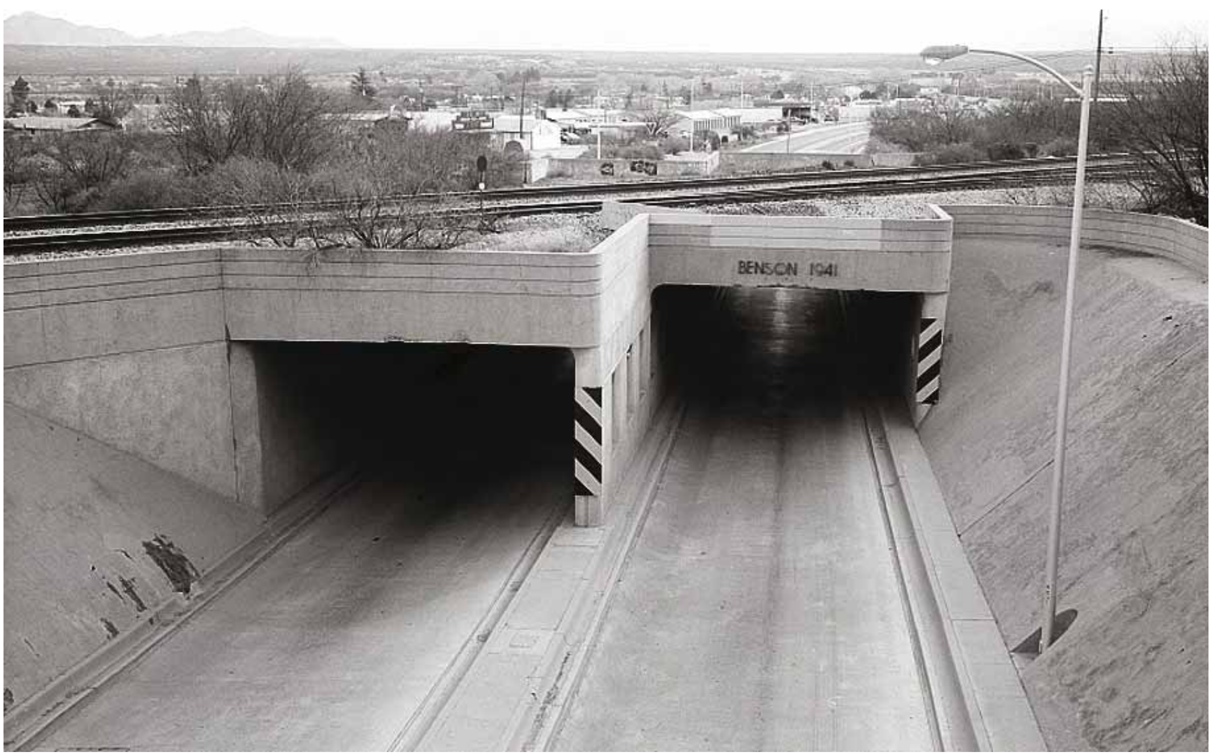

Figure 58. Benson Underpass, 2003.

Concrete rigid frame bridges were well suited to urban applications with large traffic volumes and moderate span lengths, where rigidity under load was of prime importance. Their design was easily changeable as well. Using a set profile and reinforcing configuration, a series of bridges could be built over a wide range

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of spans. They could be readily skewed to accommodate angled intersections. Their flat or slightly arched undersides provided under-bridge clearance at grade separations in constricted urban spaces. And they could be later widened to accommodate increased traffic by extending the deck and abutments. Further, the bridges could be cast plainly or adorned with a variety of applied concrete or metal ornamentation.

In the 1930s the Arizona Highway Department experimented with rigid frame design, building a few relatively small-scale structures at rural locations around the state. Where this structural type found its voice in Arizona was for urban grade separations built during the 1930s and early 1940s. Structures such as the Winslow Underpass [**0194**], the Benson Underpass [**0264**; *see Figure 59*], the 17th Avenue Underpass [**7770**; *see Figure 60*] and the Washington Street Underpass [**0535**], combined rigid frame structures with applied ornamentation to create successful architectural expressions. Although constructed during the Depression, these structures were all funded using traditional contracting procedure and built by private companies under contract with AHD, rather than work relief agencies.

Figure 59. 17th Avenue Underpass, 2002.

Significance: Concrete rigid frame bridges in Arizona may be eligible for listing in the National Register under Criterion A for their association with events that have made a significant contribution to the broad historical patterns of the country, the state or the region. Specifically, bridges that have played an important role in the development of the state's highway transportation system and, hence, in the settlement of the area. For example, a structure might be significant by its association with a particular route, such as the Ocean-to-Ocean Highway, because it was built by the State Highway Department in its formative years, or because it was built by a federal Depression-era relief program. A bridge may, in addition, be eligible under Criterion B for its association with a significant person, as long as the "significant person" was not the designer or builder of the bridge.

A bridge can be eligible by virtue of its designer or builder, but this falls under Criterion C. Indeed, most eligible bridges in Arizona qualify under Criterion C as structures of engineering significance. This can encompass a broad range of considerations. For instance, a bridge can qualify under Criterion C as a well-preserved example of a common type, or as a unique or unusual type. Concrete rigid frame bridges are sufficiently common in Arizona that to be considered eligible for listing in the National Register under Criterion C, a structure from this property type must have definitive historical documentation and some superlative feature about it that distinguishes it from its peers. Some examples of this are notably early construction date, notably long span length, or well-executed architectural design.

None of Arizona's concrete rigid frame bridges are considered to have national significance. Those dateable concrete rigid frames with physical integrity that were built by the Arizona Highway Department or the Bureau of Public Roads are generally considered to have state-level significance. Most of the locally built concrete rigid frames are also considered eligible on a state level, by virtue of their significant features. Otherwise, small-scale rigid frames built by local entities are considered locally eligible. Superlative concrete rigid frame bridges include:

Water Holes Canyon Bridge	(Coconino)	well-preserved example of singular structural type
17th Avenue Underpass	(Maricopa)	well-preserved Depression-era rigid frame
Winslow Underpass	(Navajo)	well-preserved Depression-era rigid frame
Stone Avenue Underpass	(Pima)	well-preserved Depression-era rigid frame
Casa Grande Underpass	(Pinal)	well-preserved Depression-era rigid frame

Registration Requirements: The general period of significance for concrete rigid frame bridges in Arizona begins in 1936, the date for the state's earliest example of this structural type. Although the functionality of many of the bridges continues to the present—with the majority still in active use—the period of significance generally ends in 1964, the cutoff date for the statewide bridge inventory. The period of significance for an individual structure begins with the date that significant activities or events began giving the property its historic significance (typically, initial construction). Once the resource has ceased to serve the function that makes it historically important, its period of significance has ended. Alterations made during the period of significance may be considered part of the bridge's historic fabric, if they are in keeping with the bridge's original design.

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Integrity of the structure's historic materials, configuration and setting is essential for a bridge to qualify for the National Register under any criterion. Since concrete rigid frame bridges cannot be moved, integrity of location is a given. Integrity of design, materials and workmanship are key to a bridge's eligibility, particularly if that eligibility is stated in Criterion C terms. The principal consideration when evaluating integrity of design and materials is whether the bridge retains the features that defined its character during its historic period.

Character-defining features of a concrete rigid frame bridge include the concrete superstructure, deck, railing or parapet, and abutments, wingwalls and—if present—piers. The term "deck" in this instance is defined as the traffic-carrying component of a bridge, which is supported by the bridge's superstructure. In most bridges it is a discreet structural element, built and maintained separately from the superstructural beams or truss. In the case of concrete slabs and concrete rigid frames, however, the deck and the superstructure are one in the same.

Because of their relative simplicity and below-deck superstructures, concrete rigid frames are generally visually undistinguished, and it is the guardrails that, more than anything, define the character of the bridge from the roadway. Alterations to the individual elements of a rigid frame bridge have a relative impact on the design integrity of the bridge itself. For instance, widening a roadway by adding extensions onto one or both sides and replacing the guardrails impinges more on a bridge's integrity than patching the concrete surfaces or repairing the abutments. Integrity of workmanship is closely related to design and materials but relates to the skill and craftsmanship involved in a bridge's construction.

Retaining a sense of setting is an important consideration for a bridge's overall integrity. Setting is defined as the topographic, vegetative and cultural character of the railroad's environs. Cultural character in this case generally delineates the built environment, but it can additionally indicate the socioeconomic or ethnic composition of the bridge's location. The principal consideration of integrity of setting is whether the extent to which the general environment or any particular aspect of that environment that affected the bridge's original design and construction remain intact from the bridge's period of significance. Are the salient features of the structure's environs still discernable and intact? The setting is usually defined as the viewshed from the bridge, which is to say all the natural and cultural features visible from the structure itself.

Integrity of feeling for a bridge is an amalgamation of the integrities of location, design, materials, workmanship and setting. It is a subjective appraisal of the overall experience conveyed by the structure. The principal consideration of integrity of feeling is whether the bridge under consideration and adjacent roadway convey a visceral sense of what it would have been like to travel over it during its historic period. Integrity of association relates to the link between a bridge and the distinctive events or personage that characterize it as historic. The alteration or loss of one or more of these integrities may be mitigated by other aspects of integrity of feeling and association.

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Specific requirements under Criterion A:

1. **Early and/or prominent product of the Arizona Highway Department:** In the mid-1930s the Highway Department began using concrete rigid frames for bridges and grade separations. Several remain in place today, most of which are grade separations (overpasses and underpasses, generally at highway/railroad intersections) built in urban areas.

Specific requirements under Criterion C

1. **Early and/or representative concrete rigid frame bridge:** Concrete rigid frame bridges built before 1940 are sufficiently rare in Arizona that any definitively documented example that has maintained physical integrity is considered eligible for the National Register. Bridges built after 1940 are considered significant if they can be definitively documented and they exhibit superlative features (i.e., exceptionally long span length, noteworthy architectural treatment, uncommonly good state of preservation). Concrete rigid frame bridges in Arizona tend to have been subsequently altered by installation of steel Thrie beam guardrails. This is considered a serious loss of integrity, though the installation of steel beams over the original guardrails is considered reversible and represents a less serious alteration.

2. **Bridge with exceptional aesthetic merit:** Concrete rigid frame bridges, more than any other structural type in Arizona, have been used as monumental structures in urban settings. These are considered significant as uncommon forays into bridge aesthetics by the State Highway Department.

4 Property Type: Steel Stringer and Girder Bridges

Description: Steel stringer bridges are the most rudimentary type of all-metal spans. Comprised of several parallel rows of relatively shallow, rolled I-beams placed longitudinally over piers and abutments with a continuous deck laid on top, steel stringer bridges were regularly used by Arizona railroads in the late 19th and early 20th centuries. Also termed multi-beam bridges or I-beam bridges or (incorrectly) steel girder bridges, they were used only rarely by the counties for short-span bridges, often eschewed for similarly scaled concrete bridges. (None of these earliest steel bridges is known to exist.) Substructural support for steel stringer bridges ran the gamut from stone masonry or concrete abutments to timber or steel pile bents. Like timber stringers, steel stringer bridges could consist of single-span structures over minor watercourses, or the spans could be multiplied over piers to cross wider rivers. And like timber stringers, they could be designed and built using standard tables or empirical judgment, without the need for extensive engineering.

Although fabricated in Eastern rolling mills as early as the 1850s, rolled steel beams were not generally used as vehicular bridge superstructures until well into the 20th century. More than any other bridge type, steel stringer technology has depended closely on the capacity of rolling mills that provided the steel. Reliant upon

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the mills' output of shallow beams, early Arizona stringer bridges were limited to spans shorter than 50 feet. It was necessary, therefore, to use other structural types such as steel plate girders, trusses or concrete arches for crossings requiring greater spans. The industry was able to increase spans to 75 feet in 1928, when the mills began to roll 33- to 36-inch-deep I-beams.

The longer spans made steel more economical than concrete in many highway applications, signaling the decline of long-span concrete arches in Arizona. Even more than timber stringer or concrete girder bridges, steel stringer structures were flexible in span length, span number, roadway width and substructure configuration. They could be built with simply supported bearing conditions or with the beams extending continuously over the piers. Moreover, they could be subsequently widened simply by extending the piers and abutments to the sides and adding more stringers outside of the original ones. So suitable were steel stringers to widening that they have often been used to widen the decks on other structural types such as concrete girders and slabs.

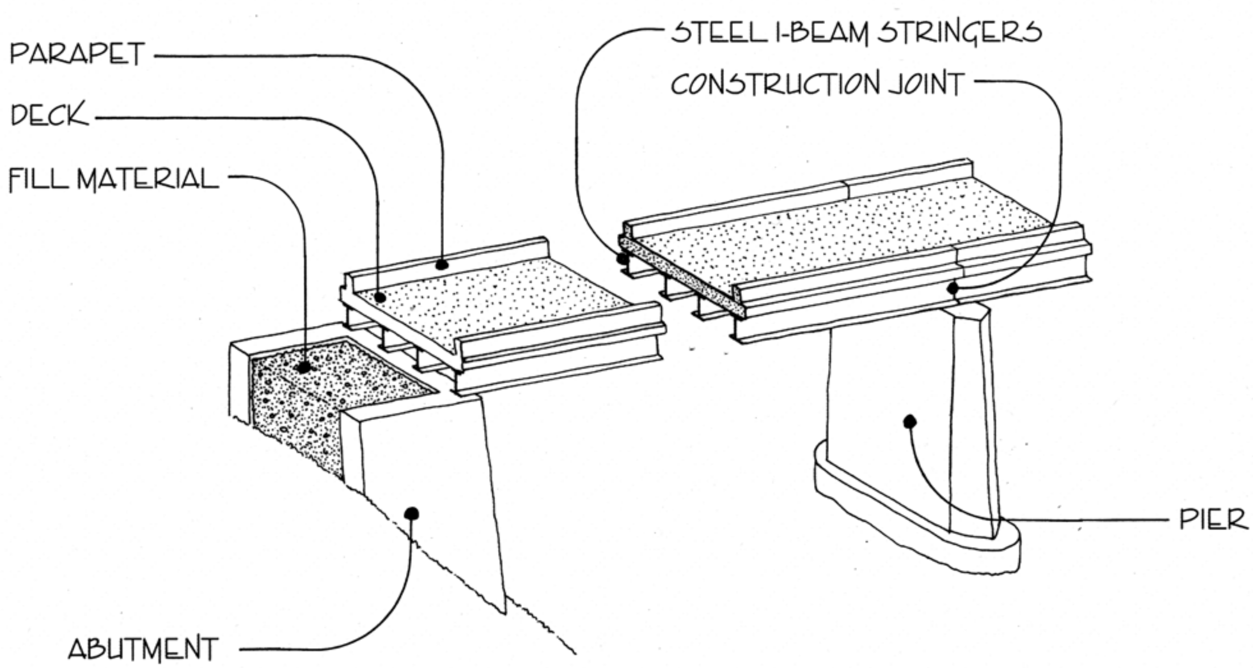

Figure 60. Steel I-beam stringer bridge diagram.

Despite these structural advantages, steel stringer bridges did not receive widespread acceptance in Arizona until more recent years. Neither the territorial engineer nor the early state engineers developed standard plans for steel stringer bridges, instead preferring concrete for short- and medium-span applications. The earliest dateable steel stringer bridge in Arizona is the Dry Wash Bridge [**0015**; *see Figure 62*] built by the state engineer in 1923 on the Apache Trail. A single short span supported by stone abutments, it was an anomaly among Arizona bridges.

The Bureau of Public Roads developed the first standard drawings for steel stringer bridges as early as 1917. The earliest I-beam structures featured timber decks, but cast-in-place concrete soon followed. The Arizona Highway Department did not begin erecting steel stringer bridges with any regularity until the 1930s [**8235**; *see Figure 63*]. During the Depression AHD built numerous steel stringer bridges, usually short-span iterations with concrete substructures. After World War II AHD built steel stringers in abundance with spans of up to 160 feet.

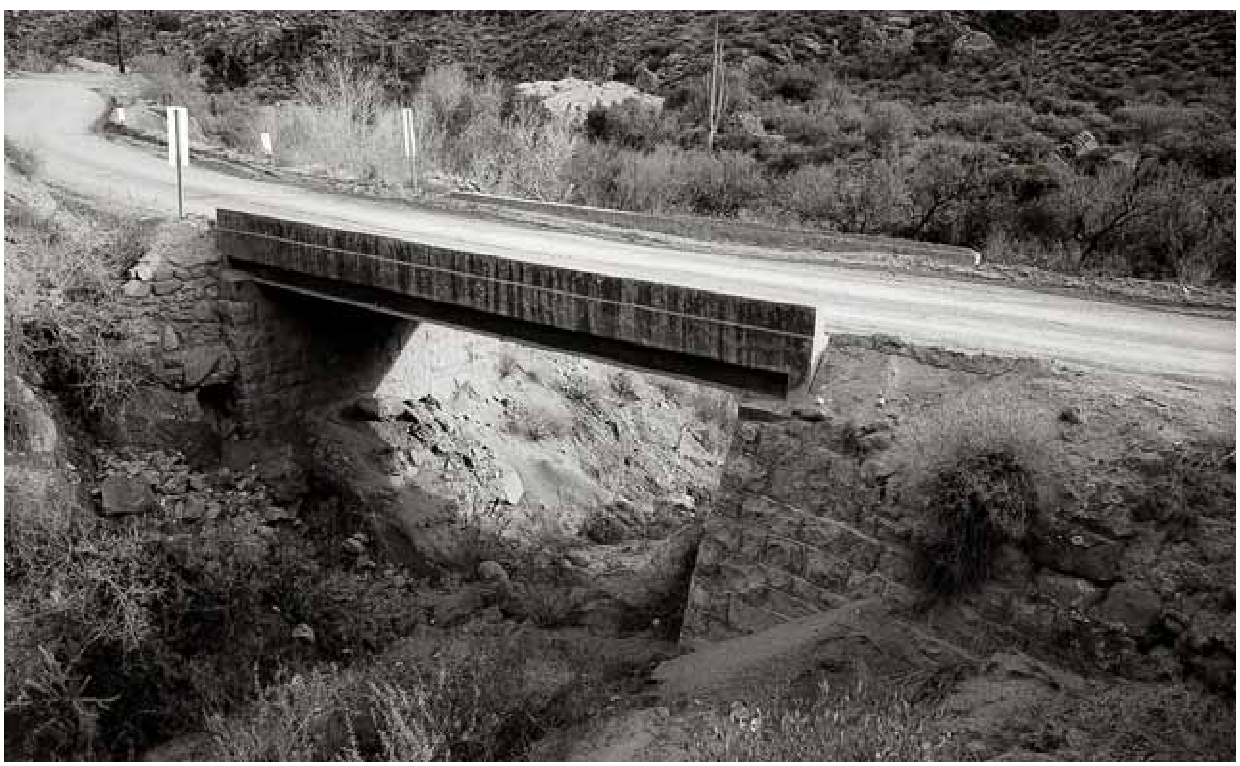

Figure 61. Dry Wash Bridge.

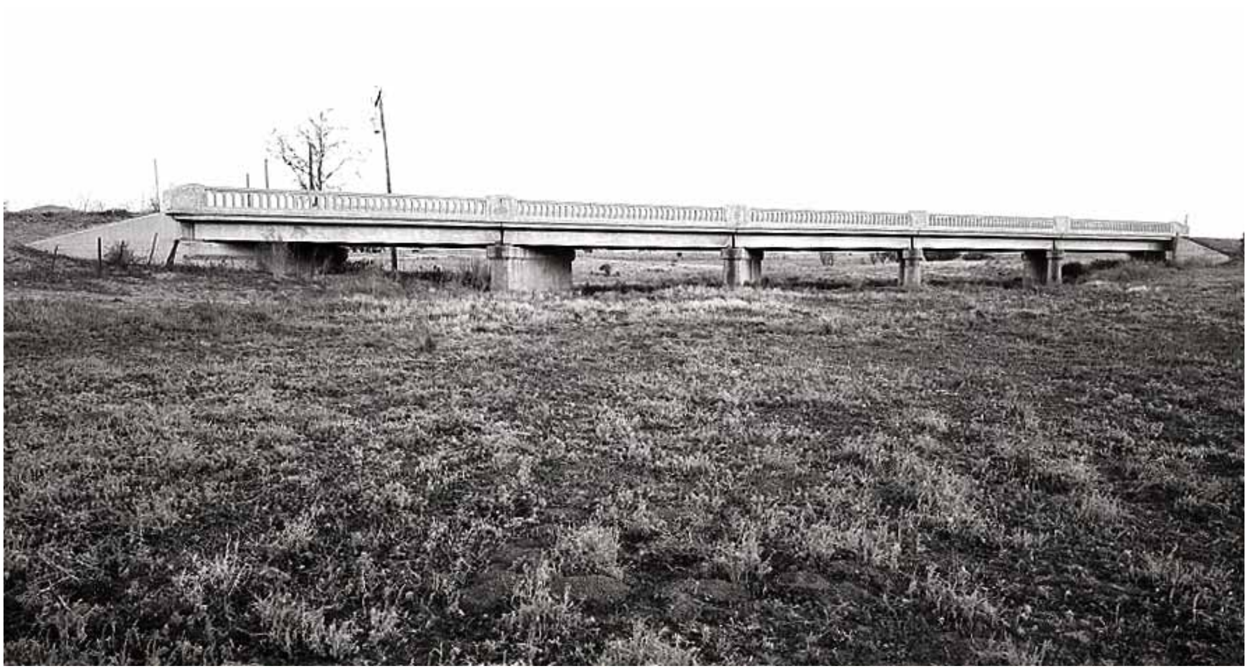

Figure 62. Wash Bridge, 2003.

Steel girders employ a technology similar to that of stringers, substituting two or more deep-profile beams for the row of relatively shallow stringers. Like concrete girder structures, they could be configured with two or more beams located beneath the roadway (deck girders) or two relatively deep beams on both sides of the roadway (through girders). With their more complicated bearing conditions, beam arrangement and floor system connections, steel girder bridges represent a step up the technological scale from stringers. It was this increased technology—along with relatively heavy superstructural weight and the physical limitation of transporting heavy, factory-fabricated girders—that limited the application of steel girders for highway use in America in the early 20th century.

The first plate girder bridge in the United States was a 50-foot span built for the Baltimore & Susquehanna Railroad in 1846. Fabricated in the Bolton Station, Maryland, shops of James Millholland, the 14-ton structure was shipped by rail to the site and erected in a piece. Railroads were well suited for girder construction, because they constituted their own transportation system capable of carrying large, heavy loads. By the late 19th century, built-up, riveted plate girders had been put to use on vehicular bridges as well. Their cost of fabrication and difficulty in hauling the heavy, cumbersome girders precluded their widespread use, however. For medium- to long-span crossings, trusses were still the preferred alternative. Since the 1930s, I-shaped plate girders

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have been used to span beyond the range of rolled I-beams. These were fabricated by riveting flange angles to a web plate and adding cover plates to the top and bottom edges. The most common configuration featured two relatively deep, longitudinal girders joined by transverse rolled I-beam floor beams and topped with a one-way concrete slab.

The earliest girder bridges employed simply supported beams that acted independently over the piers [*see Figure 64*]. By the 1930s engineers had begun to carry the beams continuously over the piers, alternating anchor and cantilevered spans [*see Figure 65*]. Using either riveted or hinged splices, these long-span structures permitted greater lengths than simply supported beams could provide. By the 1950s, as fabrication and welding techniques improved, welded girders began to replace riveted built-up beams. These typically featured I-shaped girders that increased in web depth over the bearing points. The welding on these earliest structures later proved through ultrasonic testing to be prone to fatigue and stress cracking at the weld lines, however. The use of this type of girder was discontinued in lieu of bolted connections and splices. By the 1960s steel stringer and girder bridges had been superceded by more efficient prestressed concrete beams. Their recent use has been limited to specialized conditions.

Figure 63. Wickenberg Bridge, 2003.

Figure 64. Benson Bridge, 2003.

Arizona's earliest steel girder bridges are all railroad structures, either underpasses or, in one case, a railroad bridge converted for vehicular use. During the Depression, the highway department built a handful of steel girders—both simply supported and cantilevered—but it was not until the 1940s and 1950s that the state began building these spans with regularity. In the early 1960s AHD experimented briefly with long-span, variable-depth welded beams, but only erected a handful of these prototypical structures.

Significance: Steel stringer and girder bridges in Arizona may be eligible for listing in the National Register under Criterion A for their association with events that have made a significant contribution to the broad historical patterns of the country, the state or the region. Specifically, bridges that have played an important role in the development of the state's highway transportation system and, hence, in the settlement of the area. For example, a structure might be significant by its association with a particular route, such as the Apache Trail, or because it was built by the State Highway Department in its formative years. A bridge may, in addition, be eligible under Criterion B for its association with a significant person, as long as the "significant person" was not the designer or builder of the bridge. A bridge can be eligible by virtue of its designer or builder, but this falls under Criterion C. Indeed, most eligible bridges in Arizona qualify under Criterion C as structures of engineering significance. This can encompass a broad range of considerations. For instance, a bridge can qualify as a well-preserved example of a common type, or as a unique or unusual type.

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Steel stringer and girder bridges are sufficiently common in Arizona that to be considered eligible for listing in the National Register under Criterion C, a structure from this property type must have definitive historical documentation and some superlative feature about it that distinguishes it from its peers. Some examples of this are notably early construction date, exceptionally long span length, high span number, or well-executed architectural design. None of Arizona's steel stringer or girder bridges are considered to have national significance. Those dateable stringer and girder structures with physical integrity that were built by the state engineer, the Arizona Highway Department or the Bureau of Public Roads are generally considered to have state-level significance. Most of the locally built steel beam bridges are also considered eligible on a state level, by virtue of their significant features. Otherwise, small-scale steel beams built by local entities are considered locally eligible. Superlative steel stringer and girder bridges include:

Benson Bridge	(Cochise)	well-preserved multiple-span cantilevered girder
Bylas Bridge	(Graham)	longest multiple-span steel stringer
Dry Wash Bridge	(Maricopa)	earliest steel stringer
Peoria Underpass	(Maricopa)	well-preserved, rare through girder
Gila Bend Overpass	(Maricopa)	earliest AHD use of steel stringer on grade separation
Winslow Bridge	(Navajo)	well-preserved multiple-span cantilevered girder
Black Jack Canyon Bridge	(Greenlee)	well-preserved example of uncommon subtype
Wilbur Canyon Bridge	(Yavapai)	rare welded girder
Black Canyon Bridge	(Yavapai)	rare welded girder

Registration Requirements: The general period of significance for steel stringer and girder bridges in Arizona begins in 1923, the date for the state's earliest example of these structural types. Although the functionality of many of the bridges continues to the present—with the majority still in active use—the period of significance generally ends in 1964, the cutoff date for the statewide historic bridge inventory. The period of significance for an individual structure begins with the date that significant activities or events began giving the property its historic significance (typically, initial construction). Once the resource has ceased to serve the function that makes it historically important, its period of significance has ended. Alterations made during the period of significance may be considered part of the bridge's historic fabric, if they are in keeping with the bridge's original design.

Integrity of the structure's historic materials, configuration and setting is essential for a bridge to qualify for the National Register under any criterion. Because location is of primary importance under Criterion A, a structure will rarely qualify under this criterion if it does not remain on its original site. Location can also have significance under Criterion B, but the correlation is not as universal. When focusing on engineering significance under Criterion C, the mobility of metal stringer or girder bridges is an important trait, since the structures were considered moveable. Movement of the beam superstructure under this criterion might not necessarily detract too seriously from its historic integrity. On the other hand, structural integrity is of vital importance for those bridges considered under Criterion C.

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Integrity of design, materials and workmanship are key to a bridge's eligibility, particularly if that eligibility is stated in Criterion C terms. The principal consideration when evaluating integrity of design and materials is whether the bridge retains the features that defined its character during its historic period. Character-defining features of a steel stringer or girder bridge include the steel beam superstructure, deck, railing or parapet, and abutments, wingwalls and—if present—piers. Because of their relative simplicity and below-deck superstructures, stringer and girder bridges are generally visually undistinguished, and it is the guardrails that, more than anything, define the character of the bridge from the roadway. Alterations to the individual elements of a stringer or girder bridge have a relative impact on the design integrity of the bridge itself. For instance, widening a stringer by adding extensions onto one or both sides and replacing the guardrails impinges more on a bridge's integrity than adding lateral braces to the beams or repairing the abutments. Integrity of workmanship is closely related to design and materials but relates to the skill and craftsmanship involved in a bridge's construction.

Retaining a sense of setting is an important consideration for a bridge's overall integrity. Setting is defined as the topographic, vegetative and cultural character of the railroad's environs. Cultural character in this case generally delineates the built environment, but it can additionally indicate the socioeconomic or ethnic composition of the bridge's location. The principal consideration of integrity of setting is whether the extent to which the general environment or any particular aspect of that environment that affected the bridge's original design and construction remain intact from the bridge's period of significance. Are the salient features of the structure's environs still discernable and intact? The setting is usually defined as the viewshed from the bridge, which is to say all the natural and cultural features visible from the structure itself.

Integrity of feeling for a bridge is an amalgamation of the integrities of location, design, materials, workmanship and setting. It is a subjective appraisal of the overall experience conveyed by the structure. The principal consideration of integrity of feeling is whether the bridge under consideration and adjacent roadway convey a visceral sense of what it would have been like to travel over it during its historic period. Integrity of association relates to the link between a bridge and the distinctive events or personage that characterize it as historic. The alteration or loss of one or more of these integrities may be mitigated by other aspects of integrity of feeling and association.

Specific requirements under Criterion A:

1. **Early and/or prominent product of the Arizona Highway Department:** In the 1920s the Highway Department began using steel stringer and girder bridges around Arizona. One of these, the Dry Wash Bridge [**0015**], remains in place in intact condition.

2. **Outstanding example of federal work relief programs of the Depression era:** Federal work programs in the 1930s and early 1940s, particularly those funded by the Works Progress Administration, led to construction of a number of steel beam bridges in the state. The most significant display careful craftsmanship and creative design.

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Specific requirements under Criterion C

1. **Early and/or representative steel stringer and girder bridge:** Steel stringer and girder bridges are considered significant if they can be definitively documented and they exhibit superlative features (i.e., exceptionally long span length, unusual number of spans, uncommonly good state of preservation). Steel stringer and girder bridges in Arizona tend to have been subsequently altered by installation of steel Thrie beam guardrails. This is considered a serious loss of integrity, as is the replacement of original guardrails, which are considered character-defining elements. The installation of steel beams over the original guardrails is considered reversible and represents a less serious alteration. Steel beams built after World War II are considered significant if they were prototypes or earliest examples in the state for their type.

2. **Bridge with exceptional aesthetic merit:** Most bridges built by the State of Arizona are strictly utilitarian. Occasionally, however, a structure stands out by virtue of its design, its architectural detailing or because of the quality displayed in its construction. This does not include standard-design concrete guardrails by the Highway Department. The interrelationship of a bridge and its site can also have aesthetic value as well.

5 Property Type: Steel Truss Bridges

Description: Beginning in the late 1870s, the pin-connected wrought iron truss was the bridge of choice for medium- and long-span roadway crossings in America. Made up of numerous built-up timber or metal members connected at their ends to form series of triangles in a variety of web configurations, trusses functioned essentially as complex, long-span beams. They carried traffic in three different positions: the through configuration, with the roadway positioned between two tall webs and overhead struts spanning between the webs for rigidity; the pony configuration, with the roadway positioned between two relatively short webs, without overhead struts; and the deck configuration, with the roadway carried completely on top of the truss webs.

Following their introduction in the 19th century, trusses underwent an evolution of form that reflected other technological developments. For instance, cylindrical pins were first used to connect metal truss members in 1859. Two years later, a complementary truss member—the forged iron eyebar—was introduced. Steel eyebars appeared in the 1870s as a higher-strength, more consistent alternative to iron. Production of Bessemer and open-hearth steel improved in both quality and economy in the 1880s, making bridges more reliable; by the early 1890s all-steel bridges had largely superseded wrought iron structures.

Trusses were typically fabricated by manufacturers in large-scale shops, purchased by government entities by competitive bidding, shipped in pieces to the bridge sites and assembled over temporary wooden sup-

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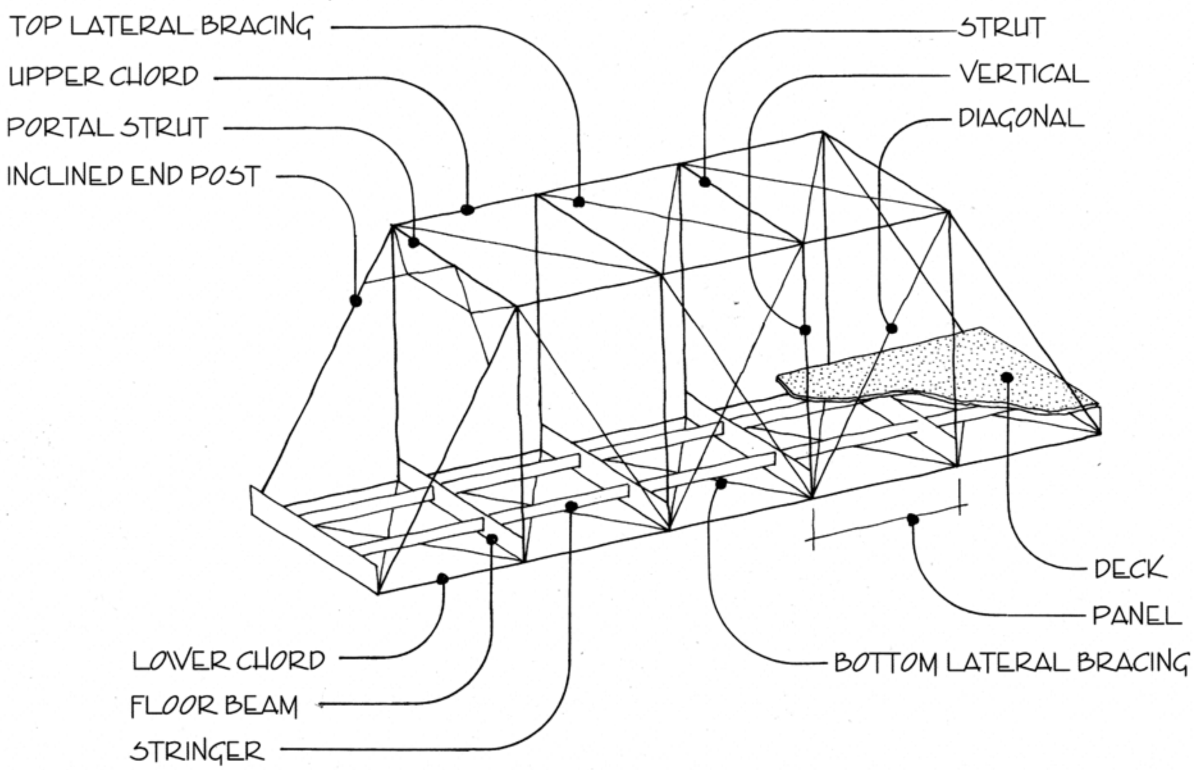

Figure 65. Truss bridge diagram.

ports, called falseworks. The bridge companies that proliferated through the Ohio River Valley and Midwest competed enthusiastically for county bridge business, marketing an ever-changing array of truss types through networks of regional sales representatives. Both patented in the 1840s, the Pratt and Warren web configurations—with their various subtypes—formed the basis for virtually all of the all-metal trusses built in Arizona in the late 19th and early 20th centuries. These structures were fabricated by such national firms as the Midland Bridge Company of Kansas City, the Missouri Valley Bridge and Iron Works of Leavenworth, Kansas, and the Omaha Structural Steel Bridge Company of Nebraska.

The earliest metal truss bridges in America featured pinned and bolted connections in some combinations. These were largely superseded by all-pinned trusses in the 1880s. Because of their relatively quick erection and easy fabrication, pin-connected trusses dominated the market until well into the 20th century. But they

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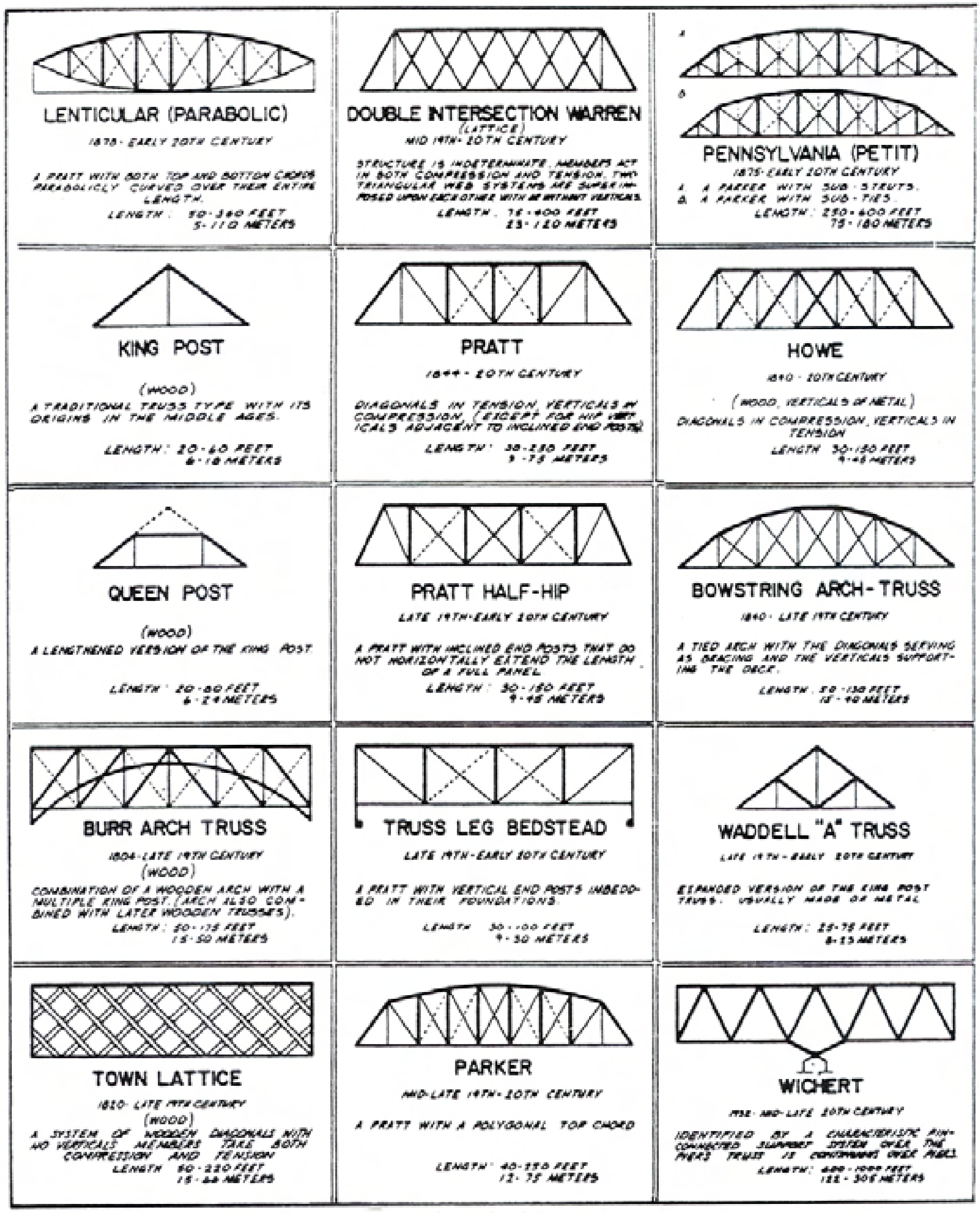

Figure 66. Truss bridge types, from Historic American Engineering Record.

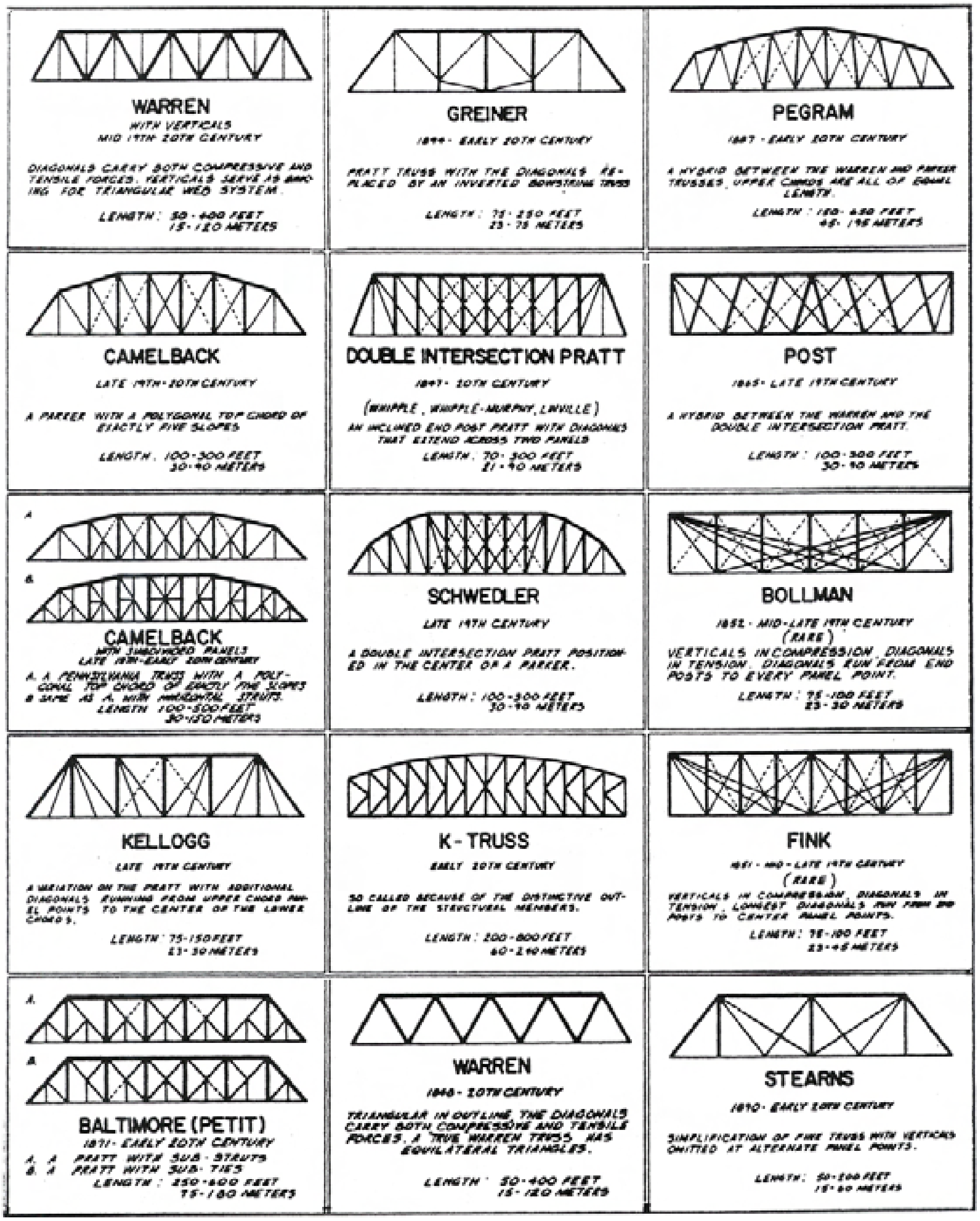

Figure 67. Truss bridge types, from Historic American Engineering Record.

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lacked long-term rigidity and could loosen over time from vibrations caused by traffic and wind. Rigid connections in trusses, with stiffening gusset plates at the joints in lieu of pins, created stronger, sturdier connections, but field riveting was not practical before portable pneumatic riveters became available after the turn of the century. In Arizona rigid-connected trusses began to overshadow pinned for highway spans around 1910.

Without question the most popular truss type of the period was the Pratt truss. Patented by Thomas and Caleb Pratt, the Pratt design was characterized by upper chords and vertical members acting compression and lower chords and diagonals that functioned in tension [*see Figure 69*]. (Compression members in a truss are distinguishable by their relatively heavy construction, typically two channels joined by lacing or batten plates; tension members are distinguishable by their relatively lighter construction, typically one or two angles on a rigid-connected truss.) The Pratt's parallel chords and equal panel lengths resulted in standardized sizes for the verticals, diagonals and chord members, making fabrication and assembly relatively easy. "The Pratt truss is the most commonly used in America for spans under two hundred and fifty feet in length," noted

Figure 68. White River Bridge, 2002.

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bridge engineer J.A.L. Waddell wrote in his influential *Bridge Engineering*. "Its advantages are simplicity, economy or metal, and suitability for connecting to the floor and lateral systems."[87]

In the highly competitive bridge manufacturing industry, in which efficiency equated with profit, Pratt trusses received almost universal use. Virtually all of the major regional fabricators manufactured Pratt trusses and marketed them to Arizona counties in the late 19th and early 20th centuries. As a result, the Pratt truss was the structure of choice in the state for medium- and long-span wagon bridges. From the straight-chorded Pratt design arose a variety of structural subtypes in the 19th century. The most common Pratt subtype was the Parker truss. Developed in the 19th century by C.H. Parker, the Parker truss was characterized by upper chords and vertical members that acted in compression and lower chords and diagonals acting in tension [*see Figure 70*]. In this it resembled the venerable Pratt and was, in fact, universally regarded by civil engineers as a Pratt subtype. Waddell gave the Parker only passing mention in his book, stating: "[The Pratt's] chords are not necessarily parallel, but may be inclined. This latter form is frequently known as the Parker truss."

Figure 69. Walnut Canyon Bridge, 2002.

[87]J.A.L. Waddell, *Bridge Engineering* (London: John Wiley and Sons, 1916), 468.

The inclined upper chords of the Parker truss afforded a degree of efficiency on long-span trusses, where bending moment stresses at mid-span greatly exceed the shear stresses at the ends. As literal manifestations of stress analysis, polygonal-chorded trusses placed the heaviest amount of metal at the point where the stresses were the greatest—in the middle. The Parker's drawback was that, unlike the straight-chorded Pratt truss, the polygonal chords necessitated different length verticals and diagonals at each panel point, increasing its fabrication and erection costs somewhat. Because trusses were generally priced on the basis of their superstructural steel weight, the lighter overall weight of a polygonal-chorded truss more than offset the slight increase in fabricating costs in spans greater than 150 feet.

Figure 70. Sanders Bridge, 2002.

A Camelback truss is a Parker with exactly five facets in its upper chord. With its distinctive profile, the Camelback configuration was disdained by many engineers for its ungainly appearance and its tendency under certain conditions to reverse compressive and tensile forces acting on individual members. As a result, Camelback trusses never received widespread acceptance in the 19th and early 20th centuries. The Whipple truss resembles the Pratt in its array of compression and tension members. Its primary difference lies in its diagonals, which extended over two panels. Patented in 1847 by esteemed civil engineer Squire Whipple, this eponymous truss was a popular choice for longer-span bridges—generally in excess of 150 feet— between 1850 and 1900. Although more costly than the single-paneled Pratt, this variation provided greater lateral support for the diagonals, a critical consideration in deep, long-span trusses. As the Whipple represents a subdivided Pratt, the Pennsylvania truss is a subdivided Parker.

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Most of Arizona's historic highway spans employ Pratt designs—either the straight-chorded Pratt itself or its later subtypes. The White River Bridge [**3129**], Perkinsville Bridge [**9474**] and Walnut Creek Bridge [**8741**] are all conventional rigid-connected Pratt through trusses. The St. Joseph Bridge [**8157**], Sanders Bridge [**3074**; *see Figure 71*] and Woodruff Bridge [**abd.**] are all rigid-connected Pratt pony trusses, and the Allentown Bridge [**3073**; *see Figure 72*] is a Pratt deck truss with end panels that cantilever over the piers. Arizona's two remaining pin-connected vehicular trusses—the Ocean-to-Ocean Bridge [**8533**] and the Park Avenue Bridge [**9633**; *see Figure 73*]—both employ polygonal-chorded Pratt web configurations. Three rigid-connected Parkers have also been identified in the state by the inventory: the Walnut Canyon Bridge [**9225**], the Salt River Bridge [**0037**] and the Boulder Creek Bridge [**0193**], which employs both polygonal- and straight-chorded Pratt spans . Additionally, three rigid-connected Camelback through trusses have been identified: the Gillespie Dam Bridge [**8021**], Walnut Grove Bridge [**8227**] and the Mormon Flat Bridge [**0026**].

Figure 71. Allentown Bridge, 2002.

Figure 72. Park Avenue Bridge, 2003.

In Arizona the Pratt and its various modified designs rode a wave of popularity well into the 20th century. The other principal truss category that competed with the Pratt in the late 19th and early 20th centuries was the Warren truss. Patented in 1848 by Captain James Warren and Theobald Monzani, the Warren truss in its classic form features a web configuration that relies on simple triangulation for its rigidity. Warrens were built sparingly in the United States in the 19th century, a period in which the pin-connected Pratt dominated the bridge industry. After about 1910, however, rigid-connected Warren pony trusses began to compete with earlier Pratt configurations for use on short- to intermediate-span highway bridges. Although these bridges displayed variations in their web configurations (some were "pure" Warrens without verticals, others had verticals at all or alternating panel points), virtually all of these early Warrens featured straight upper chords.

Fifteen Warren trusses have been identified in the Arizona inventory, more than any other truss type. One of these (Woodruff Bridge [**8156**; *see Figure 74*]) features a polygonal upper chord and through truss configuration; five (Dead Indian Canyon Bridge [**0032**], Black River Bridge [**3128**], Little Hell Canyon Bridge [**3381**], Sand Hollow Wash Bridge [**8662**] and Querino Canyon Bridge [**8071**; *see Figure 75*]) are configured as deck trusses; and the remainder are pony trusses. Built between 1913 and 1934, these all featured rigid connections and—with one exception (Chevelon Creek Bridge [**8158**])—straight upper chords.

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Figure 73. Woodruff Bridge, 2002.

The Arizona Highway Department did not develop standard truss designs in the 1920s or 1930s, instead concentrating on concrete bridge types. As a result, steel trusses never received widespread use in Arizona. The earliest trusses were all medium-length, simply supported spans, typically carried on concrete abutments or piers. These were constructed using traditional formworks, which were dismantled after the trusses' completion.[88] In the 1950s the highway department engineered a handful of long-span deck trusses, which cantilevered over the piers. Built without formworks over steep canyons, these structures featured Pratt web configurations and resembled steel arches with their polygonal lower chords. Three of these latter bridges— the Cameron Truss Bridge [**0532**; *see Figure 76*], Hell Canyon Bridge [**0483**], and the Guthrie Bridge [**0352**]—have been included in the statewide bridge inventory.

[88]The Ocean-to-Ocean Bridge in Yuma, which was assembled on a barge and floated into place, was the notable exception.

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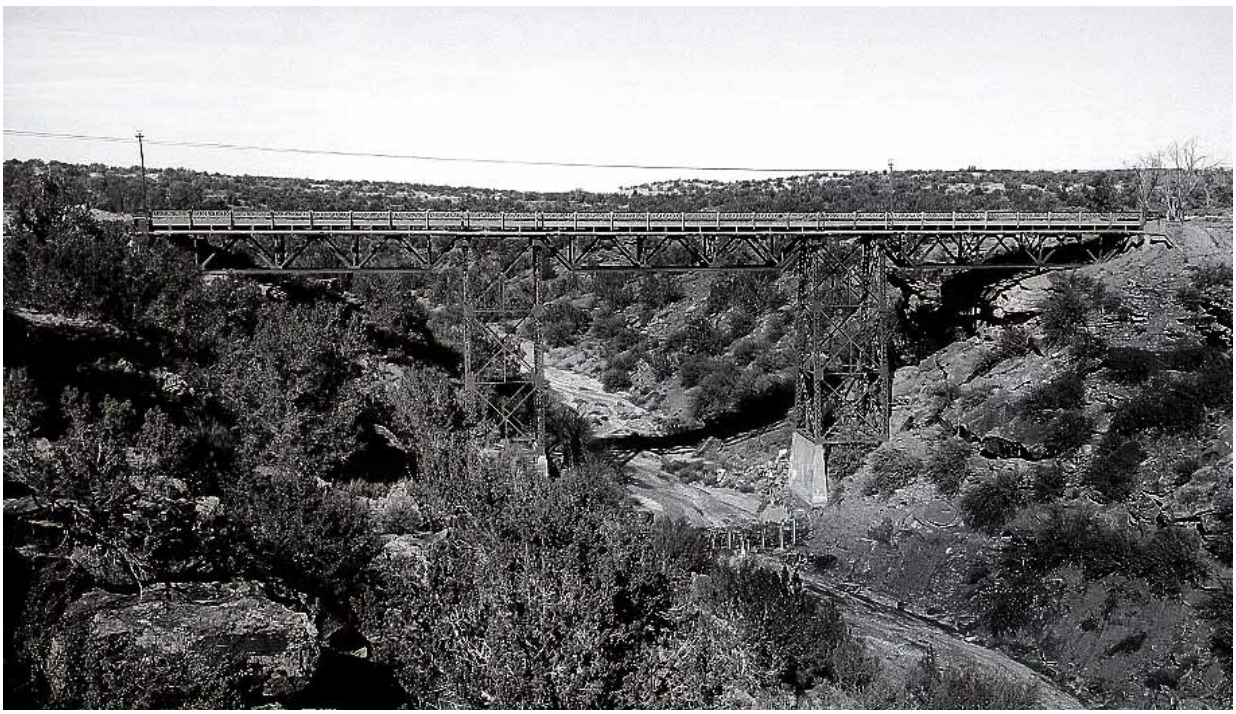

Figure 74. Querino Canyon Bridge, 2002.

Significance: Steel truss bridges in Arizona may be eligible for listing in the National Register under Criterion A for their association with events that have made a significant contribution to the broad historical patterns of the country, the state or the region. Specifically, bridges that have played an important role in the development of the state's highway transportation system and, hence, in the settlement of the area. For example, a structure might be significant by its association with a particular route, such as the Borderland Highway, or because it was built by the State Highway Department in its formative years. A bridge may, in addition, be eligible under Criterion B for its association with a significant person, as long as the "significant person" was not the designer or builder of the bridge. A bridge can be eligible by virtue of its designer or builder, but this falls under Criterion C. Indeed, most eligible bridges in Arizona qualify under Criterion C as structures of engineering significance. This can encompass a range of considerations. For instance, a bridge can qualify under Criterion C as a well-preserved example of a common type, or as a unique or unusual type.

Although their numbers are substantially diminished by attrition, metal trusses are still sufficiently common in Arizona that to be considered eligible for listing in the National Register, a structure from this property type must have definitive historical documentation. Only one of Arizona's steel truss bridges—the Ocean-to-Ocean Bridge [**8533**] in Yuma—is considered to have national significance. Those dateable trusses that were built by the state engineer, the Arizona Highway Department or the Bureau of Public Roads are generally considered to have state-level significance. Most of the locally built steel beam bridges are also considered eligible on a state level, by virtue of their significant features. Otherwise, small-scale steel beams built by local entities are considered locally eligible. Superlative steel truss bridges include:

Querino Canyon Bridge	(Apache)	well-preserved multiple-span truss
Allentown Bridge	(Apache)	earliest cantilever truss
Sanders Bridge	(Apache)	well-preserved example of early AHD truss
Dead Indian Canyon Bridge	(Coconino)	well-preserved example of uncommon truss
Cameron Truss Bridge	(Coconino)	well-preserved example of cantilevered truss
Black River Bridge	(Gila)	well-preserved truss on territorial substructure
Salt River Bridge	(Gila)	longest and oldest rigid-connected through truss
Guthrie Bridge	(Greenlee)	earliest AHD long-span cantilevered truss
Park Avenue Bridge	(Greenlee)	well-preserved pin-connected truss
Boulder Creek Bridge	(Maricopa)	well-preserved multiple-span truss
Gillespie Dam Bridge	(Maricopa)	longest multiple-span truss
Sand Hollow Wash Bridge	(Mohave)	well-preserved multiple-span truss
Chevelon Creek Bridge	(Navajo)	well-preserved, early state-built truss
Woodruff Bridge	(Navajo)	only example of rare truss type
Little Hell Canyon Bridge	(Yavapai)	well-preserved example of uncommon truss
Little Hell Canyon Bridge	(Yavapai)	well-preserved example of uncommon truss

Registration Requirements: The period of significance for steel truss bridges in Arizona generally begins in 1889, the date for the state's earliest example of this structural type. Although the functionality of many of the bridges continues to the present—with the majority still in active use—the period of significance generally ends in 1964, the cutoff date for the statewide historic bridge inventory. The period of significance for an individual structure begins with the date that significant activities or events began giving the property its historic significance (typically, initial construction). Once the resource has ceased to serve the function that makes it historically important, its period of significance has ended. Alterations made during the period of significance may be considered part of the bridge's historic fabric, if they are in keeping with the bridge's original design.

Integrity of the structure's historic materials, configuration and setting is essential for a bridge to qualify for the National Register under any criterion. Because location is of primary importance under Criterion A, a structure will rarely qualify under this criterion if it does not remain on its original site. Location can also have significance under Criterion B, but the correlation is not as universal. When focusing on engineering significance under Criterion C, the mobility of metal truss bridges is an important trait, since the structures were considered moveable. Movement of the beam superstructure under this criterion might not necessarily detract too seriously from its historic integrity. On the other hand, structural integrity is of vital importance for those bridges considered under Criterion C.

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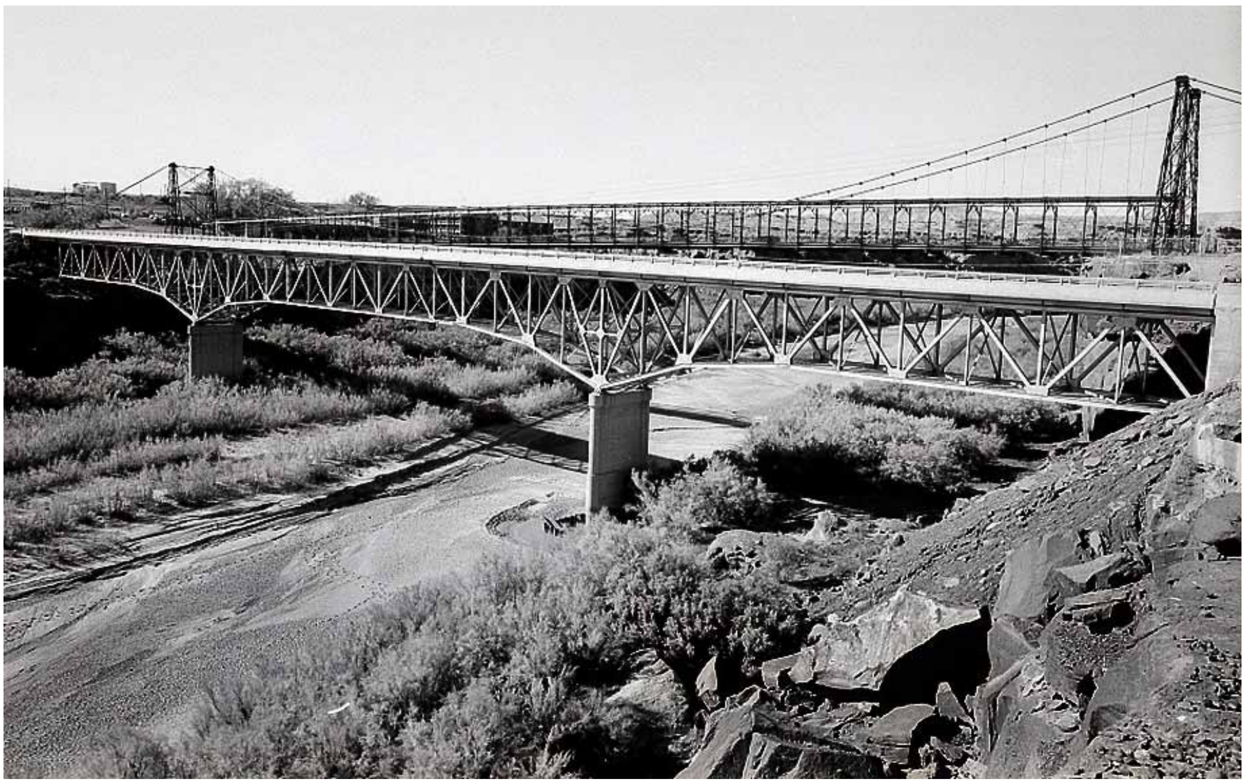

Figure 75. Cameron Truss Bridge, 2002.

Integrity of design, materials and workmanship are key to a bridge's eligibility, particularly if that eligibility is stated in Criterion C terms. The principal consideration when evaluating integrity of design and materials is whether the bridge retains the features that defined its character during its historic period. In engineering terms, a truss bridge is considered to be comprised of a group of distinct structural subsystems, rather than a single entity. These systems, in general order of importance under Criterion C, are the superstructure, the substructure, the floor, guardrails and approach spans, if any. The super- and substructure of a bridge, for instance, may have retained a high degree of physical integrity, while the floor system and approach spans may have been altered, replaced, or even removed, and the bridge may still be considered NRHP eligible.

Loss of physical integrity may also be mitigated by technological significance for unique or rare structural types. Alterations to the individual elements of a truss bridge have a relative impact on the design integrity of the bridge itself. For instance, replacing the deck or guardrails impinges more on a bridge's integrity than repairing truss members or repairing the abutments. Integrity of workmanship is closely related to design and materials but relates to the skill and craftsmanship involved in a bridge's construction. Retaining a sense

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of setting is an important consideration for a bridge's overall integrity. Setting is defined as the topographic, vegetative and cultural character of the railroad's environs. Cultural character in this case generally delineates the built environment, but it can additionally indicate the socioeconomic or ethnic composition of the bridge's location. The principal consideration of integrity of setting is whether the extent to which the general environment or any particular aspect of that environment that affected the bridge's original design and construction remain intact from the bridge's period of significance. Are the salient features of the structure's environs still discernable and intact? The setting is usually defined as the viewshed from the bridge, which is to say all the natural and cultural features visible from the structure itself.

Integrity of feeling for a bridge is an amalgamation of the integrities of location, design, materials, workmanship and setting. It is a subjective appraisal of the overall experience conveyed by the structure. The principal consideration of integrity of feeling is whether the bridge under consideration and adjacent roadway convey a visceral sense of what it would have been like to travel over it during its historic period. Integrity of association relates to the link between a bridge and the distinctive events or personage that characterize it as historic. The alteration or loss of one or more of these integrities may be mitigated by other aspects of integrity of feeling and association.

Specific requirements under Criterion A:

1. **Early and/or prominent product of the Arizona Territorial Engineer's Office, Arizona State Engineer's Office or Arizona Highway Department:** The Arizona Territorial Engineer designed a timber truss bridge (Black River Bridge [**3128**]), which was later replaced with a steel truss, and the Arizona State Engineer began delineating steel trusses (e.g., Chevelon Creek Bridge [**8158**]) soon after the office was created. Several of the state's oldest remaining vehicular bridges, which provided important crossings on Arizona's most significant highways, are steel trusses designed by the state highway department or the federal Bureau of Public Roads in their formative years.

Specific requirements under Criterion C:

1. **Early and/or representative iron and steel truss bridges:** Truss bridges built before 1930 are sufficiently rare that all documentable examples that retain structural integrity are considered significant. All trusses in Arizona—rendered rare by subsequent attrition—are considered generally significant.

2. **Exceptional example of work by an important engineer, architect or firm:** This includes local, regional and national companies and designers.

3. **Bridge with exceptional aesthetic merit:** Most bridges built in the state are strictly utilitarian. Occasionally, however, a structure stands out by virtue of its design or because of the quality displayed in its construction. This does not include standard-design concrete guardrails by the Highway Department, however. The interrelationship of a bridge and its site can also have aesthetic value as well.

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6 Property Type: Long-Span Steel Arch and Suspension Bridges

Description: Steel arch and suspension bridges are among the most dramatic and esoteric structural types developed for vehicular use. Relatively few were ever built in America. Both bridge types were typically constructed where topographic or navigational concerns precluded construction of conventional structural types, with their falseworks (trusses) or multiple spans (concrete girders). In Arizona, keeping the rivers open for navigation was not really an issue, but many of the river crossings featured deep, steep-walled canyons or extreme fluctuations of stream flow, which required long-span bridges. Arches and suspension bridges generally did not require falseworks in their erection; the arches relied on cantilevering and suspension bridges were hung from the suspension wires that spanned the watercourse. First built before the Civil War, both structural types were able to reach monumental lengths, and both continue to be built today.

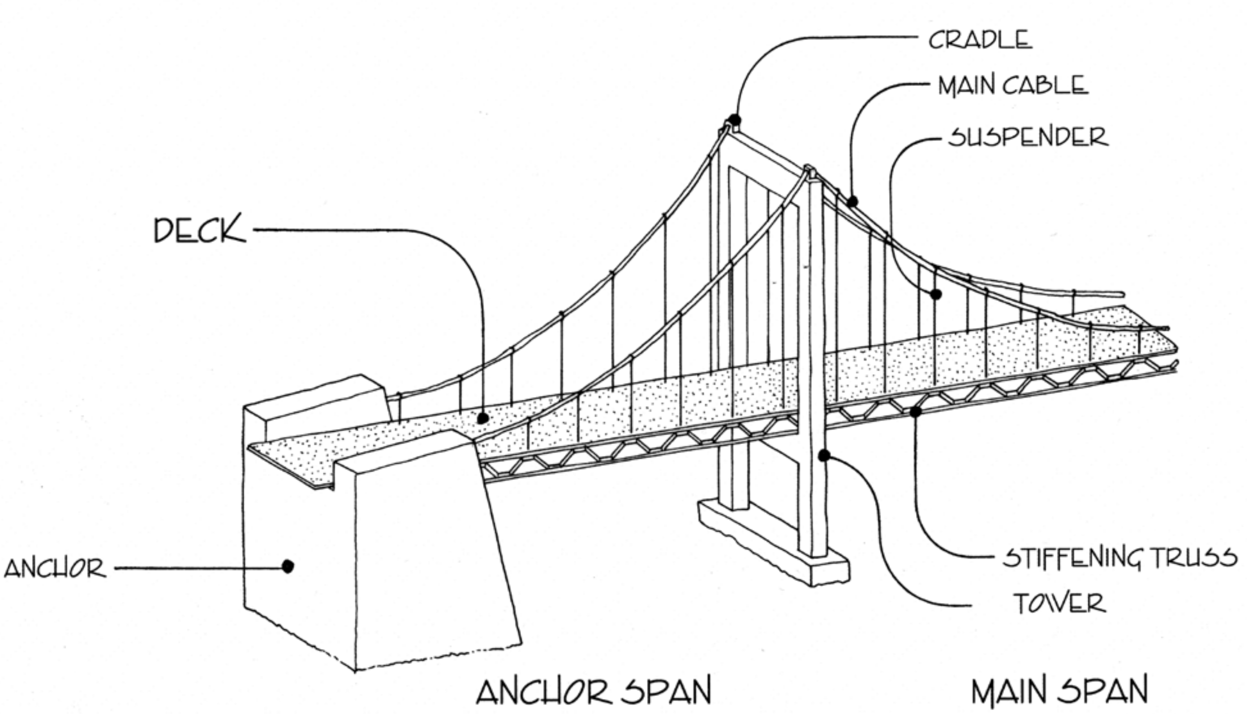

Figure 76. Suspension bridge diagram.

VEHICULAR BRIDGES IN ARIZONA

The world's first all-iron bridge, a single-span arch structure, was built in Coalbrookedale, England, in 1779.[89] This was followed eventually by other cast iron arches in Europe in the late 18th century. The first all-metal bridge built in America was an 80-foot arch made up of five cast iron tubular rings, built in 1836 on the National Road in Pennsylvania. The iron arch was never popular in 19th century America, however, because few foundries had the capacity for such large and intricate castings. As a structural type, it was superseded by the wrought iron truss.

Steel arches, also termed hinged arches, are classified by their type of articulation. Structures with continuous arches hinged at the end bearing points are termed two-hinge arches. Structures with hinges at the bearing points and an additional hinge at mid-span are termed three-hinge arches. Arches have been erected with a single hinge—typically at mid-span—but this is rare. The three-hinge-arch was considered generally too flexible for use on railroad spans, and was restricted to highway structures. The two-hinge arch is by far the most common hinge configuration and is the type used on most of Arizona's bridges. Arches are also classified by their structural configuration. They are either termed spandrel-braced arches, with relatively lightweight arch ribs reinforced by extensive lateral bracing, or girder-ribbed arches, with relatively deep I-beam arch ribs that require considerably less lateral bracing. The latter arch type is more rigid under load than the former and has been used more often in Arizona.

According to historian David Plowden, "even though the truss was the logical choice for most bridges, the suspension bridge was the only one practical for very long spans." As a structural type, a suspension bridge generally features a roadway or deck hung in place by means of vertical suspenders from two or more ropes, chains, eyebars or cables, which were draped parabolically over tall towers at each end of the span. The towers acted in compression; the cables acted in tension and were anchored at the ends to massive stone or concrete anchorages, commonly known as deadmen. Since the cables and suspenders do not provide much in the way of lateral stability under loads or in high winds, suspension bridges usually featured either stiffening trusses around the deck or ancillary cables that attached the deck at various points to side anchorages. Relatively easy and economical to build, short- and medium-span suspension bridges were erected in the late 19th and early 20th centuries at secondary crossings where traffic was relatively light. Suspension bridges are best suited for long-span crossings, however, and many of America's longest and most significant spans (e.g., the Golden Gate Bridge, Brooklyn Bridge, Mackinac Bridge) are suspension bridges.

The suspension bridge is a structural type that dates to antiquity, and iron-chain suspension bridges were built in China as early as 200 B.C. It was used intermittently in the East but rarely in the West, and the first recorded use of iron in a Western suspension bridge was a chain bridge built in 1734 near Glorywitz, Prussia. The first

[89] Remarkably, the Coalbrookedale Bridge still stands and has been restored as an internationally significant engineering site.

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suspension bridge built in America was located in western Pennsylvania. Constructed by James Finley over Jacob's Creek in 1801, the 70-foot-span structure was one of the first suspension bridges in the world built with a rigid, level deck suitable for vehicular traffic. This was followed by other chain structures in Pennsylvania, Maryland and Massachusetts. These earliest bridges used linked chains for their main suspenders and tended to collapse with distressing frequency. The country's first wire suspension bridge was a footbridge built in 1816 over the Schuylkill Falls near Philadelphia, which replaced an earlier chain bridge at this location.

Figure 77. Topock Bridge, 2002.

Steel arch and suspension bridges were never built in abundance in America, and fewer than twenty were ever built in Arizona. The first arch bridge was the Old Trails Bridge [**priv.**; *see Figure 78*], a steel three-hinge, spandrel-braced through arch built over the Colorado River at Topock in 1916. It was a nationally significant structure—a dead ringer for the Bellows Falls Arch Bridge (1905) in Vermont. At the time of its completion, the Old Trails Bridge was the longest steel arch in America and also the country's lightest and longest three-hinged arch. A year after its completion, the Arizona State Engineer proposed building a similar arch over the Gila River near Clifton, but that design was scrapped in favor of a more conventional two-span Luten arch [**8152**]. In 1924 the U.S. Bureau of Public Roads proposed another long-span through arch, this time over the Colorado River at the Grand Canyon. That design was also scrapped, in favor of a deck arch that was eventually built as the Navajo Bridge [**0051**; *see Figure 79*], completed in 1929.

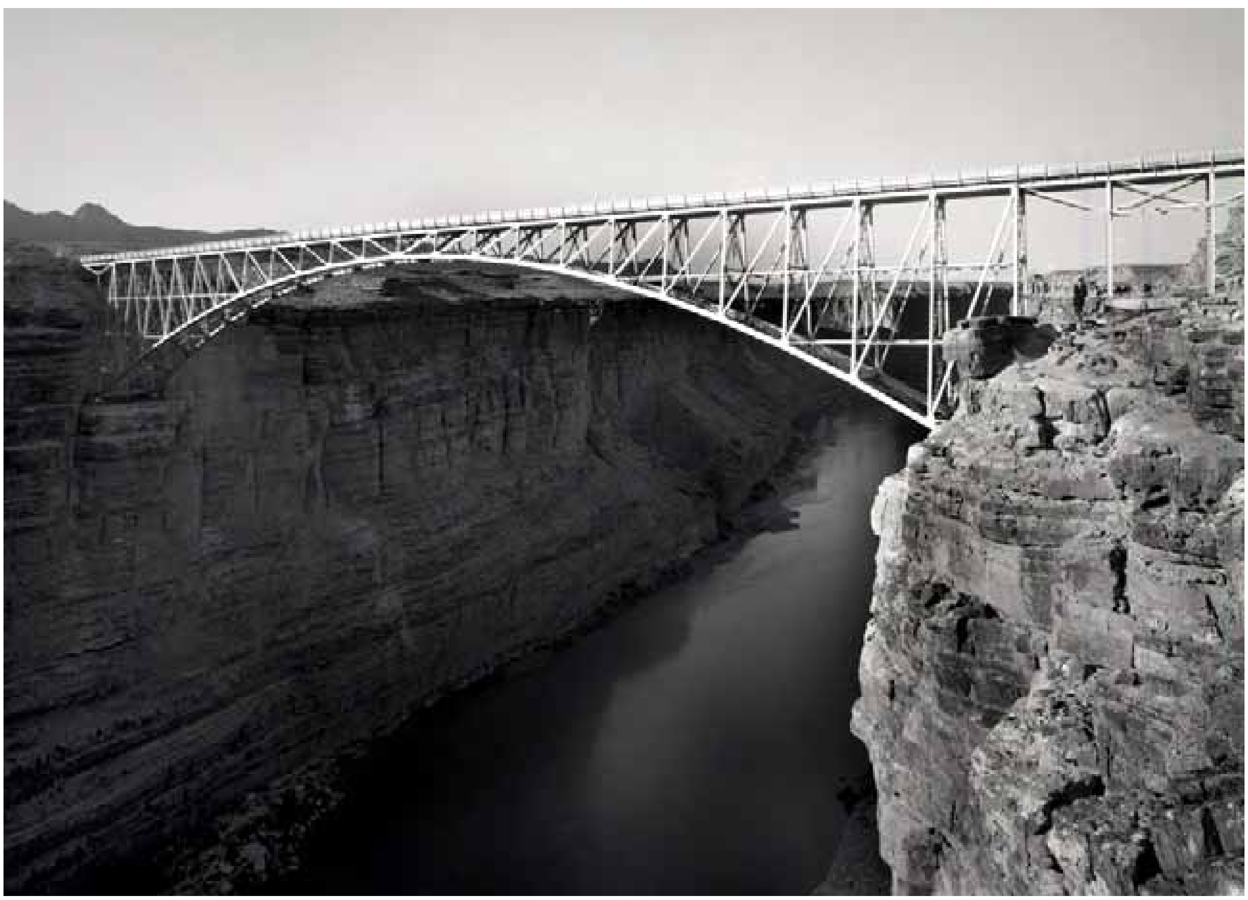

Figure 78. Navajo Bridge, 2002.

The Navajo Bridge was the second steel arch built in the state. As its designer, AHD Bridge Engineer Ralph Hoffman himself allowed, its design contained little in the way of engineering innovation. Despite this, the Navajo Bridge did mark an important milestone of engineering design, logistical planning and construction supervision. It was the first steel deck arch built in Arizona and a nationally prominent example of this uncommon structural type. What makes this bridge technologically noteworthy is its immense scale, its inspired logistical planning and its breathtaking span over one of the most spectacular bridge sites in America. Although Hoffman was concerned primarily with the functional aspects of the Navajo Bridge and not its appearance, this handsomely proportioned structure ranks among the country's most dramatic bridges. Flying high over the Grand Canyon, the Navajo Bridge is Arizona's most aesthetically and functionally successful example of civil engineering.

The Navajo Bridge was followed in 1934 by the Salt River Canyon Bridge [**0129**], a two-hinge girder-ribbed deck arch. This formed the prototype for subsequent arches in the state, including the Cedar Canyon and Corduroy Creek Bridges [**0215**; *see Figure 80*], the Pinto Creek Bridge [**0351**] and the Queen Creek Bridge [**0406**]. Other noteworthy steel arches built in the state include the Glen Canyon Bridge [**0537**], the Midgley Bridge [**0232**], and the Clear Creek Bridge [**1038**].

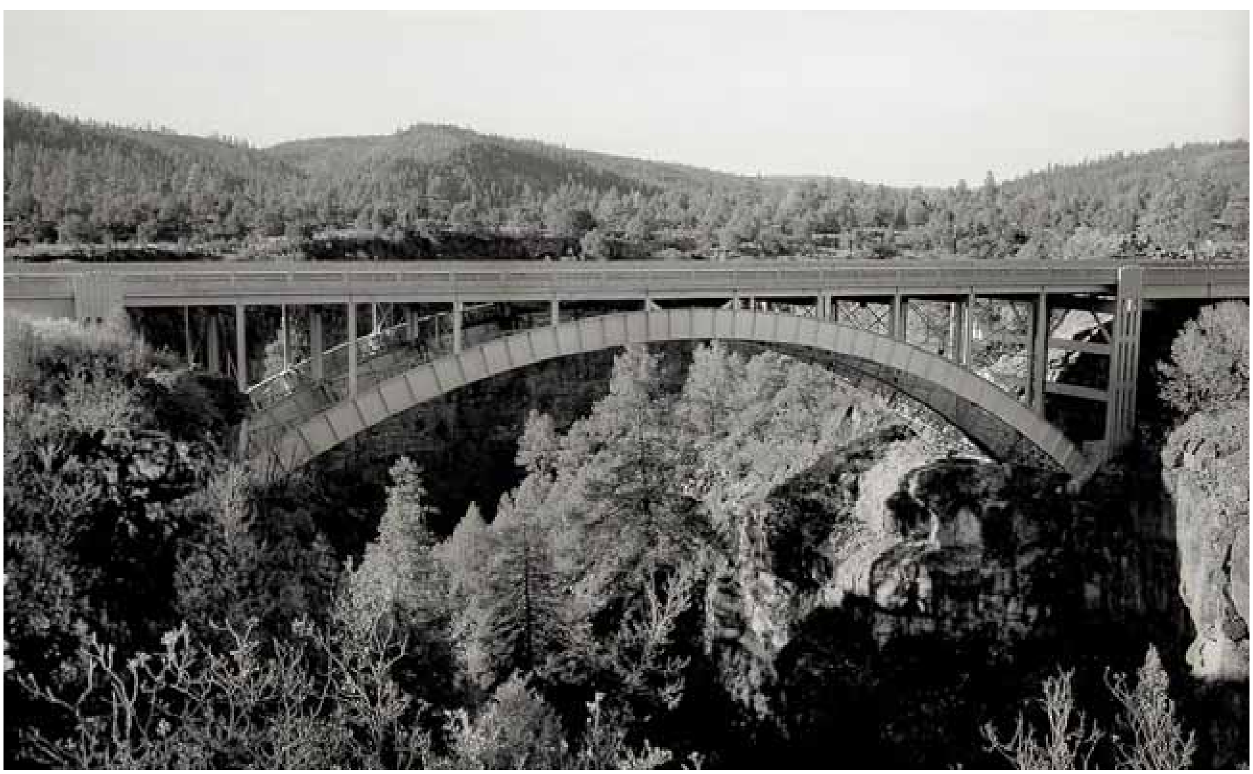

Figure 79. Cedar Canyon and Corduroy Creek Bridges, 2003.

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Arizona's first vehicular suspension bridge was built over the Little Colorado River at the Cameron Trading Post in 1911. In the early 1900s the U.S. Indian Irrigation Service and the Office of Indian Affairs had made a concerted effort to improve commerce on the extensive Navajo and Hopi Reservations in northeastern Arizona Territory. Key to this was a proposed bridge over the Little Colorado river to link the reservations with Flagstaff. OIA contracted with the Midland Bridge Company of Kansas City, Missouri, to engineer and build the long bridge. The canyon at this location was both wide and deep with steep-sided walls, requiring a single-span structure that could be erected without falsework. To solve the problem, Midland Chief Engineer W.H. Code designed this 660-foot-long suspension structure. The main suspension cables were comprised of seven woven steel cables clamped together, which were tied into massive concrete deadmen at the four corners. These cables passed over cast steel cradles at the tops of the braced steel towers. The suspended span was stiffened by a pin-connected Pratt through truss with a roadway width of 14 feet. Midland erected the Cameron Bridge [**priv.**] in 1911 [*see Figure 81*].

Figure 80. Cameron Suspension Bridge, 2002.

This was followed in the 1920s by the state's only other steel suspension vehicular bridge—the McPhaul Bridge [**abd.**] over the Gila River [*see Figure 82*]. When Arizona State Engineer Lamar Cobb first looked for a cros-

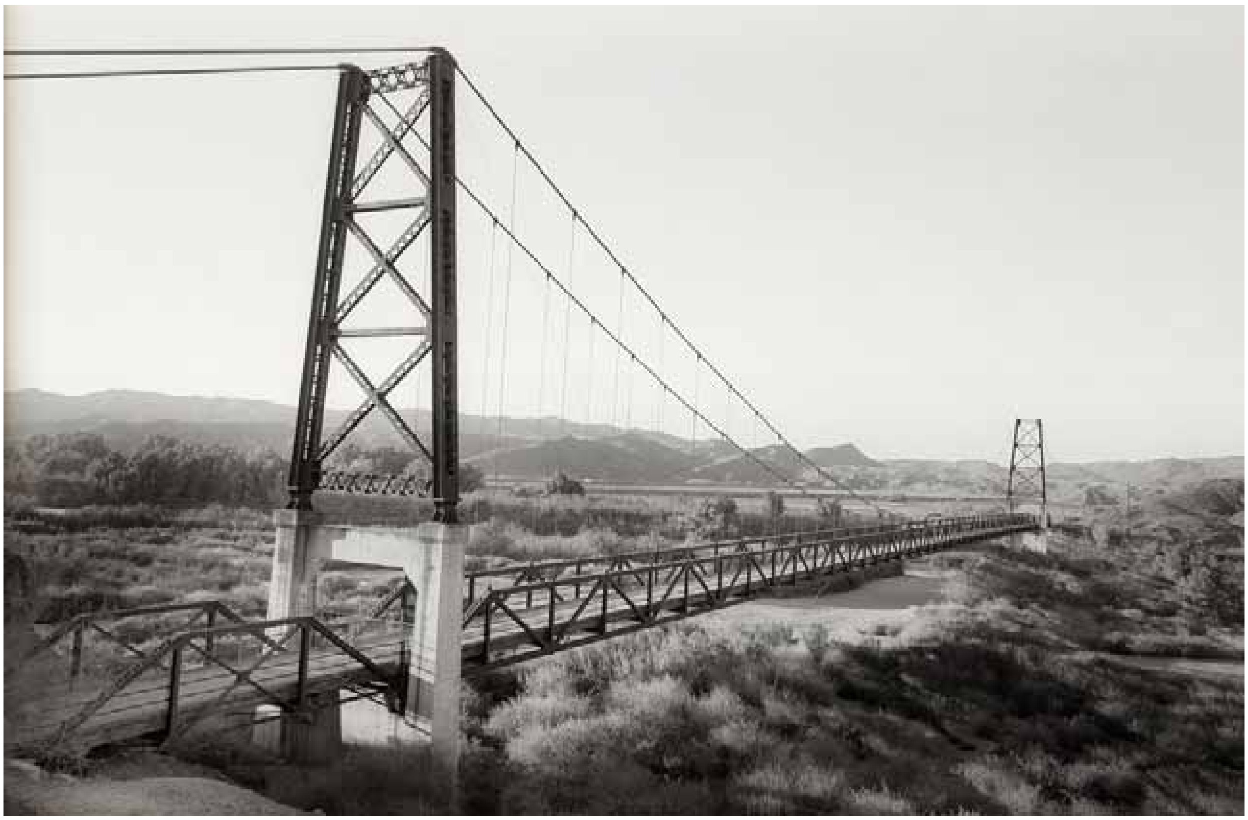

Figure 81. McPhaul Bridge, 2003.

sing location of the Gila River for the Ocean-to-Ocean Highway in Yuma County, he inspected sites at Dome and Antelope Hill and chose the latter. The Antelope Hill Bridge [**abd.**], a multiple-span concrete girder structure, was completed in 1915 and immediately began suffering damage with almost every flood on the Gila. Eventually, after years of repairs, it was abandoned altogether. The highway had already been rerouted through Telegraph Canyon, eliminating the need for the bridge altogether, when the Highway Department decided to replace the existing ford at Dome with a bridge. Soundings were taken, a site selected near a granite outcrop, and in 1927 the engineers decided to avoid the scouring problems of the Antelope Hill Bridge by free-spanning the river completely with a long suspension bridge.

In January 1928 AHD contracted with the Levy Construction Co. to build the structure. Although AHD engineers had outlined the bridge's location and span, Levy engineered the bridge with the assistance of nationally known consulting engineer Ralph Modjeski. Construction began in mid-1928 and was completed in December 1929. The McPhaul Bridge carried traffic on US 95 until its replacement in 1968. It was abandoned in place and, though closed, still spans the Gila River in unaltered and relatively good condition.

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Significance: Steel arch and suspension bridges in Arizona may be eligible for listing in the National Register under Criterion A for their association with events that have made a significant contribution to the broad historical patterns of the country, the state or the region. Specifically, bridges that have played an important role in the development of the state's highway transportation system and, hence, in the settlement of the area. For example, a structure might be significant by its association with a particular route, such as the Old Trails Highway, or because it was built by the State Highway Department in its formative years. A bridge may, in addition, be eligible under Criterion B for its association with a significant person, as long as the "significant person" was not the designer or builder of the bridge. A bridge can be eligible by virtue of its designer or builder, but this falls under Criterion C. Indeed, most eligible bridges in Arizona qualify under Criterion C as structures of engineering significance. This can encompass a broad range of considerations. For instance, a bridge can qualify under Criterion C as a well-preserved example of a common type, or as a unique or unusual type.

Steel arch and suspension bridges in Arizona are rare enough and technologically significant enough that all examples from the historic period that have retained their character-defining elements are considered eligible for the National Register. Three of these—two of which no longer carry vehicular traffic—are considered to have national significance. These are the Old Trails Bridge [**abd.**], the Navajo Bridge [**0051**] and the McPhaul Bridge [**abd.**]. All of the state's examples of these rare structural types were built either by the state (the state engineer or AHD) or by the Bureau of Public Roads, and all are therefore eligible for the National Register on at least a state level. Superlative steel truss bridges include:

Navajo Bridge	(Coconino)	Arizona's most important vehicular bridge
Cameron Bridge	(Coconino)	oldest and longest suspension bridge
Midgley Bridge	(Coconino)	well-preserved example of rare structural type
Salt River Canyon Bridge	(Gila)	oldest steel ribbed arch
Old Trails Bridge	(Mohave)	oldest and only steel through arch
McPhaul Bridge	(Yuma)	well-preserved example of rare structural type

Registration Requirements: The general period of significance for steel arch and suspension bridges in Arizona begins in 1916, the date for the state's earliest example of this structural type. Although the functionality of many of the bridges continues to the present—with the majority still in active use—the period of significance generally ends in 1964, the cutoff date for the statewide historic bridge inventory. The period of significance for an individual structure begins with the date that significant activities or events began giving the property its historic significance (typically, initial construction). Once the resource has ceased to serve the function that makes it historically important, its period of significance has ended. Alterations made during the period of significance may be considered part of the bridge's historic fabric, if they are in keeping with the bridge's original design.

Integrity of the structure's historic materials, configuration and setting is essential for a bridge to qualify for the National Register under any criterion. Because location is of primary importance under Criterion A, a

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structure will rarely qualify under this criterion if it does not remain on its original site. Location can also have significance under Criterion B, but the correlation is not as universal. When focusing on engineering significance under Criterion C, the mobility of metal arch bridges is an important trait, since the structures were considered moveable. Movement of the arch superstructure under this criterion might not necessarily detract too seriously from its historic integrity. On the other hand, structural integrity is of vital importance for those bridges considered under Criterion C.

Integrity of design, materials and workmanship are key to a bridge's eligibility, particularly if that eligibility is stated in Criterion C terms. The principal consideration when evaluating integrity of design and materials is whether the bridge retains the features that defined its character during its historic period. In engineering terms, an arch or suspension bridge is considered to be comprised of a group of distinct structural subsystems, rather than a single entity. These systems, in general order of importance under Criterion C, are the superstructure (the arches or suspender cables and towers), the substructure, the floor, guardrails and the approach spans, if any. The super- and substructure of a bridge, for instance, may have retained a high degree of physical integrity, while the floor system and approach spans may have been altered, replaced, or even removed, and the bridge may still be considered eligible for registration.

Loss of physical integrity may also be mitigated by technological significance for unique or rare structural types. Alterations to the individual elements of a truss bridge have a relative impact on the design integrity of the bridge itself. For instance, replacing the deck or guardrails impinges more on a bridge's integrity than repairing truss members or repairing the abutments. Integrity of workmanship is closely related to design and materials but relates to the skill and craftsmanship involved in a bridge's construction.

Retaining a sense of setting is an important consideration for a bridge's overall integrity. Setting is defined as the topographic, vegetative and cultural character of the railroad's environs. Cultural character in this case generally delineates the built environment, but it can additionally indicate the socioeconomic or ethnic composition of the bridge's location. The principal consideration of integrity of setting is whether the extent to which the general environment or any particular aspect of that environment that affected the bridge's original design and construction remain intact from the bridge's period of significance. Are the salient features of the structure's environs still discernable and intact? The setting is usually defined as the viewshed from the bridge, which is to say all the natural and cultural features visible from the structure itself.

Integrity of feeling for a bridge is an amalgamation of the integrities of location, design, materials, workmanship and setting. It is a subjective appraisal of the overall experience conveyed by the structure. The principal consideration of integrity of feeling is whether the bridge and adjacent roadway convey a visceral sense of what it would have been like to travel over it during its historic period. Integrity of association relates to the link between a bridge and the distinctive events or personage that characterize it as historic. The alteration or loss of one or more of these integrities may be mitigated by other aspects of integrity of feeling and association.

7 Property Type: Timber Stringer Bridges

Description: Also termed timber beam bridges, timber stringers are among the simplest and most economical bridge types to build. A timber stringer bridge consists of a wood plank deck attached to a row of longitudinally placed, sawn wood beams or stringers. The spans are supported by a variety of substructural configurations, including timber pile bents, timber cribs, concrete abutments and piers, even timber sills laid directly on grade. Timber stringer bridges are rudimentary structures limited in their span length by the practical lengths of the stringers, typically between 10 and 30 feet. Because of their susceptibility to weathering, they were generally considered impermanent structures, with a lifespan of less than 20 years.

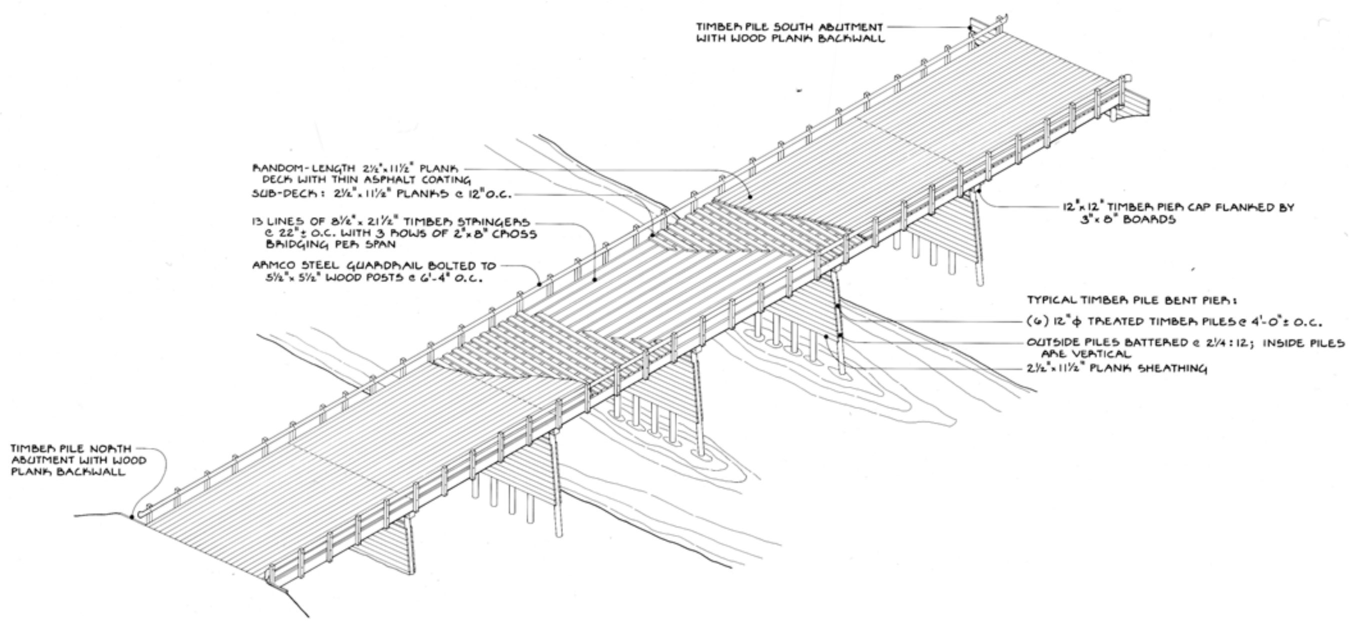

Figure 82. Timber stringer bridge diagram.

The timber stringer bridge is a structural type that dates to antiquity. First used in Colonial America and throughout the Midwest and West, timber has been used for bridge construction in Arizona for as long as there have been bridges. The railroads used timber extensively when building through the desert in the 19th century, constructing multiple-span trestles when stream conditions allowed for many pile bent piers. Bridges built for roadway use followed the same structural principles and took many of the same forms as railroad bridges. Like the railroads, early Arizona vehicular roads used timber for bridges, and for the same rea-

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sons. Early toll-road operators and county road crews typically avoided building bridges when they could, but when they could not, they built as cheaply as possible, and timber bridges were the cheapest and most quickly completed structures that could be built in the 19th and early 20th centuries.

During the 1910s the Arizona State Engineer's office generally eschewed timber trestles in favor of concrete and steel construction, and the state directed the counties away from timber construction as well. By the 1930s, however, when the Arizona Highway Department needed to build numerous small-scale drainage structures over thousands of miles of newly developed highways, the state embraced timber work, if not enthusiastically, then certainly comprehensively. During the Depression, when labor was more plentiful than materials, and during World War II, when strategic materials such as concrete and steel were embargoed by the government, timber was used by the Highway Department for bridge construction [*see Figures 84 and 85*]. That trend continued into the 1950s, and timber pile bridges continue to be built today at secondary locations.

Figure 83 Packer Wash Bridge, 2003.

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VEHICULAR BRIDGES IN ARIZONA

Wagon bridges were configured similarly to railroad structures, with parallel lines of wooden beams laid over the piers and abutments in single- or multiple-span iterations. The substructures were typically timber pile bents, but stone masonry, concrete steel pile bents or log crib bents were used as well. Timber stringer structures rarely exceeded 30 feet in span length. Those stringer bridges with longer spans were sometimes reinforced with metal tension rods attached under the beams to form what were called "jack trusses." The decks and guardrails of timber trestles were almost always made up of wooden members.

Virtually all of the earliest roadway structures in Arizona were built of timber, and many were dangerously flimsy. Often poorly constructed and unevenly maintained, these rudimentary timber structures typically washed out in floods or collapsed under load. Because of their inherently short life spans, no timber trestles for vehicular use are known to have survived from the 19th or early 20th centuries. The timber bridges found today on Arizona's roads typically date from the 1930s and later. The superstructural technology between the early and later bridges has remained essentially unchanged, with the only difference being the sizes of the members. The bridges of the mid-20th century tend to be more substantial, relying more on concrete substructures than their predecessors. During the 1930s timber was relatively easy to obtain and treat against decay, and it was an ideal construction material for use by gangs of sometimes poorly trained men.

Figure 84. Carrizo Bridge, 2002.

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Significance: Timber stringer bridges in Arizona may be eligible for listing in the National Register under Criterion A for their association with events that have made a significant contribution to the broad historical patterns of the country, the state or the region. Specifically, bridges that have played an important role in the development of the state's highway transportation system and, hence, in the settlement of the area. For example, a structure might be significant by its association with a particular route, such as the Old Trails Highway, because it was built by the State Highway Department in its formative years, or because it was built by a federal Depression-era relief program. A bridge may, in addition, be eligible under Criterion B for its association with a significant person, as long as the "significant person" was not the designer or builder of the bridge. A bridge can be eligible by virtue of its designer or builder, but this falls under Criterion C. Indeed, most eligible bridges in Arizona qualify under Criterion C as structures of engineering significance.

None of Arizona's timber stringer bridges are considered to have national significance. Those dateable timber structures with physical integrity that were built by the Arizona Highway Department or the Bureau of Public Roads are generally considered to have state-level significance. Most of the locally built timber stringer bridges are also considered eligible on a state level, by virtue of their significant features. Otherwise, small-scale timber bridges by local entities are considered locally eligible. Superlative timber bridges include:

Carrizo Bridges	(Navajo)	longest multiple-span timber stringer bridges

Registration Requirements: The period of significance for timber stringer bridges in Arizona generally begins in 1880, the earliest construction date covered in this MPD. Although the functionality of many of the bridges continues to the present—with the majority still in active use—the period of significance generally ends in 1964, the cutoff date for the statewide historic bridge inventory. The period of significance for an individual structure begins with the date that significant activities or events began giving the property its historic significance (typically, initial construction). Once the resource has ceased to serve the function that makes it historically important, its period of significance has ended. Alterations made during the period of significance may be considered part of the bridge's historic fabric, if they are in keeping with the bridge's original design.

Integrity of the structure's historic materials, configuration and setting is essential for a bridge to qualify for the National Register under any criterion. Because location is of primary importance under Criterion A, a structure will rarely qualify under this criterion if it does not remain on its original site. Location can also have significance under Criterion B, but the correlation is not as universal.

Integrity of design, materials and workmanship are key to a bridge's eligibility, particularly if that eligibility is stated in Criterion C terms. The principal consideration when evaluating integrity of design and materials is whether the bridge retains the features that defined its character during its historic period. Character-defining features of a steel stringer or girder bridge include the steel beam superstructure, deck, railing or parapet, and abutments, wingwalls and—if present—piers. Because of their relative simplicity and below-deck superstructures, stringer and girder bridges are generally visually undistinguished, and it is the guardrails that, more than anything, define the character of the bridge from the roadway. Alterations to the individual elements of a stringer or girder bridge have a relative impact on the design integrity of the bridge itself.

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For instance, widening a stringer by adding extensions onto one or both sides and replacing the guardrails impinges more on a bridge's integrity than adding lateral braces to the beams or repairing the abutments. Integrity of workmanship is closely related to design and materials but relates to the skill and craftsmanship involved in a bridge's construction.

Retaining a sense of setting is an important consideration for a bridge's overall integrity. Setting is defined as the topographic, vegetative and cultural character of the railroad's environs. Cultural character in this case generally delineates the built environment, but it can additionally indicate the socioeconomic or ethnic composition of the bridge's location. The principal consideration of integrity of setting is whether the extent to which the general environment or any particular aspect of that environment that affected the bridge's original design and construction remain intact from the bridge's period of significance. Are the salient features of the structure's environs still discernable and intact? The setting is usually defined as the viewshed from the bridge, which is to say all the natural and cultural features visible from the structure itself.

Integrity of feeling for a bridge is an amalgamation of the integrities of location, design, materials, workmanship and setting. It is a subjective appraisal of the overall experience conveyed by the structure. The principal consideration of integrity of feeling is whether the bridge and adjacent roadway under consideration convey a visceral sense of what it would have been like to travel over it during its historic period. Integrity of association relates to the link between a bridge and the distinctive events or personage that characterize it as historic. The alteration or loss of one or more of these integrities may be mitigated by other aspects of integrity of feeling and association.

Specific requirements under Criterion A:

1. **Early and/or prominent product of the Arizona State Engineer or State Highway Department:** In 1912 the Arizona State Legislature established the State Engineer's Office, and this evolved into the State Highway Department in the 1920s. Numerous timber stringer bridges were designed by the Highway Department in the 1920s and 1930s, and a few remain in place today.

Specific requirements under Criterion C

1. **Early and/or representative multiple-span timber stringer bridge:** Timber stringer bridges built before the Great Depression are sufficiently rare in Arizona that any definitively documented example that has maintained physical integrity is considered eligible for the National Register. Additionally, although Arizona once had numerous multiple-span timber bridges, only four such structures with five or more spans have been identified from the historic period by the statewide historic bridge inventory. These are considered the most significant examples of their type.

2. **Bridge with exceptional aesthetic merit:** Most bridges built by the state, particularly timber stringer structures, are strictly utilitarian. Occasionally, however, a structure stands out by virtue of its design or because of the quality displayed in its construction. The interrelationship of a bridge and its site can also have aesthetic value as well.

8

Glossary

Abutment	the outermost end supports of a bridge, which carry the weight of the superstructure and usually retains the approach embankment
Anchorage	massive, secure fixing on or under the ground, usually comprised of concrete, to which cables in a suspension bridge are fastened; also called deadman
Approach	roadway leading up to the end of a bridge
Approach span	relatively short span on either or both ends of a main span that connects the main span with the abutments, using piers
Arch barrel	surface of the inner arch that extends the full width of the structure
Arch ring	outer sourse of stone or brick; also called voussoir
Balustrade	concrete or stone railing system that includes the top rail balusters and sometimes a lower rail
Beam	rigid, usually horizontal structural element
Built-up	structural member (usually metal) that is comprised of smaller members joined together by means of riveting, bolting or welding
Cantilever	structural beam or element that projects beyond its vertical support (i.e., a diving board)
Cast-in-place	concrete that is poured within site-built formworks to create a structural element (e.g.; pier, arch, girder, slab); also called poured-in-place
Centering	temporary wooden frame used to provide support and hold masonry or concrete for an arch bridge under construction
Chord	horizontal member of a truss web; usually referred to as upper or lower chord
Column	vertical structural element that is rigid to withstand compressive forces
Compression	force that pushes along the axis of a structural element, acting to make it shorter
Concrete	mixture of water, sand, stone aggregate and a binding cement, which, when cured into a rock-like consistency, is used for both substructural and superstructural construction; may be used in units (e.g., concrete blocks) or poured in place; may be combined with steel reinforcing bars or beams to form reinforced concrete or may be used without steel reinforcing to form mass concrete
Continuous span	superstructure designed to extend continuously over one or more intermediate supports

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Dead load	static load acting vertically downward cause by the weight of the bridge itself
Deck	supported roadway on a bridge that directly carries both vehicular and pedestrian traffic
Deck truss	bridge in which the superstructural truss is positioned entirely beneath the roadway
Diagonal	sloping member of a truss web
End post	end compression member of a truss, either vertical or inclined
Eyebar	long metal tension member of a pin-connected truss with holes punched or forged on one or both ends to accommodate the metal pins at the chord connections
Expansion joint	mechanical device that provides for movement within a structure to accommodate expansion or contraction cased by temperature changes, load and other forces
Falsework	temporary wooden frame used to provide support for a bridge span under construction
Floor beam	horizontal beam that transfers the weight of the deck to the superstructure
Footing	lowermost part of substructure that is enlarged beyond the footprint of the abutments or piers to distribute the weight of the structure, either to piles or the earth
Force	push (compression) or pull (tension) applied to an object
Foundation	structural component that distributes the weight of a bridge to the earth
Girder	main support beam that usually received loads from floor beams or stringers; also any large beam, especially if built up
Gusset plate	metal plate (usually in a truss) used to connect structural members by means of riveting, bolting or welding
Hanger	tension member that suspends an attached member
Hinge	point in a structure at which a member is free to rotate
I-beam	rolled steel member with a cross-sectional shape similar to an "I"
Lateral bracing	secondary structural member connected to main members to provide rigidity and brace against lateral loads (e.g., wind)
Live load	dynamic load caused by the weight of vehicular or pedestrian traffic on a bridge deck
Main span	the longest span of a bridge, usually located over the main channel of a watercourse
Parapet	low wall along outside edge of a bridge deck
Pier	vertical supporting structure that carries the superstructure of a multiple-span bridge between the abutments; a pier may be configured as a pile bent (several steel or timber piles joined by horizontal or diagonal braces), a crib (horizontal members stacked to form the full height, solid concrete or masonry, spill-through concrete or concrete pile

Pile	vertical structural member made of wood, steel or concrete, which is driven forcibly into the ground to support the abutments or piers
Pin connection	connection of metal members on a truss by means of cylindrical metal pins
Plate girder	Rigid beam comprised of a relatively deep steel sheet with flange plates attached by flange angles of fillet welds
Panel	portion of a truss between adjacent points of intersection of web and chord members
Pony truss	bridge in which the roadway is positioned over the lower chords, with the truss webs positioned on either side but without overhead struts
Portal	unobstructed space forming the entrance to the structure on either end of a bridge
Precast concrete	concrete that is cast (usually with reinforcing steel) into a structural member away from the bridge site, cured and shipped to the site for erection
Reinforced concrete	concrete with steel rods or beams embedded within to provide tensile strength and durability
Rigid connection	connection of metal members (usually on a truss, usually using metal gusset plates) by means of rivets or bolts
Simple span	span of a bridge that is carried by longitudinal members (e.g., abutments, piers) without being connected structurally to adjacent spans
Skew	the acute angle between the alignment of the bridge and centerline of the substructure on a bridge where the superstructure is not perpendicular to the substructure
Span	distance a bridge extends between two supports
Stringer	longitudinal beam supporting the bridge deck; may be a primary superstructural element, as on a steel or timber stringer bridge, or a secondary element as part of the deck
Strut	structural member that acts to resist compressive stress
Substructure	foundation of a bridge that supports the superstructure (e.g., footings, piles, anchorages)
Superstructure	spanning portion of a bridge
Tension	force that pulls along the axis of a structural element, acting to make it longer
Thrie beam	modern steel guardrail with a cross-sectional shape similar to a "W"
Through truss	bridge in which the roadway is positioned over the lower chords, with the truss webs positioned on either side and joined by overhead struts
Truss	rigid beam superstructure comprised of short, straight pieces that form triangles or other stable shapes