



A Context For Common Historic Bridge Types

NCHRP Project 25-25, Task 15

**Prepared for The
National Cooperative Highway Research Program
Transportation Research Council
National Research Council**

**Prepared By
Parsons Brinckerhoff and
Engineering and Industrial Heritage**

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ABSTRACT

This study has been produced under the National Cooperative Highway Research Program (NCHRP). It is NCHRP Project 25-25, Task 15, “A Historic Context for Historic Bridge Types.” The study has been prepared by the firm of Parsons Brinckerhoff, with the assistance of Engineering and Industrial Heritage, and has been overseen by a review panel assembled specifically for the NCHRP 25-25 Task 15 study.

This study covers bridges built in the United States through 1955, up to the year of the passage of the Federal Aid Highway Act of 1956, which created the Interstate Highway System. It is intended to provide assistance to practitioners with assessing the historic significance of bridge types within the context of the United States, and can improve the significance evaluation process through providing a picture of the bridge types that are very common and those that are much less common, as well as providing an assessment of the technological and historical significance of the individual types. The study lays the foundation for evaluating whether a bridge to be removed requires additional documentation. (It is important to note that the study does not address one-of-a-kind and other rare historic bridges.)

Chapter 1 describes the research methodology, and provides background guidance to users of this study on assessing the significance of historic bridges, including assessing their individual eligibility for the National Register of Historic Places (NRHP).

Chapter 2 assists the user in determining where a bridge fits into the general historic context of bridge development in the United States. Many factors have influenced bridge development, and this chapter focuses on the evolution of the field of engineering, technological advancements, and important events that influenced bridge development history.

Chapter 3 presents the 46 most common historic bridge types identified. For each type, the study provides a brief development history; a description of the type and subtypes; identification of its period of prevalence; and a statement of its significance within the context of the most common bridge types identified in this study. This significance evaluation is geared toward the engineering significance of the bridge types, that is, NRHP Criterion C. Historic significance under NRHP Criterion A, however, is also factored into the evaluation of the bridge types.

The final Chapter (4) provides a table summarizing the significance assessments presented in Chapter 3. Issues encountered in the conduct of this study are identified, such as: 1) the lack of a national historic bridge database/repository for bridge studies; 2) the inability of the Study Team to identify the requested fifty common bridge types; 3) the lack of scholarship and NRHP listed or Historic American Engineering Record (HAER) recorded examples of the more recent bridge types, 4) use of inconsistent terminology in the numerous extant historic bridge studies; and 5) the inability of the Study Team to locate volunteer peer reviewers. The study also makes a number of recommendations for the near and distant future of studies and actions that can, along with this study, improve the bridge significance evaluation process.

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1.0 INTRODUCTION

This study has been produced under the National Cooperative Highway Research Program (NCHRP). It is NCHRP Project 25-25, Task 15, “A Historic Context for Historic Bridge Types.” The study has been prepared by the firm of Parsons Brinckerhoff, with the assistance of Engineering and Industrial Heritage, and has been overseen by a review panel assembled specifically for the NCHRP 25-25 Task 15 study. The panel is comprised of:

Chris Hedges, Senior Program Officer, Cooperative Research Programs
Rowe Bowen, Georgia DOT
Susan Gasbarro, Ohio DOT
Paul Graham, Ohio DOT
William R. Hauser, New Hampshire DOT
Timothy Hill, Ohio DOT
Mary Ann Naber, Federal Highway Administration
Nancy Schamu, State Services Organization

1.1 Research Objective

The objective of this study is to present a context for the most common historic bridge types in the United States. According to the National Park Service’s National Register Bulletin, *How to Apply the National Register Criteria of Evaluation*, a historic context is “an organizing structure for interpreting history that groups information about historic properties that share a common theme, common geographic area, and a common time period. The development of historic contexts is a foundation for decisions about the planning, identification, evaluation, registration and treatment of historic properties, based upon comparative historic significance” (1, p.53).

This study is intended to provide assistance to practitioners in assessing the historic significance of bridges within the context of the United States. The use of the study can improve the significance evaluation process by providing a picture of the bridge types that are very common and those that are much less common, as well as providing an assessment of the technological and historical significance of the individual types. The study lays the foundation for evaluating whether a bridge to be removed requires documentation, and to what level should the bridge be documented.

The research statement developed for this study by the NCHRP 25-25 Task 15 review panel is included below:

In recent years, numerous historic bridges have required replacement throughout the Nation. In each case, a permanent record is made which documents the historic context of the bridge. This level II Historic American Engineering Record (HAER) ranges in cost from \$9,000 to \$28,000. Currently, most state DOT’s lack the framework to evaluate whether this level of recordation is prudent for each and every historic

bridge. For most bridges in any given type, much of the historic context is common, and compilation of the HAER involves a good deal of unnecessary duplication. If the basic historical context were compiled for the most common historic bridge types, transportation agencies would be able to develop the permanent record for specific bridges much more quickly and at a lower cost. The research will provide centralized documentation for future researchers on a national level, and will assist DOTs in evaluating national significance. The National Cooperative Highway Research Program, Research Results Digest June 2003-Number 277, "Review and Improvement of Existing Processes and Procedures for Evaluating Cultural Resource Significance" concludes, "awareness of existing guidance and the utility of historic contexts and resource inventories may improve the significance evaluation process practiced within agencies that currently do not use these tools."

1.2 Report Contents

This chapter describes the research methodology and provides background guidance to users of this study on assessing the significance of historic bridges, including assessing their individual eligibility for the National Register of Historic Places (NRHP).

Chapter 2 provides a historic context overview on a national level that illustrates where the different bridge types fit into the evolution of bridge design in the United States, and how events in the engineering, technological and political world influenced bridge design. The overview traces bridge development in the United States from its earliest times, through 1955, up to the passage of the Federal Aid Highway Act of 1956. This chapter is intended to help the user determine where a bridge fits into the general historic context of bridge development in the United States.

Chapter 3 provides a historic context for each of the most common extant historic bridge types in the United States. It begins with the definition of what constitutes a historic bridge type for the purposes of this study and then describes the most common bridge types identified by the Study Team. (The methodology for developing this list is described in Section 1.3 below.) For each bridge type, the text includes a summary history of its development, a structural description, and a statement of significance for the type within the context of common bridge types in this study. Each subsection also includes a list of examples that are listed in or eligible for the NRHP and an example that has been recorded for the Historic American Engineering Record (HAER), when the Study Team was able to find such examples. Users of the study can easily access the HAER examples on line at http://memory.loc.gov/ammem/collections/habs_haer/. One or more photographic examples of the type are also provided, as available, and some of the types have accompanying drawings. Unless otherwise noted, the photographs in this study are from the HAER collection. The bridge drawings were developed by Larry McGoogin of Parsons Brinckerhoff.

The final chapter (4) identifies issues encountered in the study and recommendations for future research related to the study topic.

1.3 Research Methodology

The Study Team, comprised of Margaret Slater of Parsons Brinckerhoff; Robert Jackson, formerly of Parsons Brinckerhoff; and Eric DeLony of Engineering and Industrial Heritage, utilized their knowledge, extensive libraries and contacts in the historic bridge field to draft a list of the most common bridge types. The Study Team also drafted a definition of what would constitute a “common historic bridge type” for the purposes of this study. The Study Team sent the draft list and definition to the Task 15 review panel for review and comment.

Once approved by the review panel, the draft list and the definition of what constitutes a “common historic bridge type” was sent via e-mail to all State Historic Preservation Offices (SHPOs) through Nancy Schamu of the National Conference of State Historic Preservation Officers (NCSHPO). The query was also posted by Kevin Cunningham of the Delaware Department of Transportation (DOT) to the TransArch List Serve, which reaches state DOT and Federal Highway Administration (FHWA) cultural resource staff. A request was made of the recipients to review the list and definition and to provide comments to the Study Team. The Study Team then considered the comments received, and made revisions to the list and definition, as appropriate. The Study Team sent a follow-up e-mail to respondents, which thanked them for their assistance, and included a table that summarized the comments and explained how the Study Team would address them.

The Study Team solicited the involvement of the Transportation Research Board (TRB) Committee on Historic and Archaeological Preservation in Transportation at the TRB’s January 2005 National Conference. As a result of that solicitation, Mary McCahon of Lichtenstein Consulting Engineers provided the Team with information on some of the more recent bridge types, for which existing scholarship is limited. The Team consulted the National Bridge Inventory (NBI), but was unable to readily sort and extract data useful for this study from the NBI. Carol Shull, Keeper of the National Register at that time, and her staff, provided guidance during the development of the work plan for this study.

The Study Team then commenced with the development of the summary historic context and the context for each of the historic bridge types identified, respectively, Chapters 2 and 3 of this study. Sources used for these chapters included state historic bridge surveys, NRHP multiple property historic bridge contexts and other historic bridge context reports, bridge and engineering history books, the HAER collection of the Library of Congress and other sources in the Study Team’s personal libraries. The Study Team developed the list of the five examples required for each type using this information, and came up short on the number of examples needed for certain types, particularly, the types that came into use later in the study period. To obtain missing examples, the Study Team developed a second e-mail query and received assistance in

the form of examples and photographs of some of the bridge types for which examples were missing, from Martha Carver of Tennessee DOT, Robert Hadlow of Oregon DOT, Kara Russell of PENNDOT, Mary McCahon of Lichtenstein Engineering and Andrew Hope of Caltrans.

The NCHRP review panel reviewed and commented on a preliminary draft of Chapter 3, while it was a work in progress. Paying consideration to the review panel’s comments, the Study Team developed a preliminary draft report for “in-house” review. The following volunteer peer reviewers and editors reviewed and commented on the various chapters of the report:

Martha Carver, Historic Preservation Section Manager, Tennessee DOT
Debra Skelly, Certified Project Administrator, Parsons Brinckerhoff
Claudette Stager, National Register Program Coordinator, Tennessee SHPO,
Lisa Zeimer, AICP, Senior Professional Associate, Parsons Brinckerhoff

The preliminary draft was then revised and a Draft Report submitted to the NCHRP Task 15 review panel. The Study Team received and responded to the panels’ comments, and then at the instruction of Chris Hedges, completed this final report.

1.4 Assessing Significance

1.4.1 What Makes a Bridge Significant?

As previously stated, this report intends to assist study users in making significance evaluations of historic bridges. The guidance for evaluating significance provided within this report is primarily for assessing the engineering significance of bridges within their historic context, and can assist practitioners with the evaluation of bridges for national, state, or local significance. The guidance is geared toward assessing the individual significance of bridges. But, it is important to note that bridges that are within historic districts have the potential to gain significance, beyond the significance level identified in this study, as a contributing element of the district.

This report provides a statement under each of the common bridge types regarding the level of significance of the type within the context of the most common types described in this study. Within certain types, statements are made identifying the most significant bridges within a type, such as structures built in the early years of a type’s development. (This study does not provide guidance on assessing rare bridge types, as this is outside the study scope.).

Chapter 2 summarizes key events and trends that had a major impact on bridge development history in the United States. Bridges that possess integrity and are associated with these historic events and trends will likely possess historic significance. Relatively intact bridges associated with events, such as those listed below and those described in Chapter 2, will likely possess significance within the context of this study. For example, bridges that are associated with the following, likely possess significance:

- Early turnpikes and canals,
- The early development period of the railroad,
- Creation of state transportation departments, and
- The Depression-era work programs.

Both Chapters 2 and 3 identify significant activities in the field of bridge engineering that have a bearing on evaluating the significance of bridges. For example,

- Bridges associated with a prominent engineer or bridge designer or builder,
- Patented bridge designs,
- Government development of standardized bridge plans, and
- Innovations in the use of bridge construction materials and design.

Bridges, of course, can also be significant under local historic contexts, but this type of significance assessment is outside the scope of this study. Guidance on assessing such bridges is available in most of the state-wide bridge survey reports sponsored by the state departments of transportation and within the numerous state historic bridge contexts (multiple property contexts) that are listed in the NRHP. A list of a number of the completed contexts and 2004 links to a digital copy of these contexts is included as Appendix A to this report.

The first step for the evaluator who is attempting to assess the engineering significance of a bridge is to answer two questions: 1) Is the structure associated with an important historic context; and 2) Does the structure possess integrity, i.e., does it retain those features necessary to convey its historic significance?

1.4.2 Bridges and the National Register of Historic Places

If a bridge is important under the national contexts identified in this study, the bridge evaluator can assess the eligibility of the structure for the NRHP. As previously discussed, state and local contexts can provide additional guidance.

To be considered eligible for the NRHP, bridges must be at least 50 years old or it must possess exceptional importance. In addition, bridges must be significant under one or more of the NRHP criteria of eligibility. For example, they may possess historic significance for their association with crossings important in the development and growth of the nation, as examples of a solution to a difficult engineering challenge, as examples of new and innovative technologies, as examples of the work of prominent engineers, or for their architectural or artistic distinction.

Below is a discussion of the application of the NRHP criteria of eligibility to bridges.

Criterion A: A bridge associated with events that have made a significant contribution to the broad pattern of our history.

Under this criterion, bridges would need to have an important and direct connection to single events, a pattern of events or significant historic trends. A bridge could be significant under Criterion A, for example, for its association with important events or activities in transportation, community planning and development, or commerce. It must, however, have made a significant contribution to historical development. A bridge that possesses no ties to significant events would not meet Criterion A.

Criterion B: A bridge associated with the lives of persons significant in our past.

This criterion is not generally applicable to historic bridges because structures associated with important engineers or designers are represented under Criterion C.

Criterion C: A bridge that embodies the distinctive characteristics of a type, period, or method of construction, or represents the work of a master or possesses high artistic values.

This is the criterion under which most bridges would be NRHP eligible. According to the National Register Bulletin, *How to Apply the National Register Criteria for Evaluation* (1,18), to be NRHP eligible, a property must clearly contain enough of the type's distinctive characteristics (also known as character defining features) to be considered a true representative example of a particular type, period, or method of construction. According to the Bulletin:

A structure is eligible as a specimen of its type or period of construction if it is an important example (within its context) of building practices of a particular time in history. For properties that represent the variation, evolution, or transition of construction types, it must be demonstrated that the variation, etc., was an important phase of the architectural development of the area or community in that it had an impact as evidenced by later [structures] (1, p.8).

This criterion applies to the common types of bridges that are technologically significant or that illustrate engineering advances. This means, for example, that the early examples of a bridge type may be NRHP eligible. The longer and more complex examples of a common type may also be eligible under this criterion. In addition, an unaltered, well-preserved example of a type may be NRHP eligible, regardless of whether it is more or less common within the context of this study. Examples that are not likely significant include structures built later in a type's development history that do not possess any extraordinary features and those that have been extensively altered through repairs or renovations.

Regarding bridges that represent the work of a master, examples of the common types of bridges that can be documented as the work of a well-known bridge engineer or fabricator are likely NRHP eligible if they possess integrity.

Bridges that possess high artistic value may be landmark bridges (that may also be significant due to their type or designer) such as the Brooklyn Bridge in New York or the Golden Gate in San Francisco, or they may be common types with applied decorative finishes, parapets or railings.

Examples of the less common bridge types identified in this study may also be significant due to their engineering significance, combined with their relative “rarity” within the context of common bridge types.

Criterion D: A bridge that has yielded, or may be likely to yield, important information in history or prehistory.

This criterion generally does not apply to bridges, but it could in rare instances apply to a bridge. According to the *Third Ohio Bridge Inventory, Evaluation and Management Plan* (2, Appendix B), Criterion D “can apply to structures or objects that contain important information if the structure or object is the principal source of important information. This could apply to an unusual or technologically significant bridge for which no plans or other documentation survives” (2, Appendix B).

Criterion Considerations

While moved properties are not commonly NRHP eligible, a bridge could be NRHP eligible under Criteria Consideration B: Moved Properties. Some types of bridges, such as pony trusses and moderate-length through trusses, were marketed as being “portable,” and these bridges have been historically relocated and more recently, have been relocated to off-system uses, such as pedestrian bridges. If they retain their historic appearance and function in the manner for which they were designed and have an appropriate new location, then they may be NRHP eligible. In addition, a technologically significant bridge that has been moved may also be NRHP eligible.

Bridges can also qualify for the NRHP that are less than fifty years old under Criteria Consideration G: Properties that have achieved significance within the last fifty years if they have exceptional importance. However, bridges that fall under this criterion are outside the context of this study, which ends at the end of 1955.

1.4.3 Integrity

To be individually eligible for listing in the NRHP, a bridge must not only meet one or more of the criteria of eligibility, but it also must have integrity. In a bridge, this means retaining its historic appearance and materials and its ability to function in the manner in which it was designed. Integrity is defined in *How to Apply the National Register Criteria for Evaluation* as “the ability of a property to convey its significance”

(I, 44). This National Park Service publication (2, 44-45) provides seven aspects, or qualities, that in various combinations define integrity:

1. Location is the place where the historic property was constructed or the place where the historic event occurred.
2. Design is the combination of elements that create the form, plan, space, structure, and style of a property.
3. Setting is the physical environment of a historic property.
4. Materials are the physical elements that were combined or deposited during a particular period of time and in a particular pattern or configuration to form a historic property.
5. Workmanship is the physical evidence of the crafts of a particular culture or people during any given period in history or prehistory.
6. Feeling is a property's expression of the aesthetic or historic sense of a particular period of time.
7. Association is the direct link between an important historic event or person and a historic property.

The question of integrity is answered by whether or not the property retains the identity for which it is significant. A property that retains integrity will possess many or most of the seven aspects. For bridges, some elements of integrity may have more importance. For example, while materials are of high importance to the integrity of a bridge that possesses engineering significance, the setting is less important.

To determine whether a structure retains integrity, the evaluator needs to ascertain whether the structure retains the elements of design and the materials necessary to convey the period in which it was constructed, i.e., its character defining features. The identification of alterations to a structure must be done to determine if they change the appearance, design or the way a bridge functions in a way that would compromise its historic or engineering significance. For example, it is highly unlikely that a fifty-year old bridge would retain its original deck or wearing/travel surface. Covered bridges would not likely retain their original siding, roofs or decks. In older bridges, original deck beams may have been replaced. This does not automatically eliminate the structure from NRHP eligibility, as deck replacement is common and necessary and was likely done periodically throughout the bridge's history. A bridge that retains its original deck structural system, however, would have higher integrity than a bridge with a replaced deck.

The use of the structure can be different than originally intended, such as a bridge converted to pedestrian use, but, the structure needs to function in the way it was originally intended, for example, a truss should still function as a truss. An exception to this criterion would be a rare, one-of-kind bridge that has been set by the side of the road or moved to a protected location. The authors know of several outstanding bridges that

have received this treatment. Though not perfect, it has preserved the artifact until a more appropriate use and location is found.

It is important to note that integrity does not apply to the structure's state of repair or its functional obsolescence (e.g., too narrow or structurally insufficient to meet modern traffic needs).

The evaluator should consult its state's historic bridge survey(s) or one of the many historic contexts listed in Appendix A for additional guidance on integrity and on specific character-defining features of bridge types.

1.5 Chapter 1 References Cited

1. National Park Service. National Register Bulletin. *How to Apply the National Register Criteria of Evaluation*. 1991.
2. Lichtenstein Consulting Engineers for the Ohio Department of Transportation, Federal Highway Administration and Ohio Historic Preservation Office. *Third Ohio Bridge Inventory, Evaluation and Management Plan for Bridges Built 1951-60 and the Development of Ohio's Interstate Highway System*. 2004.

2.0 SUMMARY HISTORICAL CONTEXT OF BRIDGES IN THE UNITED STATES THROUGH 1955

As discussed in Chapter 1, this report covers bridge building in the United States through 1955, the year before passage of the Federal Aid Highway Act of 1956, which created the Interstate Highway System. Many factors have influenced bridge development, but this chapter focuses on the evolution of the field of engineering and technological advancements during the period covered in this report. It also highlights historic events that influenced bridge development history. This section is organized by era, as noted below:

- Early Bridge History
- Late Eighteenth Century to the Outbreak of the Civil War (1861)
- Civil War to 1899
- 1900 through 1955

2.1 Early Bridge History

The earliest “roads” in the United States were trails, established by both animals and Indian tribes. These trails marked the easiest line of travel; avoiding natural obstacles and crossing streams at narrow, shallow points. The Native Americans, however, most assuredly encountered creeks and rivers that they desired to cross at locations that were not amenable to fording. While many associate the first bridges in the United States with the arrival of the Europeans, in actuality, the indigenous American Indians built the first “bridges.” While little readily available documentary evidence exists, it is known that in the early 1540s, when Coronado’s expedition first explored New Mexico, the party’s historian, Castenada, reported that the stream flowing through the present Taos Pueblo “was crossed by very well [hand-] hewn beams of pine and timber” (*I*, p. E-2). The builders of this bridge were the descendants of the Chacoan road builders.

The first European bridge building effort in what is now the United States is claimed to have occurred in 1540 -1541, during Coronado’s expedition. The explorers were in search of the mythical city of gold, Quivera. When the expedition reached the Pecos River, near what is likely present-day Puerto de Luna, New Mexico, the party was forced to construct a bridge. It purportedly took them four days to build the structure needed for the party of over 1,000 soldiers and Indians, as well as livestock, to cross the river (*I*, p. E-20).

Like the American Indians, early European settlers encountered obstacles to transportation—watercourses, ravines and other natural features. Fords served for crossing most streams and rivers, while wet or marshy places were sometimes traversed by causeways (raised roads or pathways on a base of stones, logs, timbers and earth, capped with clay for weatherproofing). For larger rivers, boats and ferries were used to transport people and goods across rivers.

Gradually, people who needed to cross streams and rivers for commercial or personal endeavors began to devise bridges using the materials and skills at hand. The materials used for the early bridges were locally available, such as wood or stone gathered or quarried near the bridge site.

Settlers generally used the narrowest and the shallowest creek location at which a crossing could be made, such as the head of the waterways. The earliest bridges were probably crude and simple spans, most likely trees cut to fall across streams or stone or wood slabs laid across piles of rock. Where skills existed to build a structure, simple timber bridges were commonly used. These timber bridges were either basic beam bridges or rudimentary wooden trusses (e.g., king post and queen post). Stone bridges were expensive and time-consuming to build, but some were erected during Colonial times.

Because the early bridge builders lacked engineering knowledge and adequate financial resources were not available, the bridges built were all of a temporary nature. Despite their impermanence, however, according to bridge historian Donald Jackson, these early bridges “represented logical engineering solutions to the problem at hand: they did not require extensive amounts of labor to build, they used local materials, and they could be quickly rebuilt if destroyed. They also required only rudimentary design and construction skills” (2, p. 15).

In the seventeenth century, the first major bridge in the colonies was “the Great Bridge,” built across the Charles River to Boston in 1662. The structure consisted of “cribs of logs filled with stone and sunk in the river, hewn timber being laid across it” (3, p. 35). This structure remained the only Charles River crossing for more than a century.

The colonial legislatures began to address bridges in the seventeenth century. An example of an early Colonial Period road act is Maryland’s first comprehensive general road act, passed into law by the Colonial Assembly in 1666. This act delegated to the County Courts or Commissioners the responsibility to lay out a highway system that would make the heads of rivers and creeks “passable for horse and foot.” The 1696 colonial law (re-passed in 1704) required that “good and substantial bridges” be constructed over the heads of rivers, creeks, branches and swamps. In 1724, colonial Maryland law gave the county road overseers the right to use suitable trees on adjacent lands in order to build or repair any bridge maintained at public or county expense (4, p. 121).

An early stone arch bridge in the United States that is still in use is the Frankford Avenue Bridge in Philadelphia, built in 1697 by township residents. In the eighteenth century, the major roads were almost exclusively county or privately built and maintained farm roads. These roads facilitated migration of the population westward from the eastern seaboard. In 1761, the first known pile-supported vehicular bridge was built in accordance with an engineering plan based on a site survey—Sewall’s Bridge over the York River at York, Maine.

In the settlement period of the United States, bridge building by the country's new population began at different times in different locations. Because of the early settlement dates and denser populations, Colonial towns along the eastern seaboard built bridges at a time when exploration of the American West had not even begun. The east also had a greater likelihood that persons designing and building creek and river crossings would have some skills, either gained in the New World, or brought to America from the Old World by European settlers. The southwest had bridges built by the Spanish explorers.

From the eastern seaboard into the American West and Northwest, settlement, and consequently construction of roads and bridges, did not occur until much later. These early western settlers addressed the transportation problems in the same manner as their antecedents in the east. They built bridges of whatever materials were at hand and with the skills that were available.

2.2 Late Eighteenth Century to the Outbreak of the Civil War (April 1861)

The United States made great strides in bridge design between the 1790s and the outbreak of the Civil War in the spring of 1861. This era was influenced by advances in engineering education; the construction of canals, railroads and government infrastructure projects; and by legislation that facilitated the construction of roads and bridges.

2.2.1 The Profession of Engineering

The period between the end of the eighteenth century and the outbreak of the Civil War was a transition period between self-taught engineers and educated engineers. The changes in the field occurred through such forces as: the creation of engineering schools, the institution of engineering courses in extant colleges, and on-the-job training.

George Washington had long pushed for the creation of a national military academy, whose principal function would be the education of engineers. Three years after his death, Congress created the United States Military Academy at West Point in 1802. By the end of the decade, the school's engineering curriculum had assumed the model of the respected French school, the Ecole Polytechnique. Theoretical and mathematical approaches to engineering were stressed and there was a strong reliance on French textbooks and French-educated instructors (5, p. 124).

Until mid-century, "virtually the only academic route [for engineers] was the United States Military Academy (USMA) at West Point, which up to then had produced about fifteen percent of the nation's engineers" (5, p. 124). Between 1802 and 1837, 231 West Point graduates entered the field of civilian engineering during some point in their careers (5, p. 182).

In the first half of the nineteenth century, the greatest demand for engineers in the country was in the civil field, due to demand for infrastructure improvements, e.g., roads, harbors, canals and above all, railroads. West Point-trained engineers were regularly assigned to conduct surveys in the American frontier and they played a major role in internal improvement projects of national interest. Of the 572 West Point graduates between 1802 and 1829, 49 had been appointed chief or resident engineers on railroad or

canal projects by 1840 (6, p. 4). The academy also became “an indispensable source of needed non-military engineers” (5, p. 124). During this era, West Point USMA graduates were largely responsible for the construction of most of the nation’s initial railway lines, bridges, harbors and roads (7).

The first civil engineering course outside of West Point was offered in 1821 by an academy, the American Literary, Scientific and Military Academy, renamed Norwich University in 1834. In Troy, NY, the Rensselaer School was reorganized as the Rensselaer Polytechnic Institute (RPI), and modeled on the French school, the Ecole Centrale des Arts et Manufactures. In 1835, RPI began to offer a degree course in engineering and granted its first engineering degree, but it had graduates before that time who had become engineers. Of 149 RPI graduates between 1826 and 1840, 31 became civil engineers. Apart from West Point, RPI was “the most important technical school in the United States during the first half of the nineteenth century” (8, p. 248).

By the middle of the nineteenth century, West Point had lost its dominant position. Other colleges, beyond military and technical schools, created engineering departments and university-based schools of engineering emerged to meet the growing demand for formally trained engineers. Union College in Schenectady, New York established a civil engineering course in 1845. At about the same time, engineering was introduced into the curricula of Ivy League and other institutions, Brown in 1847, Dartmouth in 1851, Cornell in 1868, Yale in 1860, Harvard—first engineer graduated in 1854, and Massachusetts Institute of Technology in 1861. Other schools that instituted engineering programs between 1840 and 1860 included Wesleyan, University of Michigan, New York University, Dartmouth, Rutgers, Indiana University, Cincinnati College, University of Pennsylvania, University of Virginia, University of Maryland, and University of Georgia. By around 1855, about 70 institutions of higher education had initiated engineering programs (6, p. 5).

According to authors John Rae and Rudi Volti, “a reliable estimate puts the number of people who could be considered qualified engineers in 1816 at not over 30” (5, p. 120). The country remained heavily dependent on European engineers to supplement the small number of trained engineers, but still needed more engineers than had been domestically trained to design and supervise the massive infrastructure jobs being undertaken.

To fill this need, the infrastructure projects served as the “universities” for budding engineers (6, p. 4). By 1825, two new transportation modes had emerged: canals and railroads. Both served as an important training ground for American civil engineers. The canal companies were the first enterprises that provided for training of engineers through an apprenticeship system. Many of the great antebellum-era bridge engineers began as surveyors or mechanics and learned bridge building by working for the canal companies or the railroads on such projects as the Erie Canal (1825) and the Baltimore and Ohio Railroad (1829). One author reported that in 1837, 65 of 87 engineers, or 75 percent, were trained on the job by rising through the ranks of civil engineering projects (8, p. 240).

By mid-century, the profession of civil engineering had become firmly established, but still many of the companies and individuals that listed “bridge building” among their skilled trades were carpenters. Attempts to organize a national engineering organization began in the 1830s, but it was not until 1852 that the American Society of Civil Engineers was founded.

2.2.2 *Advances in Bridge Design/Technology*

The era witnessed the development and patenting of many new bridge designs. Between 1791 and 1860, many bridge patents were granted, though only a dozen or so gained general acceptance (3, p. 37). Between 1840 and the outbreak of the Civil War in 1861, bridge design became more standardized, as professional engineers began to design bridges, primarily for the railroad companies. Engineers made great strides in devising mathematical methods to analyze shapes and sizes best suited for bridge parts, and they came to better understand the behavior of rivers and streams so that they could devise piers and abutments that would not sink or be washed away in torrential waters. The following text chronicles seminal events in the advancement of bridge engineering during this era.

In 1792, architect Timothy Palmer (1751-1821) built the first significant truss bridge in the United States, the Essex-Merrimac Bridge in Newburyport, Massachusetts. It was a wood truss-arch type called a Palladian.

Five years later, on January 21, 1797, Charles Wilson Peale, portraitist of George Washington, received the first United States patent for a bridge design. The bridge, which was not built, was planned for erection across the Schuylkill River at Market Street in Philadelphia. That same year, Peale published *An Essay on Building Wooden Bridges*. The Schuylkill Permanent Bridge Company was formed on March 16, 1798, to bridge the Schuylkill. But, it was not until January 1, 1805, that the 550-foot long bridge designed by Timothy Palmer across the Schuylkill River at 30th Street in Philadelphia, opened. Investors of the Schuylkill Permanent Bridge Company demanded that the bridge be covered to protect their investment and Palmer reluctantly agreed to do so. The timber structure was a combination arch and king post truss design.

In 1801, James Finley erected the first modern suspension bridge, the Jacobs Creek Bridge, near Uniontown, Pennsylvania. Finley used iron chains and a stiffened floor system.

In 1803 - 1804, Theodore Burr, one of America’s great pioneer bridge builders (3, p. 39), built the first bridge combining numerous king post trusses with a wooden arch. In 1806, Burr patented the design, which strengthened timber bridges and influenced future timber bridge designs.

The National Road, on which construction began in 1811, was a massive undertaking that involved road and bridge construction and marked the first use of federal funds for major civil works construction. The road featured many stone-arched bridges along its route, all built with local materials.

Ithiel Town, a trained and recognized architect, received a patent for a truss design in 1820 and another one in 1835. Plowden states that Town's impact on bridge building was three-fold: 1) his invention was the first true truss; 2) his truss could be assembled with small amounts of wood, a few bolts and trenails and; 3) it could be built in an afternoon by carpenters regardless of whether they possessed experience (3, p. 41).

Starting in 1825, canals were constructed in the eastern United States to serve as artificial commercial water routes. Private canal companies were chartered by the states to construct and maintain these canals. For example, the Chesapeake and Ohio (C&O) Canal connected Washington DC and Cumberland in western Maryland. Bridges were integral parts of these canal systems. Many bridges were built to provide access over canals, and numerous structures i.e., aqueducts, were built to carry the canals over streams and other natural barriers (2, p. 16). Many of these structures were built entirely of stone. The companies' apprenticeship programs, use of civil engineers, and the innovative construction methods influenced the advancement of bridge technology.

In the 1830s, railroads emerged shortly after canals and competed with the canals for commercial traffic. Engineer J.A.L. Waddell wrote in 1916 that "the introduction of railroads in the United States in 1829 marked the beginning of bridge engineering" (9, p. 21). The railroads led the way in the application of new bridge types and standard plans, and in the use of "modern" materials (e.g., metal) for bridge construction. The railroad companies revolutionized bridge design, as they required more sophisticated designs and durable materials for carrying the heavy loads of the railcars.

In the east, the railroads built massive high and/or long stone viaducts along the Baltimore and Ohio (B&O) Railroad. The first major engineered railroad bridge was the Carrollton Viaduct, completed in 1829 across Gwynn's Falls, west of Baltimore City. Constructed of approximately 12,000 granite blocks, the 312-foot long bridge featured an 80-foot arch over the waterway. Other early stone viaducts included the Thomas Viaduct (1835) and the Erie Starrucca Viaduct (1845).

In the West, the railroad constructed many of the region's early bridges and, prior to 1900, was responsible for the most technologically advanced bridge designs. While stone was often used in the East, timber was generally used by the western bridge builders because of the pressure to quickly and economically get new railroads on line, and timber was generally abundant and cheap.

The 1840s witnessed the beginnings of the shift from the use of wood to the use of iron for bridge construction. The public and the engineering profession were growing weary of the many bridge failures. A metal arch bridge, the Dunlap's Creek Bridge, was built on the National Road in southwestern Pennsylvania in 1839. Still standing in Brownsville, Pennsylvania, this bridge is the oldest iron bridge in the United States.

The first patent truss to incorporate iron into the timber fabric was the Howe Truss, patented in 1840 by William Howe, a young millwright. This truss featured diagonal bracing and top and bottom chords of timber, with vertical iron rods in tension. The structure was stronger than the trusses that preceded it and was easy to erect. Howe

truss members were prefabricated and shipped to bridge sites. The Howe truss was the dominant form for wooden railroad bridges for many years. The pin method of connecting the metal parts was introduced during this era.

In the 1840s, advances in the design of suspension bridges were being made, due primarily to the efforts of Charles Ellet, Jr., who had received engineering training in France, and John Augustus Roebling, who received a civil engineering degree in Berlin in 1826. In the 1830s, Roebling manufactured the first wire ropes in America. He exchanged ideas with Ellet, who is credited with the first successful wire suspension span built in the United States, the 1842 Fairmount Park Bridge over the Schuylkill River in Philadelphia. Ellet and Roebling continued to advance suspension bridge design, became competitors, and completed a number of landmark bridges during this period, including the bridges over the Niagara River, and the Brooklyn Bridge in New York. After the 1848 discovery of gold in California, suspension bridge technology moved rapidly westward and a number of such structures were built in the state.

In 1844, Thomas and Caleb Pratt patented the Pratt Truss, which reversed the Howe system and incorporated vertical timber members in compression and diagonal iron rods in tension, a “combination” structure. The structural principle in this design was used well into the twentieth century when all parts were made in steel.

In 1845, the Philadelphia and Reading Railroad built the first all iron railroad bridge. Names such as Wendel Bollman and Albert Fink were early innovators in the use of iron for truss bridges along the railroad. The quality of the iron produced in the pre-Civil War period, however, was not high.

Squire Whipple, an engineer from New York who was largely self-taught, published *A Work on Bridge Building* in 1847, the first correct analysis of stresses in a truss structure and claimed by author David Plowden to “have ushered in the era of scientific bridge design” (3, p. 65). Although iron bridges had been designed, patented, and built in the United States early in the first half of the nineteenth century, Whipple was responsible for the “world’s first scientifically designed metal bridge” (3, p. 63). He built his first iron truss in 1840 over the Erie Canal. In 1847, Whipple took his design a step further when he developed an all-iron truss with cast compression members in top chords and vertical supports, and wrought members for the diagonals and lower chords in tension. He achieved longer spans by lengthening the diagonals so that they traversed the two panels, forming a Whipple, or Double-Intersection Pratt, in addition to the bowstring arch-truss bridge.

The next year (1848), the Warren truss was patented by two British engineers, James Warren and Willoughby Monzani. This truss design had alternating diagonals in either tension or compression, and vertical components that strengthened the structure.

In 1847, Herman Haupt, an engineer who, like Whipple, was concerned with the lack of theoretical understanding of bridge construction, wrote a book on bridge engineering, but “could find no engineer capable of reviewing it and no publisher who dared to put it forth” (3, p. 65). Six years earlier, Haupt had written a pamphlet, in which

he wrote: “to my great surprise I found that no attempts were made to make calculations and the strain sheets showing the distribution and magnitude of strains were entirely unknown. Even counter-braces, so essential to the rigidity of structure, were not generally employed in the railroad and other bridges of the day” (as quoted in 3, p. 65). Finally in 1851, Haupt’s book was published under the title *General Theory of Bridge Construction*. According to Plowden, at the time Whipple’s and Haupt’s books were published “there were probably no more than ten men in America . . . who designed bridges by scientifically correct analytical methods” (3, p. 65).

Shortly before the outbreak of the Civil War, English engineer Henry Bessemer introduced a process for the production of steel from molten pig iron. Patented in 1855, the Bessemer process allowed steel to be made much more cheaply than it had previously been made and in greater quantities.

During this same period, Wendel Bollman, a former railroad engineer who had resigned from the B&O railroad in 1858, started a company that “was to become the model for many competitive bridge-fabricating establishments in the years to come” (3, p. 68). Through his company, he developed innovative designs or variations of extant designs, and had wide networks of sales people. Author David Plowden stated that Bollman also “realized that a great advantage would be gained by the substitution of wrought iron [for cast iron], a material strong equally in tension and in compression” (3, p. 68).

2.2.3 *The Bridge Builders of the Antebellum Period*

The Federal Government. As noted by Donald Jackson in *Great American Bridges and Dams*, by the end of the eighteenth century, “many people began to recognize the importance of building a permanent, reliable system of roads to bind together the newly formed United States of America” (2, p. 15).

The United States government organized a “Corps of Artillerists and Engineers” in the late eighteenth century. In 1802, Congress created a separate “Corps of Engineers,” which has since been in continuous existence. The early Corps designed and built fortifications, but the Corps’ greatest legacy was its work on roads, rivers and canals. These travelways were highly important to defense, commerce and westward expansion.

Between 1801 and 1803, the United States Army built the Natchez Trace, between Nashville, Tennessee, and Natchez, Mississippi. Military roads were also constructed to protect the new settlements in the American West, by connecting the string of forts. The crews leveled the steepest grades, built bridges over streams, and basically cleared ways of trees and brush. Examples of these military roads were those built in the New Mexico territory in the late 1840s.

The government also built the National Road. Under supervision of United States Army topographic engineers, the government built the section of the National Road from Cumberland, Maryland, to Wheeling, West Virginia, between 1811 and 1818.

Local Participation in Bridge Building. Despite the federal government’s appropriation of funds and lands for a few roads such as military roads, the Natchez Trace and the National Road, the overriding attitude of most governmental leaders was that road and bridge construction should be the responsibility of local governments. It was the locals who needed the roads and bridges to allow transport of goods to market and to facilitate development of the West through the great western migration. Stagecoach companies also wanted routes westward, and covered wagons that carried settlers westward appeared in the 1850s.

Bridges in the east were being built on early nineteenth century turnpikes, constructed by state-authorized private turnpike companies. Private entities built other toll roads, as well. Bridges on these routes were generally simple timber beam structures.

Local residents constructed many of the first bridges developed west of the Mississippi by the immigrant Europeans. In North Dakota, for example, the early bridges “were normally built without government involvement, resulting in primitive, informal designs. Most were built of timber with relatively short spans. . . rarely did these bridges last more than a few years before either collapsing under a heavy load or washing away in a spring flood” (10, p. E-7). In Iowa, for little traveled crossings, simple timber stringers were the rule. As was common in cash-poor areas, Nebraska settlers preferred to repeatedly reconstruct inexpensive timber bridges rather than invest in more permanent, but expensive, iron and stone structures. The ultimate example of cheap/inexpensive bridges were those crafted by pioneers from a “readily available material,” sod (11, p. E-3).

As was the case in the eastern United States over 100 years earlier, most bridges farther west were not built by the government, but instead were built by private initiatives. Sometimes through legislation, the state or county government provided permission to the locals for the development of roads and bridges. In territorial Iowa, for example, bridges were acknowledged in 1814 legislation that stated that male citizens and slaves between the ages of 16 and 45 would construct bridges over smaller streams, while the county would fund bridge building over larger streams. But, apparently few bridges were built under this act (12, p. 9). At the time of Missouri Statehood in 1828, the Governor requested that the state legislature put three percent of the state profits from land sales aside for the construction of durable bridges (12, p. 9).

Throughout the United States, counties and townships relied on private initiatives to span major crossings. Local civic and business leaders created and funded private bridge corporations in an effort to promote regional trade and boost a community’s economic standing. Once completed, these privately-owned structures operated as toll bridges, with each county setting the charges and regulations for their use. Monies collected were used to repay shareholders and recover operating expenses. Often, the county would later purchase the bridge and open it up for free passage.

In the 1820s, Missouri enacted legislation that enabled the construction of toll bridges. In 1831, the Arkansas State Legislature granted a franchise, good for 20 years, to William S. Lockhart for the construction and operation of a toll bridge over the Saline

River where the military bridge crossed it. Lockhart was permitted to “receive of all persons crossing, and for all species of stock, such rates as the proper court . . . shall from time to time authorize and direct” (13, p. E-1 and E-2). The legislature mandated that the bridge be in operation within three years of the granting of the franchise, and that it be kept in “good order and repair” (13, p. E-2). The provisions of the Act stated that the bridge should not “prohibit any person from fording the river, free of toll, at or near the crossing of the road, when the river is fordable and the traveler preferred that method of passing over it” (13, p. E-2). The licensing of private individuals or bridge companies to construct, own and operate toll bridges, was the primary means that many states used to fund bridge construction during this period. In Arkansas, for example, these early toll bridges were usually constructed from cut timbers in a pony-truss design (13, p. E-1- and E-2). To allow the locals to construct these bridges, portable saw mills were sometimes used to produce the needed lumber.

In 1836, one of first acts of the Congress of Texas authorized county courts to lay out and construct roads, establish ferries, and contract for toll bridges. The 1836 Act required that all free males work on public roads. Prior to the Civil War, the Texas Legislature granted charters to more than 100 toll bridge corporations—most early toll bridges were simple, timber structures, built by craftsmen who had little or no knowledge of bridge engineering or construction. By the 1850s, most counties relied on private initiatives to span major crossings. Once completed, the bridges would operate as toll bridges. The tolls collected would be used to repay the shareholders and cover maintenance expenses.

The legislature that created the Nebraska territory granted county commissioners both the authority and responsibility for opening and maintaining county roads: “All public roads shall be surveyed, opened, made passible (sic) and kept in repair, 40’ wide; and all bridges on any public road shall be at least 16’ wide, with a good and sufficient railing on each side, 3’ high, the whole length of the bridge” (11, p. E-2). The territory’s first legislature, which convened in 1855, established ten territorial roads and incorporated a number of bridge and ferry companies. The author of the Nebraska Multiple Property Listing for Highway Bridges in Nebraska, stated that she was fairly certain that the legislature’s dictates about bridge width and railing were largely ignored. Bridges for little traveled crossings were likely simple timber stringers, and for more important locations, a combination of wood and iron was used, known as “combination bridges,” because of their mix of materials (11, p. E-2).

Alexander Major, a partner in a firm that dominated military freight hauling in the 1850s, needed a better route from the terminal in Nebraska City to Fort Kearner. In 1860, he hired August Harvey, a civil engineer, to survey and establish a direct route to replace the existing, circuitous trail. A note on Harvey’s 1862 map of the new route proudly proclaimed: “This road worked and opened in 1861—every stream bridged – no fords – no ferries” (11, p. E-2).

Foundries and Fabricators. Until mid-century, the railroad companies had designed and built their bridges from timber or a timber-iron combination. Around that time, railroads began to use iron truss bridges and a new industry of metal foundries and

fabricating shops appeared. These shops formed bridge members, drilled the members and assembled and connected the truss members, before packaging and shipping them to the bridge site. By 1860, the railroads were almost exclusively relying on these private concerns to fill their bridge needs with pre-fabricated parts. Most of these companies manufactured common truss types, but some companies also developed unusual truss designs.

2.3 Civil War to 1899

Influences on bridge technology and design during the last forty years of the nineteenth century that are discussed in this section are:

- The Civil War
- The Engineering Profession
- Advances in Bridge Technology
- Bridge Companies
- City Beautiful Movement

2.3.1 The Civil War

By 1860, the country's annual iron output had climbed to almost one million tons. That tonnage, however, could not meet the demands of railroads, manufacturers, the construction industry, or bridge builders. After its outbreak in 1861, the Civil War intensified the need for faster and better ways to work iron, and timber was still widely used. The timber trestle, with its ease of erection and abundant materials made it important "during the American Civil War, when for the first time, railways played an important tactical role. Railway bridges became targets for artillery or sabotage and, in some places, needed frequent rebuilding" (14, p. 84).

The United States Corps of Engineers played a major role in the construction of wartime infrastructure. For example, during the winter of 1861-1862, military engineers supervised the building of a series of 77 separate forts or redoubts for the defenses of Washington, DC. In 1863, military engineers undertook clearing obstacles and the construction of roads, bridges, palisades, stockades, canals, blockhouses, and signal towers. In the area of bridge construction, the Corps laid down hundreds of pontoon bridges and built or repaired bridges and railroad trestles.

Private enterprises also sponsored transportation projects in the Civil War period. Started during the war in 1863 and completed in 1869, the Transcontinental Railroad connected the Union and Pacific Railroads and stretched over 2,000 miles between the Missouri River and California. Numerous bridges were built along this route, which served the North in its Civil War efforts and paved the way for westward expansion. The railroad's interest in stronger rails and bridges prompted substantial progress in bridge engineering technology and in American iron (and later steel) production.

The first notable example of the swing bridge, the only movable bridge type built until the end of the nineteenth century, was completed in 1863. Designed by engineer Wendel Bollman, the structure spanned the Mississippi River at Clinton, Iowa.

2.3.2 *The Profession of Bridge Engineering*

Engineering Education: A greater number of specialist civil engineers with particular skills in bridge design, analysis, and construction began to emerge following the Civil War. Hayden wrote that “the emergence was a gradual process within the engineering profession, and from the late 1800s, some engineers appeared who are remembered specifically as bridge engineers rather than the all-rounder of the profession’s early days” (3, p. 85).

After the end of the Civil War, there was a gradual shift from engineers who learned through an apprenticeship system by working on canals and railroads to a university-based system of education. By the 1860s, higher education was becoming more accessible, and many politicians and educators wanted to make it possible for all young Americans to receive some sort of advanced education. The Morrill Act of 1862 granted land to each state that had remained in the Union to sell and use the proceeds for the establishment of colleges in engineering, agriculture, and military science.

The land grant colleges that stemmed from the Morrill Act were very important to the field of engineering, as many newly-created schools quickly established engineering schools. Over seventy land grant colleges were established under this Act, and within ten years of its passage, the number of American engineering schools had increased from six to seventy and the number of graduates rose rapidly. (In 1890, a second Act extended the provisions to the sixteen southern states.) Through this rapid development of engineering education, more and more practicing engineers evolved with extensive academic backgrounds. However, John Rae and Rudi Volti, authors of *The Engineer in History*, wrote that “Quantity was not always matched by quality. . . many of the new engineering schools were marred by incompetent faculty, ineffective teaching, and lack of support by university administration” (5, p. 183). Private colleges also multiplied at this time.

In 1866, four years after the passage of the Morrill Act, there were about 300 graduates in engineering, by the turn of the century, 10,000 students were studying engineering in colleges and universities. In 1890, the United States had 110 colleges of engineering. This surge in professional engineers marked a turning point for the profession, but the change was gradual. “The impact of turning engineering into an occupation to be learned in the university was not fully felt until well into the twentieth century” (5, p. 183).

American Society of Civil Engineering (ASCE): While the ASCE had been organized in 1852; it took a hiatus during the Civil War and experienced a resurgence in 1867. Between 1870 and 1892, a review of the ASCE member records shows that a substantial number of member engineers had no formal engineering degree; for example, between 1870 and 1874, 40 percent of the members had no degree. The remainder were graduates of more than nine schools, RPI having the highest number—20 percent of the

total. Between 1885 and 1892, 27 percent had no formal degree and members were distributed among 42 schools, with RPI still claiming the highest percentage (14 percent) (8, p. 238).

2.3.3 *Advances in Bridge Technology*

During this period, the railroad companies continued to be in the forefront of bridge design. The era's leading railroad engineers and theorists began espousing computation of bridge stresses through methods such as analytical and graphical analyses, testing of full-scale bridge members, and metallurgical analysis.

Metal truss bridges experienced a tremendous wave of popularity, as they represented a significant improvement over stream fording, ferrying and timber bridges. The mobility of the structures was also a selling point. Author Martin Hayden called the 100-year period between 1780 and 1880, the “age of iron” (3, p. 84). After 1880, steel, which had been around for centuries, but was limited in use due to its high cost, supplanted iron as the metal of choice for bridge builders.

As they had in the antebellum and Civil War periods, railroad companies continued to introduce new design concepts. One of these was the viaduct, a structure intended to carry railroads over roads and topographical features or over other railroads. The design of these structures was originally based on timber trestles. Before the end of the 1860s, the quality of iron had improved and the demand for it had increased. A uniquely American bridge form then emerged, the metal, railway viaduct (3, p. 73). According to David Plowden, a viaduct can be built using any bridge type, as opposed to a trestle, which is a very specific type of structure executed in wood or metal only (3, p. 73). The first true metal viaduct in the United States was built in 1858 by the B&O Railroad in Virginia (West Virginia today)—the Tray Run Viaduct.

Prior to the Civil War, 300-foot long spans had been considered extremely long and hard to erect (3, p. 72). “Longer spans with their increased stresses necessitated the most exact calculations and presented problems not heretofore thoroughly understood, let alone solved” (3, p. 72). A variety of solutions to the long span were put forth. Jacob H. Linville, a renowned bridge builder and employee of the Pennsylvania Railroad erected a 320-foot long iron railroad bridge across the Ohio River at Steubenville, Ohio. This 1865 bridge is generally considered the first long span truss bridge in the United States (3, p. 72). Almost all early long-span trusses were of the Whipple-Murphy truss.

Demand for metal that was stronger and more durable than wrought iron brought about a growing interest in steel production after the end of the Civil War. Steel is highly refined iron, with a carefully controlled low carbon content. The first practical production of Bessemer Steel in the United States occurred in February 1865 by Winslow, Griswold and Holley. This process entailed blowing air through molten cast iron to remove the impurities that made it brittle. The resultant steel was softer than iron and less expensive than earlier steel.

Another method of steel production was developed by a German, William Siemens. Although Siemens patented the Siemens Process in 1844, steel was not fabricated using that process until around 1864, when Frenchman Pierre-Emile Martin used the process. The basis for modern steel production, the Siemens Process, was undertaken in an open hearth, in which iron was purified by using combustion gases to heat the air blast. This method utilized scrap and pig iron, and created a higher quality and lower cost product than Bessemer steel. In this same period, new iron deposits were discovered and innovative techniques to extract the ore and transport it to the mills were implemented.

During the 1870s and 1880s, the Bessemer converter and open-hearth processes were perfected, making possible the production of large amounts of steel at a low cost. United States production rose from 16,000 tons in 1865 to nearly five million tons in 1892 to 11.4 million tons in 1900. The United States assumed world leadership in steel production in 1889. These advances essentially ended the “iron age,” and brought the United States to the forefront of the steel industry.

The drop in the world price of steel by 75 percent in the 1870s signaled a new phase of bridge building. The first important bridges to use steel were constructed in the United States. The Washington Bridge (historically the Harlem Bridge) and other pioneering steel masterpieces, such as the Brooklyn Bridge, the Eads Bridge in St. Louis, and the works of George S. Morison and C. Shaler Smith, had clearly proven the structural superiority of steel. According to David Plowden, with the acceptance of steel, “the greatest age of American bridge building was now at hand” (3, p. 171). Towards the end of that pioneer period (circa 1870 into the early twentieth century), steel became clearly preferable to iron, as cantilevers, trusses and arches were built on a scale that had never before been imagined. Most of the big bridges of the time were for rail transport and thus had to be both extremely strong and resistant to damage from vibration.

The Eads Bridge, built in St. Louis between 1869 and 1873 and a major crossing of the Mississippi River, was one of the nation’s first steel bridges, although it was not entirely steel. According to David Plowden, almost everything about the steel arch structure “was without precedent, the choice of material, the decision to use arches instead of using trusses suspending the bridge, the length of the spans, the methods of construction, the use of pneumatic caissons, the depth of the foundations, the cantilevering of the arches, the stringent specifications that forced the mills to produce high-quality steel, and the proof that steel could be used as a structural material” (3, p. 131). The bridge was designed and built by James Buchanan Eads, who had little formal education, but “a natural gift for engineering” (12, p. 12). Eads shares credit with perfecting the method of using caissons for bridge foundation construction with Washington Roebling. Eads used the caisson method and was the first to use them at such a depth. At the Eads Bridge, workers went deeper than any others had done with compressed air—the 136-foot depth they reached is still the record (3, p. 129). According to Plowden, however, “although the pneumatic caisson was an ingenious solution to the problem of founding bridge piers at a great depth, it presented extreme hazards to those that worked within it and was extremely expensive to use” (3, p. 129).

Engineer J.A.L. Waddell credits George S. Morison's 1873 specifications for an Erie Railroad bridge as "probably the first printed bridge specifications ever adopted by any American railroad" (as quoted in *11*, p. E 14). Waddell wrote that Morison "required successful bidders to submit stress sheets and plans for approval before starting work, and later began the inspection of materials and workmanship" (as quoted in *11*, p. E 14).

In the period following the Civil War, a number of occurrences had dampened the early enthusiasm for using wrought iron for construction of bridges. Numerous bridge failures had occurred, the causes attributed to basic defects in wrought iron as a structural material. For example, an event occurred in 1876 that widely publicized the problems encountered with iron bridge construction. In 1865, the first all-iron Howe truss design had been completed on the Lake Shore Railway over a steep gorge near Lake Erie at Ashtabula, Ohio. Eleven years later, the wrought iron structure collapsed under an eleven-car train, killing 92 people. The subsequent suicide of the railroad engineer was attributed to the public and press outcry following the accident. The "main reason for the failure was a combination of the lack of knowledge about the behavior of wrought iron under tension, and the fact that the bridge had a high dead load (or self weight) and was insufficiently braced. More simply the accident showed that in poor designs, iron was too heavy and unreliable to hold itself up" (*14*, p. 85). The Ashtabula disaster made it clear to engineers that iron presented problems for use in truss bridges and by the 1880s, about 25 iron railway bridges in the United States were failing per year.

A decade later, a contract was awarded for a bridge across the Kentucky River at Dixville, Kentucky. Plowden states that this great bridge "at once represented the culmination of iron-bridge design and its swan song" (*3*, p. 125). Designed by C. Shaler Smith and Louis Frederick Gustave Bouscaren, this bridge was the longest cantilever bridge in the United States. Completed in 1877 after less than a year of construction, the superstructure was entirely of wrought iron and the trusses were of the Whipple-Murphy type. Bridges built before the Kentucky River Bridge had been designed so that each span rested independently on its piers or abutments. The structures did not continue over and past the piers. This cantilever design proved that for long-span structures, "it was economically desirable to design the truss to run continuously over a pier, thus constructing a bridge that would cantilever, or extend, beyond the piers" (*2*, p. 31).

"The development of the cantilever, which goes hand in hand with the changeover from iron to steel, was enormously important in the history of bridge engineering" (*3*, p. 163). In building multiple span truss bridges, bridge engineers recognized that the span could be longer and stronger if the independent trusses could be joined together to form a continuous structure. Since each span would anchor, or balance, the load in the adjacent span, a continuous truss bridge acts with a cantilever effect on adjacent spans. The railroads quickly adopted it, primarily for longer spans.

The earliest all steel bridge was the 1879 Glasgow Bridge, built by the Chicago and Alton Railroad across the Missouri River at Glasgow, Missouri. The steel used for the five Whipple trusses of this bridge was produced through the Hay process, which had been developed by A.F. Hay of Iowa. This process increased the carbon content of steel and, consequently, its tensile strength.

The second cantilevered bridge design in the United States is credited to Charles Conrad Schneider, who had a mechanical engineering degree from Britain. In 1882, he designed and built the Fraser River Bridge in British Columbia for the Canadian Pacific Railway, which was followed in 1883 by a cantilevered structure across the Niagara Gorge for the Canada Southern Railway. The latter was a composite structure of steel and iron, “hailed as an outstanding achievement in design and engineering” (3, p. 164). Arch bridges had been constructed for centuries before steel became available. It was not until the advent of steel, however, that the cantilever principle became really feasible as a form for long spans. Again, it was the railways that provided the impetus for this bridge type.

The combination of continuous and cantilever principles was the next logical step in American bridge design. An early pioneer of an unusual combination, the through cantilever, was George S. Morison’s 710-foot long 1892 Mississippi River Bridge at Memphis, Tennessee. In this structural type, the railway or road deck is supported on the bottom chords of main bearing cantilevers, which are continuous with the linking trusses.

Advances were also being made in movable structures. Swing structures had historically been used when a movable structure was required, but in 1872, Squire Whipple patented a vertical lift structure. Twenty-one years later, in 1893, J.A.L. Waddell developed a design for what is thought to be the first large scale vertical lift ever built (15, p. 103). Also in 1893, the modern bascule bridge (rolling lift) appeared in Chicago’s Van Buren Street Bridge, built using a William Scherzer-patented design.

Changes also occurred in the post-war period in the way that metal bridges were connected. During most of the nineteenth century, pins had connected metal bridges. The metal bridge members had holes drilled in their ends that were aligned with one another. A cylindrical pin was placed in the openings to form the structural connection. Pin connections facilitated quick erection of the trusses, but they were susceptible to loosening under vibration from heavy loads. In 1865, London engineer Ralph Hart Tweddell invented the first hydraulic riveting machine. Rivets provided a solid, rigid means of connecting the truss members. American bridge builders began to use hydraulic shop riveting in place of steam riveting around 1865, but the use of hydraulic riveting machines developed slowly. By the late nineteenth century, American inventors had succeeded in reducing the size of hydraulic riveting machines, even taking them out of the shop to places where bridges and buildings were being erected, but their weight and size still required substantial rigging and a large crew for their operation in the field.

In 1875, pneumatic riveting machines began to appear. Although less expensive than hydraulic machines, these machines also developed slowly (16, p. 45). Riveting could not be done in the field, so the use of riveting for bridges did not really take off until the portable pneumatic riveting systems were developed in the 1880s and 1890s. In 1898, St. Louis-based Joseph A. Boyer invented a pneumatic riveting hammer that could be handled by a single person. Patented in 1901, Boyer’s invention, along with the invention of a portable compressor, made it possible for railroad companies to create “portable” riveting plants that were mounted on railroad cars and which greatly facilitated bridge erection in the field. By the turn of the century, a practical means of pneumatic

field riveting was in place. This greatly reduced the labor costs of erecting bridges and led to a general shift from bolted and pinned connections on metal truss and arch bridges to riveted connections. Field riveting solved a common problem in bolted or pinned connected structures, the tendency of the pin and bolt holes to enlarge with age and use, making the bridge less stable and secure.

In the United States, as early as 1818, Canvass White used a form of natural hydraulic cement on the facing of some of the Erie Canal's aqueducts. The first authenticated use of plain concrete as a structural material in the United States was in the foundations of the Erie Railroad's Starrucca Viaduct at Lanesboro, Pennsylvania, completed in 1848 (3, p. 304). Concrete is natural sand and small stones, or artificial mineral materials, bound together by mineral cement, which hardens and strengthens over time as a result of chemical reactions with water. Concrete is strong in compression, but lacks tensile strength.

The first concrete bridge in the United States was the 1871 Cleft Ridge Park Bridge, a pedestrian bridge in Brooklyn's Prospect Park. The early concrete structures were built of solid concrete, which possesses the same structural properties as stone, great compressive strength, but virtually no tensile strength. Hence the arch, a compressive form, was used for early concrete bridges and was the only option available for bridge engineers working with concrete during this era.

The advances in steel technology made possible the growth in the use of concrete for bridge construction. Near the end of the nineteenth century, engineers began to discuss embedding steel rods within concrete to give it the desired tensile strength, i.e., reinforced concrete. Thomas Curtus Clarke made the first proposal in the United States for a reinforced concrete bridge in 1885, but it was not built. In 1885, Ernest Ransome received a patent for his twisted reinforcing bar. Five years later, Ransome designed the first reinforced concrete bridge, the Alvord Lake Bridge in San Francisco's Golden Gate Park. The bridge featured imitation rusticated stone voissiors and custom made cement stalactites dripping from the arch.

In the last decade of the nineteenth century, trends in concrete development found their way to the United States from Europe. Joseph Melan, a Viennese engineer, received a patent in the early 1890s for his reinforcing system. His method involved embedding parallel metal I-beams in concrete. Melan's system of steel embedded in concrete arches was introduced in the United States in 1893 and came to be used extensively in highway and pedestrian bridges. Fritz von Emperger, who received a patent, popularized the Melan reinforcing method in the United States. In 1893, von Emperger built the first bridge in the United States (in Rock Rapids, Iowa) based on the Melan technique. During the decade of the 1890s, United States bridge engineers also began to develop designs using reinforced concrete.

Despite these developments in the late nineteenth century, however, the use of concrete in non-water transportation structures did not become common and generally accepted until the early twentieth century. The understanding of the chemical processes in concrete was not well understood until that time period.

2.3.4 Bridge Companies

In the nation's industrial history, the period between 1860 and the turn of the nineteenth century was unprecedented in the production of prefabricated iron truss bridges and produced an extremely wide range of bridge designs.

By the late 1860s, fabricating companies, many exclusive to bridges, came to dominate the bridge field. Bridge truss technology was advanced through the efforts of these numerous small, private bridge companies. Such companies were concentrated in the Northeastern and Midwestern states, and often specialized in a few particular types. Many firms were even based on a single patented bridge design. These firms produced their patented type and sold it through illustrated catalogs, which were used for both educational and sales purposes. In the 1870s, these bridge companies were sending salesmen across the country to sell their product. The firms' engineers could develop a specific proposal for a site, an alternative to employing a costly engineer. They designed and fabricated bridges for use by cities, counties and railroad companies. Other larger firms, able to design, fabricate, or erect singly or in combination, also bid for and won major commissions for many major bridges.

According to the Multiple Property Listing form for Historic Highway Bridges in Michigan, these bridge companies filled an important need as:

America's frontier galloped westward. They did not, however, always do it in the most efficient or ethical manner. Problems were fostered by the process local governments typically use to procure bridges. Road commissions advertised the letting of a contract for one or more bridges, often providing only the bare minimum of specifications, such as span length and structural type. Since township supervisors were rarely competent to judge the structural merits of proposals, bridge companies sometimes supplied inappropriate or inadequate designs to win the contract as the cheapest bidder. Even when good plans were submitted, unscrupulous contractors insisted on provisions allowing substitution of 'like-kind' structural members...The plans appear attractive to the board and may call for a strong, heavy structure, but the contractor, taking advantage of the substitution clause in the contract and the lack of training of the board, actually builds a much lighter, weaker and consequently cheaper bridge (17, p. E-2 and E-3).

Bridge manufacturing had three distinctive tasks: 1) producing iron and steel from raw materials; 2) rolling iron and steel into structural shapes; and 3) fabricating (making) the bridge parts (members and connection pieces). American rolling mills began producing, or rolling, metal into a wide variety of structural shapes, such as I beams, channels, angle sections and plates in wrought iron. By the mid-to-late 1880s, many of these mills were retooling their machines to make structural shapes in steel. As the industry evolved, mills began producing parts in standardized shapes and sizes. Most rolling mills, along with fabricating shops, were in the steel belt of the Eastern United States and in the Midwest.

Bridge fabricators produced bridge members from the metal parts produced by the rolling mills. One of the primary tasks was to create built-up members using channels, angles, plates and other parts from rolling mills. By the late 1800s, bridge fabrication had become a complex, yet standardized, manufacturing process. According to James L. Cooper, author of *Iron Monuments to Distant Posterity, Indiana's Metal Bridges, 1870 – 1930*, many fabricators employed engineers for competitive reasons. “Even as the price of iron and steel dropped, metal remained too expensive to waste on unnecessary or unnecessarily heavy members. Trial-and-error reductions in metal use could lead to bridge failures, news of which competitors’ salesmen quickly spread across the countryside. Over time, scientific bridge fabrication produced cheaper and sounder structures, a happy coincidence of private and public interest” (15, p. 8).

After a bridge fabricator received an order for a bridge, clerks would arrange contractual and shipping details, while the engineering department was preparing detailed plans and instructions for fabrication and erection. The template shop would make or provide existing wood patterns to workers in the riveting shop, who would cut, punch, and bore the metal. Fabricators would undertake as much assembly as possible, e.g., riveting together chord members, struts and other built-up sections before transporting them to the bridge site for assembly. For pin-connected bridges, the forge shop would produce eye bars and other items that required foundry and blacksmith work.

The bridge fabricator would then prepare the shipment, which would include an assortment of lightweight bridge members and necessary connection pieces, such as pins, eye bars, and bolts. When the shipment arrived by rail at the closest point to its destination, bridge agents or locals would haul the bridge members by wagon to the site where the components would be assembled and erected on piers or abutments. Locally built approach spans (often timber or I-beam trestle) and a timber plank deck would complete the structure. Fabricators could usually fill orders quickly, within a few days or weeks. The expansion of railroads throughout the country allowed fabricators to ship to almost every part of the country.

Iron and steel makers introduced a number of improved processes and laborsaving devices. These allowed them to charge less for their product and to increase their profits. The growing standardization of rolled shapes reduced the milling costs, leading to price reductions; some of these reductions were then passed along to the buyers. For example, the price of pig iron was reduced by over one-third, while productions increased by two-thirds during the 1890s (15, p. 8). By the end of the nineteenth century, steel had replaced wrought iron and bridge manufacturing had evolved to a highly refined American industry. In 1900, a trade journal noted that the American bridge shops had “reached as high a state of perfection as any other class of manufactories” (18, p. E-11).

2.3.5 *City Beautiful Movement and Bridge Aesthetics*

In the late nineteenth century, a reform movement that sought to improve the nation’s cities through beautification, gained wide exposure through the Chicago World’s Fair of 1893. Known as the “World’s Columbian Exposition,” the fair expressed the ideals of the City Beautiful reformers through the creation of a “White City” of

architecture and infrastructure built in the Beaux Arts style, a tour de force in city planning. The fair featured both architectural cohesiveness and a state-of-the-art transportation system. Not only were the bridges built on the system state-of-the-art, they were visually appealing. Many architects and bridge engineers well into the twentieth century embraced the fair's Beaux Arts style.

2.4 1900 to 1955

The early twentieth century was an era of tremendous advances in bridge building technology, with the evolution of more durable materials, the development of standard plans and the growth of a cadre of specialized bridge engineers and state highway departments. Other forces contributing to the advances were the Good Roads Movement and Federal Legislation, and events such as the Great Depression of the 1930s and World War II. This section discusses bridge engineering, historic events that influenced bridge design and construction, and new technologies and advances in bridge design during the period between the turn-of-the-century and 1955, the year before the Federal Aid Highway Act of 1956 created the interstate highway system.

2.4.1 *Bridge Engineering*

At the turn of the nineteenth century into the twentieth, approximately 1,000 engineering degrees were awarded, and 43,000 engineers were employed in the United States. Yet, many practitioners continued to learn skills in non-academic settings. In 1905, the ASCE president wrote that “bridges are frequently designed by incompetent or unscrupulous men, and the contracts are awarded by ignorant county officials, without the advice of a competent engineer. The merit of the design receives generally no consideration, and the contract is awarded in many cases to the one offering the poorest design and making a bid which is satisfactory to the officials, if not the taxpayers” (19, p. E12).

Competitive pressures in the bridge business led to the closing or takeover of many smaller bridge-fabricating firms. The largest consolidation occurred in 1900 when Andrew Carnegie bought out more than 25 of the largest bridge fabricators in the country and absorbed them into the American Bridge Company of New York. This expedited the decline of the independent bridge firm, which disappeared almost entirely after World War I.

The workplaces of engineers had also started to change. In the early twentieth century, many engineers were employed by the new state highway departments, and many were employed by the large bridge and engineering companies that designed and built bridges and undertook other infrastructure work for the government. A listing in a 1907 Kansas City Directory illustrates how the bridge industry was becoming more specialized, as it separately listed bridge companies, bridge contractors, bridge engineers, and iron and bridge work (12, p. 16).

In the years that followed World War I, a new trend in bridge building arose. Rather than one company designing, fabricating and erecting bridges, the bridge industry

was often divided between consulting engineering firms that developed bridge designs and steel-fabricating firms that manufactured and erected the spans. By the 1930s, this trend was solidified, resulting in a new type of bridge building company that specialized in designing and constructing bridges and not fabricating the parts.

During this era, the bridge engineering field was advanced through the existing and newly formed engineering organizations, such as ASCE and the American Association of State Highway Officials (later American Association of State Highway and Transportation Officials/AASHTO). These and other organizations had technical journals that focused on bridge design and construction. Government circulars addressing bridge design and construction also began to be published.

An example of an engineer dispersing knowledge through publications was Kansas City engineer and bridge designer, J.A.L. Waddell. Waddell was known for his extensive technical reports and publications regarding bridge design and construction. An example is the article that appeared in the *Journal of the Western Society of Engineers* in October of 1927 and then again, with a discussion of the article by a number of engineers, in May of 1928. The article was entitled “Suitability of the Various Types of Bridges for the Different Conditions Encountered at Crossings.” The article addressed the question of what type of bridge to build, by enumerating the many factors that must be considered in selection of an appropriate design. One commenter on the article wrote that “while any young engineer would profit from a thorough-going study of the hundreds, if not thousands, of such articles in engineering periodicals or in transactions of engineering societies, yet only a specialist in bridge engineering, who has had extensive and successful experience in responsible charge of design and construction, can possibly write such an article” (20, p. 17).

By the end of this period, state transportation departments passed more and more work to consulting engineers.

2.4.2 *Historic Events that Changed Bridge Construction*

The Good Roads Movement. The decade of the 1890s was a time of transportation reform efforts throughout the country. The national “Good Roads Movement” emerged with the goal of improving the condition of local roads. The popularity of bicycling gave impetus to the movement, and bicyclers aligned with the farmers in demanding smooth, all-weather roads. It was essentially a rural grass roots movement in which bicyclers and farmers and their families lobbied for better roads, the farmers to facilitate transporting their products to market and interacting with their neighbors.

States began to heed the public outcry for better roads and formed statewide “Good Roads” organizations. In Iowa, for example, the Governor called the first Iowa Good Roads Association meeting in April of 1903, a meeting which signaled a shift in control of roads from local to state government (21, p. E-15).

Federal Legislation. Between 1893 and 1915, the federal government advanced the organization of the federal government’s transportation department. The following key events occurred:

- 1893—Secretary of Agriculture J. Sterling Morton instituted the Office of Road Inquiry on October 3, 1893. The office issued its first bulletin the following year.
- 1905—An Act of Congress consolidated the renamed Office of Public Roads Inquiries with the Division of Tests of the Bureau of Chemistry into the Office of Public Roads (OPR).
- 1910—The OPR established a Division of Bridge and Culvert Engineering to collect data, publish circulars, and construct demonstration bridges. Within a few years, the division was publishing standard bridge specifications and preparing standard plans for a variety of structural types for state and local use.
- 1915—An Act of Congress consolidated the Office of Experiment Stations, the farm architectural work of the Office of Farm Management Investigations with the Office of Public Roads to form the Office of Public Roads and Rural Engineering.

The Federal-Aid Road Act of 1916 ushered in a new level of commitment by the federal government to road building, including the building of bridges. Through this Act, Congress acknowledged the need for a more efficient road network that connected the states. The Act was in response to the advocates of the Good Roads Movement and to lobbying from groups and organizations such as farmers, the interstate road associations, and the United States Postal Service, which had problems delivering mail in many rural areas due to the poor condition of the roads.

The goal of the 1916 legislation was the development of an interconnected system of well-built and maintained roads throughout the country. The Act provided for the construction of rural public roads with federal contributions not to exceed fifty percent of the total estimated cost of each road project and specified that each state had to maintain the roads constructed under the Act’s provisions. In addition, in order for a state to receive federal highway aid, it had to establish a state highway department if it did not already have one.

A provision of the Act stipulated that applications for proposed highway projects had to be submitted through state highway departments, a requirement that established centralized authority for road construction in the states and removed control from the counties. States were directed to prepare plans and specifications for roads and bridges, which would then be approved by the Office of Public Roads and Rural Engineering. These provisions served as “an important first step in the effort to bring professionalism and organization to state highway planning across the nation” (*10*, p. E-19).

The Federal Aid Highway Act of 1944 authorized designation of a “National System of Interstate Highways,” which would be selected by joint action of the state

highway departments. This act, however, included no special funding or funding increases and it made no federal commitment to construct the system. Construction began on some portions, but moved slowly. The Federal Aid Highway Act of 1952 authorized the first funds that were specifically to be used for interstate highway construction, but such funding was inadequate. In 1954, the Federal Aid Highway Act provided additional funding, but still not enough. The Federal Aid Highway Act of 1956 authorized substantial monies for constructing the interstate highway system and called for uniform interstate design standards.

Creation of State Transportation Departments. In the first two decades of the twentieth century, all states created state highway departments. In 1903, the Pennsylvania legislature passed an act that created a state highway department, one of the first in the country. The department provided assistance to counties and municipalities concerning road improvements, but it was not until eight years later that the Sproul Act created a state highway system.

As other state highway departments were created, bridges were included in the departments' responsibilities. For example, the New York Highway Law of 1908 established the New York State Department of Highways, which was mandated to supervise state-funded bridge projects. The law established a state commission to aid, supervise, and direct the local administration of public roadways. The state highway department was generally prohibited from building bridges, but merely assisted county and municipal governments, for example, by providing recommendations on the design and construction of bridges.

In 1914, the American Association of State Highway Officials (later, AASHTO), a non-profit, scientific, tax-exempt association was established. As soon as the association was formed, it immediately began working on a draft of a federal-aid highway bill, which evolved into the 1916 Federal Aid Road Act.

In 1915, the New York Transportation Department's Bureau of Bridges had grown to be one of the most important bureaus in the department (22, p. 68). Other states DOTs were also creating bridge bureaus or divisions.

By 1915, only five states did not have state highway departments: Tennessee, Florida, Indiana, South Carolina and Texas. In anticipation of federal action, Tennessee and Florida created departments in 1915, with the last three states forming departments in 1917, the year after the enactment of the 1916 Federal Aid Road Act.

The Texas Highway Department, an example of a department established pursuant to the government mandate, was established in 1917 and charged with the tasks of designing, constructing, and maintaining an adequate system of state highways. The following year, the department created a bridge office, and assigned to it the primary responsibilities of preparing standard designs and drawings in an attempt to bring some uniformity to the bridges being constructed by the counties and to meet the intent of the federal regulations.

In 1918, Missouri created a separate bridge bureau within its state highway department in an attempt to strengthen efforts to expand and standardize both bridge design and maintenance (*12*, p. 23). The department recognized the importance of standardization in the state's bridge designs and set up a drawing section to prepare bridge and culvert designs. The bureau's goal was to "rectify poor designs with bridge engineering. . . a specialized branch of engineering requiring a knowledge of mechanics and the strength of materials" (*12*, p. 23).

By the 1920s, newly-funded state DOTs controlled large amounts of federal construction monies, which were tied to federal restrictions, such as the use of approved standardized bridge designs.

The Great Depression: The federal government's work programs of the Great Depression years were a boon for highway and bridge construction. The 1934 National Industrial Recovery Act (NIRA) funded a comprehensive program of public works. NIRA provided grants for highway work that were intended to increase employment through implementation of road and bridge projects, with no state money required.

That same year, Congress passed the 1934 Hayden Cartwright Act, which one author heralded as "the most outstanding piece of highway legislation since the Federal Aid Highway Act of 1916" (*17*, p. E-14). This Act extended NIRA and for the first time allowed the use of federal dollars for highway improvements in municipalities; it also permitted funding of highway planning surveys. Subsequent legislation encouraged grade separating railroads and roads and widening bridges.

The Works Progress Administration (WPA) was a relief measure established in 1935 by executive order. Between 1935 and 1943, the WPA built or maintained over 570,000 miles of rural roads, erected 78,000 new bridges and viaducts, and improved an additional 46,000 bridges throughout the United States. A contemporary report stated that "many of the [new] bridges were small, replacing structures that were dilapidated or inadequate, or taking the place of fords; and many were two-lane bridges built to replace one lane bridges" (*17*, E-15). Many WPA bridges were built in parks. WPA bridge designers, who paid great attention to aesthetics, carefully crafted these often-picturesque park bridges: often the small park structures were either Art Deco influenced or rustic.

The 1940s and World War II, and the Post-War Period. After the United States became involved in World War II, road construction generally ground to a halt, with the exception of roads designated for military purposes. Materials needed for bridge construction, such as steel, were needed for the war effort. This shortage of materials led to the use of salvaged materials, use of un-reinforced concrete and construction of timber structures. When steel and other war materials were used for bridge construction, they were used prudently.

The decade of the 1940s ushered in wide acceptance of mathematical formulas that had been developed to calculate difficult design concepts. In addition, improvements in technical and mechanical equipment were made that influenced bridge design and construction.

The Bailey pony truss bridge, a bridge type designed to be easily moved, had been adopted in early 1941 as the standard military bridge. It was used extensively by allied forces throughout the European campaign and was also made in America. After the war, the military offered Bailey bridges for sale across the country through the War Assets Administration.

In the decades after World War II, the government made great strides in improving the country's road systems. This was prompted by the rapid growth of suburban development, increased traffic, and by the country's defense concerns. Such a massive effort led to increasing standardization of highway and bridge construction.

2.4.3 *New Technologies and Advances in Bridge Design*

The evolution of the preferred bridge materials from wood and iron to concrete and steel that began in the last quarter of the nineteenth century continued into the twentieth century. Bridge designs that best used those materials also evolved. Such designs advanced structural strength and durability, and sometimes also saved money.

The advent of the automobile resulted in the need for stronger bridges. In 1914, an Iowa writer wrote that “the structure that would be safe and sufficient ten years ago to carry the average load on the country road, would today be unsafe and inadequate. . . the average bridge or culvert today must have a carrying capacity of at least fifteen tons and the roadway over these structures must be wider than heretofore made” (18, p. E-16).

During the first 20 years of the century, bridge engineering was in an experimental stage, resulting at times in bridges that were over-engineered. But by the 1920s, highway bridge design had been elevated to the high standards of design, construction, and maintenance of railroad bridges, due both to the growth in the engineering profession and to government adoption of standardized bridge designs.

Below are highlights of standard design during this era, followed by a discussion of specialized bridges.

Standard Bridges. In the twentieth century, advances were made in the design of both concrete and steel structures. The state DOTs created standard plans for concrete and metal bridges using proven, up-to-date technologies. These designs were to be used on state highways and could also be used by the local (county or city) governments on local roadways.

Concrete: As previously discussed, the popularity of reinforced concrete bridges grew through the 1890s into the twentieth century. By 1904, Fritz von Emperger, pioneering concrete bridge designer, wrote that “ten years ago the number of concrete-steel bridges was so small that there would have been no difficulty in giving a complete list, whereas now it would be quite impossible to give such a list” (23, p. 12).

By the twentieth century, bridge engineers had fully liberated concrete bridges from dependence on the arch. The design innovations devised for concrete (with its counterparts in steel) replaced the truss bridge, the most popular nineteenth century

bridge type, as the standard American bridge (3, p. 328). They were described in publications as permanent, in that they purportedly required minimal maintenance, in contrast to the continual upkeep required for wood and metal trusses.

Throughout the country, reinforced concrete technology grew steadily through the first three decades of the twentieth century and became the dominant bridge type. The selling points of concrete were its durability and minimal maintenance, less reliance on the big steel companies, and they were touted as “more aesthetically pleasing and less visually intrusive in rural areas than metal truss bridges” (23, p. 12).

Bridge engineers James Marsh and Daniel Luten had a profound influence on reinforced concrete bridge design in the early twentieth century. During the 1920s and 1930s, Marsh’s engineering company was known primarily for its concrete arch bridges. His 1912-patented Rainbow Arch, which integrated steel and concrete into an arch, had a low construction cost and a high aesthetic value, factors that promoted its appeal. Luten established an extremely successful business building reinforced arched concrete structures, which were sold through several regionally-based construction firms. Bridge companies took advantage of Luten and Marsh’s success and designed and constructed their own design variations of the rainbow, closed spandrel, and open spandrel arches.

Better ways to calculate the amount of reinforcing bar and concrete needed to safely carry loads were being developed in the 1910s and 1920s. These calculations were used in the development of many of the state transportation departments’ standard plans of that period. In Virginia, for example, by the end of the 1910s, standard plans had been developed for the three most common non-arched concrete bridge types: slab, deck girder, and through girder (23, p. 13).

Because of the tremendous demand for roadway bridges in the 1920s and 1930s, reinforced concrete bridges, which could be quickly erected, were often the bridge of choice for highway department and local governments with tight budgets” (13, p. E-6). The popularity of concrete is demonstrated by several patents recorded during this period. By the 1930s and 1940s, concrete arch technology had advanced to allow much more delicate structures than had previously been built.

The first forty years of the twentieth century saw great improvements in concrete as a bridge construction material. Design innovations included concrete slab and girder (both 1898), continuous slab (1909), rigid frame (1922), T-beam and prestressed concrete (1937).

The concrete slab, simply a thick piece of concrete placed between two abutments, was commonly used for short-span bridges. To allow for longer spans, the continuous slab was first used in 1909. The structure carried a roadway over the railroad tracks in St. Paul, Minnesota. The first continuous slab for the railroad was built in 1913 on a design by the Union Pacific Railroad engineering staff.

While many nineteenth century wood, iron and steel structures were essentially girders, the concrete girder was not introduced into the United States until 1898. Girders

are solid beams that extend across a small-span crossing. By 1905, the simple concrete girder span appeared, in essentially the same form in which it has been used ever since (2, p. 38).

In the 1920s and 1930s, T-beam construction became the norm. New, standardized T-shaped beams, or “T-beams,” supplanted the deck girder, and had lighter, non-structural railings. These T-beam structures required considerably less concrete to build than either the slab or the girder.

In the 1920s, an innovation in concrete bridge construction was developed by Arthur Hayden, the concrete rigid frame. It was first used in Westchester County, New York, in the development of a comprehensive system of parkways and was important as a cost-saving design. Between 1922 and 1930, 74 rigid frame structures were built on the Westchester County parkway system. Since then prestressing has largely superseded the rigid frame, but the development of the rigid frame is recognized as an important step in the evolution of bridge engineering.

Prestressing of concrete was developed by Eugene Freyssinet who, according to author Thomas Hayden, “made enormous contributions to the ideas and practice of bridge making in concrete” (14, p. 137). While he developed the concept early in the twentieth century, it was not until 1930 that Freyssinet’s method was used in the United States, at the Rogue River Bridge at Gold Beach, Oregon. In concrete that is not reinforced, the material comes under no stress until the forms are removed during construction. Freyssinet introduced stress into the concrete before the point at which stress had previously been introduced, stresses that would counteract those in the completed bridge structure. According to Hayden, “the implications of Freyssinet’s techniques have been enormous, and have led to pre-stressed concrete being used for cast numbers of the short and medium spans necessary in the construction of modern motorways” (13, p. 138). Pre-stressing allowed concrete bridge parts to be mass-produced at the factory, instead of at the site. It also allowed improvements in quality and cost control since “such construction used at least 70 percent less steel and between 30 and 40 percent less concrete than ordinary reinforced concrete” (14, p. 138).

Steel: The innovations of the late nineteenth century in bridge construction, such as field riveting and the use of steel, were refined in the early twentieth century. By that time, steel had clearly supplanted iron as a structural material for bridges and, in 1911, the first national standards for reinforcing steel were implemented.

Of course, steel was used during this era as a reinforcing material for concrete bridges, but steel bridges were also built. Between 1890 and 1925, the Pratt truss was basically the standard American bridge form. The Warren truss, more refined and economical in its use of materials, superseded the Pratt and has been the most common truss form since the late 1920s. Plowden stated that the “swan song” for the Pratt truss, was the “Big Four” railroad bridge over the Ohio River at Louisville, Kentucky, the last major bridge to use this form (3, p. 236).

Steel was also commonly used for girder bridges, which are formed by riveting together large steel plates. During this period, suspension bridges, the type of bridge that can be built economically for wide spans, were built with steel towers, as were moveable bridges.

Specialized Bridges: As discussed previously, standard plans were developed by state DOTs, for both concrete and steel structures. These designs were utilized on the state highway systems and likely also by the counties for bridge crossings. However, long crossings, locations for which aesthetics were important, and crossings that needed a movable structure required the development of a special bridge design.

The railroads designed and built very long structures, such as the 48-arch 1902 Rockville Bridge over the Susquehanna River and the 1915 Tunkhannock Viaduct in northeastern Pennsylvania. Both were built through massive improvement programs; the former is the world's longest concrete and masonry arch bridge, while the latter is the largest all-reinforced concrete bridge.

Enormous steel arches were designed and built in the first quarter of the twentieth century. An example is the 1917 Hell Gate Bridge, built for the New England Connecting Railroad across the Hell Gate at the northern tip of Manhattan. Designed by Gustav Lindenthal, the bridge is a two-hinged truss arch, which, when built, was the longest and heaviest steel arch in the world.

The designs for movable bridge structures were also being advanced and records were being set on their sizes. In the thirteen years between 1914 and 1927, the world's longest double-leaf bascule (the 1914 Canadian Pacific Railroad Bridge in Sault-Sainte Marie, Michigan); the longest single-leaf bascule (the 1919 Saint Charles Airline Railway Bridge in Chicago); and the longest single-span swing bridge (the 1927 Atchison, Topeka and Santa Fe Railroad Bridge over the Mississippi River at Fort Madison, Iowa) were all built.

In May 1937, the Golden Gate Bridge opened in San Francisco. For twenty-seven years, the bridge stood as the world's longest span, and while its aesthetics were criticized by some, according to author Martin Hayden, "the bridge was a triumph, a symbol, once again, of man's mastery over nature and that particularly American belief that technology could cope with anything" (14, p. 122).

In 1940, the four-month old Tacoma Narrows Bridge over Puget Sound collapsed due to the forces of the wind on the suspension structure. The event led to intense research on the dynamics of the effects of wind in large structures. The collapse coincided with the outbreak of World War II and the construction of large suspension bridges came to a standstill. The massive suspension bridges built after World War II, in the 1950s and generally shortly after the end date for the period addressed in this report, were based on substantial research that produced new formulae and standards for truss-stiffened suspension spans.

2.4.4 *Concern with Aesthetics*

Aesthetics became a much more important facet of bridge design and selection for bridges in the twentieth century. The Melan bridge type was ideally suited for the ‘memorial’ bridge, which sprang up in numerous cities in the United States. The great majority of these were built in cities as replacements at some of the more prominent crossings for trusses, which some perceived at the time as “unattractive.” A well-known example was the Memorial Bridge completed in 1900 across the Potomac in Washington, DC.

In the early twentieth century, these bridges often reflected the Beaux Arts Style of the City Beautiful movement and were either concrete copies of stone construction or were concrete bridges sheathed in stone. Author Martin Hayden wrote that “these bogus structures satisfied the aesthetic requirements of the turn of the century and cost much less to build than an all-stone bridge, despite the excessive ornamentation some of them received” (14, p. 306).

Engineer J.A.L. Waddell wrote in the early twentieth century that “there is little excuse for building an ugly concrete bridge” (11, p. E-20). At first, bridge designers, who had little experience in concrete structures, left the surface plain. After a few years of working in concrete, these engineers became more creative, creating decorative features in concrete.

In the 1930s, a report of the Nebraska transportation department stated that “bridges should be given architectural treatment to the end that their appearance would be in harmony with the general scheme of beautification attempted by the average mid-western city” (11, p. E-29). Aesthetic concerns such as these led to widespread use of the rigid frame bridge, a monolithic, flat-arch style of reinforced concrete or steel with concrete facing. Developed by New York’s Westchester County Park Commission in the early 1920s, the style was felt to be both picturesque and practical.

As discussed in the Great Depression section, Depression-era bridge designers often considered aesthetic appeal in the bridges they designed and built. Artists were likely involved in the design of the many attractive bridges that the WPA built in parks and urban areas.

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3.0 HISTORIC CONTEXT FOR COMMON HISTORIC BRIDGE TYPES

This Chapter presents the historic contexts for the most common bridge types extant in the United States today. A “common historic bridge type,” as defined for the purposes of this study, will possess all of the characteristics below.

- 1) It is *Common*: a bridge type that is prevalent, i.e., the type is widely represented in extant examples throughout the regions of the United States. (As the discussions of the individual bridge types in this chapter indicate, some types are much less common than others.)
- 2) It is *Historic*: a type of bridge that meets National Register of Historic Places (NRHP) criteria for evaluation of significance, as outlined in the National Register Bulletin, *How to Apply the National Register Criteria for Evaluation*. This includes types that are more than fifty years of age as of 2005. The date of 1955 was selected as the cut-off date for this study because it covers the period up to the passage of the Federal Aid Highway Act of 1956, which established the Interstate System and which permanently changed highway planning and design. (Since there are few NRHP-eligible or listed examples of types that have developed since 1955, they are not considered both historic and “common.”)
- 3) It is a *Bridge Type*: the primary determinate of “type” is the “form,” or manner in which the structure functions. A bridge type is not defined strictly according to materials; method of connection; type of span; or whether the majority of the bridge structure exists above or below the grade of travel surface. (Some patented or proprietary systems are listed in the most common bridge types listed below due to the importance of that system, even though the actual type is covered by a separate “type” designation.)

The list below presents the bridge types that have been identified as both common and historic, using the methodology presented in Chapter 1. They are arranged essentially by categories and then by type, but some types may fit into more than one category. Within each category, the Study Team attempted, when possible, to arrange the types chronologically. The 46 most common historic bridge types discussed in this study are listed below.

CATEGORY 1: TRUSS

- King Post Truss
- Queen Post Truss
- Burr Arch Truss
- Town Lattice Truss
- Howe Truss
- Bowstring Arch Truss
- Pratt Truss
- Whipple Truss
- Baltimore Truss

- Parker Truss
- Pennsylvania Truss
- Warren Truss
- Subdivided and Double-Intersection Warren Truss
- Ventricular Truss

CATEGORY 2: ARCH

- Stone Arch
- Reinforced Concrete Melan/von Emperger Arch
- Reinforced Concrete Luten Arch
- Reinforced Concrete Marsh or Rainbow (Through) Arch
- Reinforced Concrete Closed Spandrel Arch
- Reinforced Concrete Open Spandrel Arch
- Steel Tied Arch
- Reinforced Concrete Tied Arch
- Steel Hinged Arch
- Reinforced Concrete Hinged Arch

CATEGORY 3: SLAB, BEAM, GIRDER & RIGID FRAME

- Timber Stringers
- Reinforced Concrete Cast-In-Place Slabs
- Reinforced Concrete T Beams
- Reinforced Concrete Channel Beams
- Reinforced Concrete Girders
- Reinforced Concrete Rigid Frames
- Reinforced Concrete Pre-Cast Slabs
- Pre-stressed Concrete I-Beams
- Pre-stressed Concrete Box Beams
- Metal Rolled Multi-Beams
- Metal Built-Up Girders
- Metal Rigid Frames

CATEGORY 4: MOVABLE SPANS

- Center-Bearing Swing Span
- Rim-Bearing Swing Span
- Vertical Lift Span
- Simple Trunnion (Milwaukee, Chicago) Bascule Span
- Multi-Trunnion (Strauss) Bascule Span
- Rolling Lift (Scherzer) Bascule Span

CATEGORY 5: SUSPENSION

CATEGORY 6: TRESTLES AND VIADUCTS

CATEGORY 7: CANTILEVERS

For each bridge type, the text in this chapter includes a brief history of the type's development; a description of the type and subtypes; identification of the period of prevalence; and a statement of each type's significance within the context of the most common bridge types identified in this study. This significance evaluation is geared toward the engineering significance of the bridge types, that is, National Register of Historic Places (NRHP) Criterion C.

The evaluation describes the “character-defining” features of each type, i.e., structural elements that are key to conveying the structure's type and construction era. The significance assessment has been derived by the Study Team through consulting numerous historic bridge context studies and comprehensive bridge survey reports and through their cumulative knowledge of historic bridges.

Study users desiring to evaluate a historic bridge can use the guidance presented in this study, but must also consider a structure within its local or state context. Such information is available in comprehensive bridge surveys and the historic bridge contexts that have been prepared by many states. In this study, within the context of the most common historic bridge types in the United States, if a type or subtype is denoted as *highly significant*, it will likely be eligible for the NRHP if it retains a high or medium level of integrity. If a type or subtype is noted as *significant*, it may be eligible for the NRHP if it retains a high level of integrity. Types or subtypes that have moderate significance would need to have a very high level of integrity and may need added elements of significance to be considered NRHP eligible. Example of elements that may increase the significance of a bridge within the context presented in this report, include association with an important designer or historic event. Types or subtypes labeled as having low significance are very common types that either played no important technological role in the context of this study or bridges that are more recent and their relative significance cannot yet be determined because of the limited scholarship on these types.

Study users must also make determinations of bridges that are within NRHP eligible historic districts. For these determinations, its level of significance as presented in this report will not be a deciding factor. If the bridge fits within a district's period of significance and generally retains its character-defining features, it is likely to be considered as “contributing” to the district and thus, NRHP eligible as a contributing element of the district.

Examples of each type are provided; the examples are either listed in or eligible for the NRHP or recorded for the Historic American Engineering Record (HAER). Documentation for the NRHP listed examples is available at the respective State Historic Preservation Offices or at the Office of the Keeper of the Register in Washington, DC. The determined eligible examples may also be accessed at the Shops or the transportation departments of the respective states. Often, the comprehensive bridge survey findings of the various states are used as their NRHP Determinations of Eligibility. The HAER documents are available at The Library of Congress in Washington, DC and can be accessed on-line at http://memory.loc.gov/ammem/collections/habs_haer/hhquery.html.

Appendix A provides links to online copies of a number of NRHP historic contexts and multiple property submittals, which provide a wealth of information.

Photographs are included for all of the bridge types, primarily from the HAER collection, and drawings accompany some of the types.

Figure 3-1 illustrates some of the bridge member shapes that comprise the numerous bridge types described in this report. Appendix B contains a copy of *Bridge Basics*, taken from <http://pghbridges.com>, and used with the gracious permission of Bruce Criddlebaugh, creator of the pghbridges website, “Bridges and Tunnels of Allegheny County and Pittsburgh, PA.” This is a very helpful website. Appendix C contains a copy of *Trusses, A Study by the Historic American Engineering Record*, provided for use in this document by staff of the National Park Service/HAER.

3.1. Trusses

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

Truss bridges are usually differentiated by the location of the deck or travel surface in relation to the rest of the superstructure. In a pony truss the travel surface passes between trusses on either side that constitute the superstructure. These trusses are not connected above the deck, and are designed to carry relatively light loads. In a through bridge the travel surface passes through the superstructure, which is connected with overhead lateral bracing above the deck and traffic surface by cross bracing. Through trusses are designed to carry heavier traffic loads than the pony truss and are longer in span, some approaching 400 feet. In a deck truss, the superstructure is entirely below the travel surface of the truss, and the traffic load is carried at or near the level of the top chord. Like the through truss, deck trusses can be designed to carry relatively heavy traffic loads and can have fairly long spans.

Metal truss bridges may also be differentiated by the method of connecting the structural members. The oldest examples were connected by pins. Riveted connections proved to be more stable than pin connections, which were prone to wear at the point of connection. In the twentieth century, welding became a common method of joining structural members.

Refer to Appendices B and C for additional information and drawings of truss types.

In this section on trusses, the first five truss types are commonly found in wood covered bridges, while the last nine are commonly found in metal spans. Figure 3-2 depicts three basic types of truss configurations.

Figure 3-1. Basis shapes of bridge members. From *Bridge Inspector's Training Manual*, U.S. Department of Transportation, 1991.

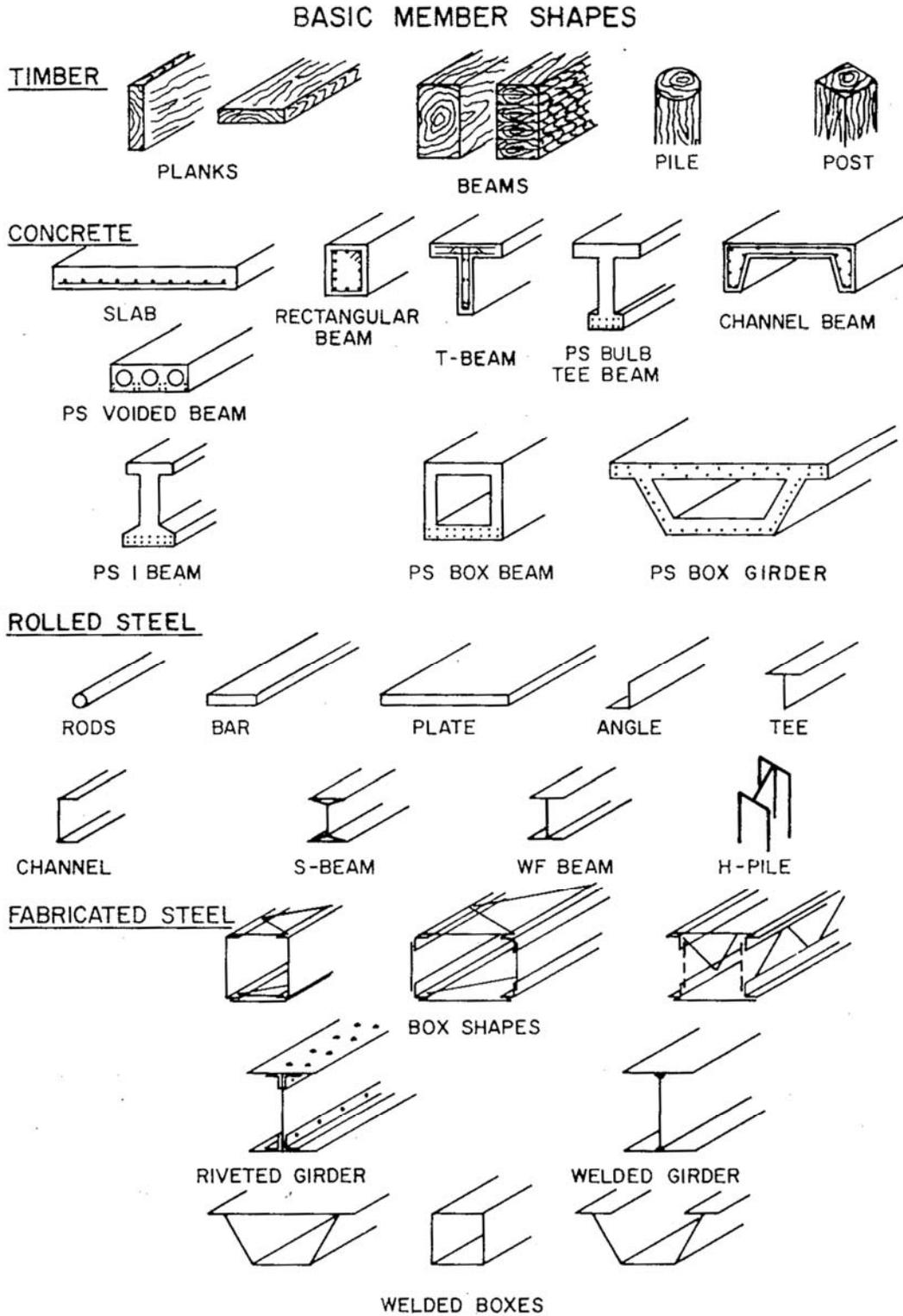
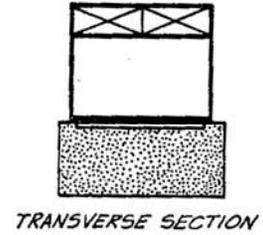
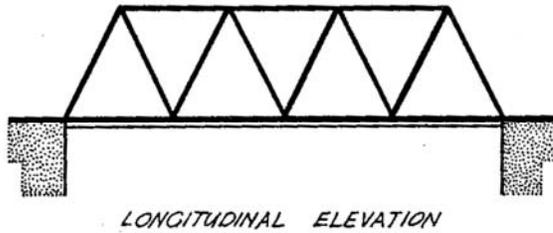
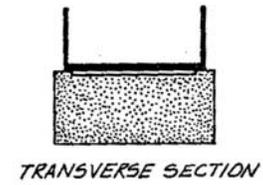
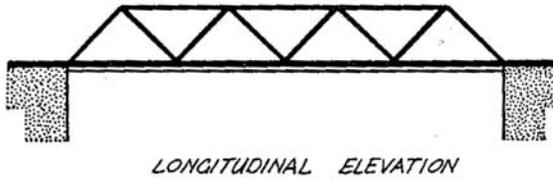


Figure 3-2. Three basic types of truss configurations. From Historic American Engineering Record, National Park Service.

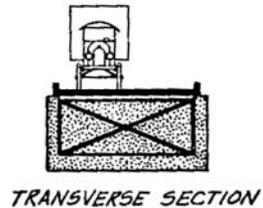
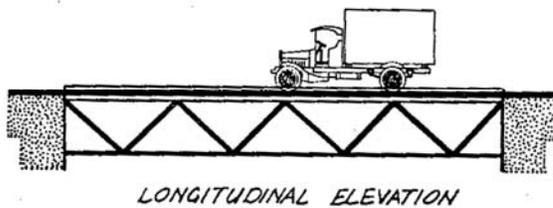
TRUSS BRIDGES



THROUGH TRUSS



PONY TRUSS



DECK TRUSS

3.1.1 King Post Truss

History and Description: The king post form dates from Medieval times, if not earlier. It served as the framework for the basic gable roof. The multiple king post dates from the Renaissance and was first illustrated by Palladio in his classic, *I Quattro Libri dell'Architettura*. After Isaac Ware translated this book into English in 1738, the book was widely distributed and the king post truss came into wide usage.

The king post (or kingpost) truss, the simplest of all truss designs, is now commonly found in covered wood bridges. It is not amongst the most common of the types discussed in this study, but is included because it is derivative. Most of the rectilinear trusses evolved from the king and queen post forms (discussed in Section 3.1.2). The simple form king post truss can be found on country roads or in parks, but it is most commonly found as a multiple kingpost in covered bridges. In the United States, the earliest multiple kingposts were the exposed timber frame bridges built in the first few decades of the nineteenth century by builders such as Timothy Palmer and Theodore Burr. Burr combined the multiple kingpost with the arch resulting in bridges of even longer spans.

The king post truss is usually constructed of heavy timbers that form three sides of an isosceles or equilateral triangle, with a metal vertical tie rod or wood post (the king post) extending from the middle of the lower chord supporting the travel surface to the apex of the two diagonal timbers; however, some examples were built with main structural members of metal.

When used in bridge construction, the king post truss could be constructed with the main diagonals above or below the travel surface. Simple king post trusses were used only to span very short distances up to about 30 feet, but occasionally a series of king post trusses were combined to form a long timber bridge. Although the king post truss was often built without any covering or housing, the most common extant king post truss bridges are covered by a roof and siding to protect them from the weather.

A good example of an extant metal king post truss bridge is Bridge No. 1482 (1908), which was moved to its present location in Rock County, Minnesota, in 1990. This bridge has diagonal braces, which make it similar to the Waddell “A” truss. The Waddell “A” truss is a version of the king post truss with diagonal bracing between the main diagonal members and the lower chord, with a vertical tie or strut from the apex of the top members to the middle of the lower chord, and sub verticals from the intersection of the sub-diagonals to the lower chord. Only one Waddell “A” truss in its original location is known to survive in the United States; a span on the Kansas City Southern Railroad Cross Bayou Bridge (1927) near Spring Street in Shreveport, Louisiana.

The multiple king post bridge is essentially composed of a king post truss in the center with multiple panels to either side formed by vertical posts with diagonal counters matching the angle of the diagonals in the center truss, and a horizontal upper chord that is parallel with the lower chord. Three good extant examples are the Blacksmith Shop

Covered Bridge (1881) and the Dingleton Hill Covered Bridge (1882), both over Mill Brook in the town of Cornish, New Hampshire; and the Humpback Covered Bridge over Dunlap Creek in the vicinity of Covington, Virginia.

Below are NRHP listed or eligible and/or HAER-recorded examples of the king post truss type.

Significance Assessment: Few wooden bridges survive from the first decades of the nineteenth century so most bridges of this type will date from the 1840s and 1850s, when other truss forms, such as the Pratt and Warren, supplanted them. However, multiple kingposts persisted until the 1880s.

The king post truss is one of the less common types of the 45 types in this study. King post trusses from the 1840s and 1850s, if they retain their character-defining features, would be considered significant within the context of this study. The character defining features are the structure's triangular shape (either an isosceles or equilateral triangle) and a metal vertical tie rod or wood post (the king post) subdividing the triangle.

Intact late nineteenth century examples of the multiple king post are also considered significant. Twentieth century examples would possess less significance within the context of this study, but examples of king post bridges from this era have been identified as significant, particularly through the Section 106 process and subsequent HAER recordation as a mitigative strategy for proposed demolition.

Examples of King Post Truss

1. Crooks Bridge (1856), Parke County, IN. NRHP listed 1978.
2. Stony Brook Covered Bridge (1899); Washington County, VT. NRHP listed 1974.
3. Waddell "A" Truss Bridge (1898), Originally spanning Lin Branch Creek, Trimble vicinity, Clinton County, MO, moved to Parkville, MO. HAER MO-8.
4. Battle Creek King Post Truss Bridge (circa/ca. 1900), Phillips County, KS. NRHP listed 2003 in Metal Truss Bridges in Kansas 1861-1939 Multiple Property Submittal (MPS).
5. Neal Lane Bridge (1939), Douglas County, Oregon. HAER OR-126.
6. Chow Chow Suspension Bridge (Ca. 1950), spanning Quinault River, Taholah vicinity, Grays Harbor County, WA (Quinault Indian Reservation). HAER WA-51.
7. Humpback Covered Bridge (1857) over Dunlap Creek, Covington vicinity, Allegany County, VA. HAER VA-1.
8. Philadelphia & Reading Railroad, Walnut Street Bridge (no date/n.d.), spanning Reading main line at Walnut Street, Reading, Berks County, PA. HAER PA-119.
9. Bridge over New Fork River (1917), Sublette County, WY. NRHP listed 1984 in Vehicular Truss and Arch Bridges in Wyoming MPS.

Figures 3-3 through 3-5 provide a drawing and examples of the single and multiple kingpost truss.

Figure 3-3. Elevation drawing of king post truss.

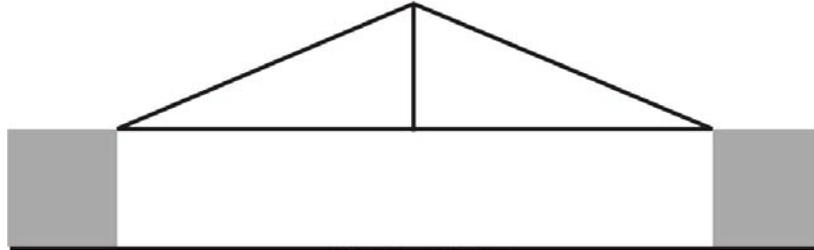


Figure 3-4. Philadelphia & Reading Railroad, Walnut Street Bridge (n.d.) spanning Reading main line at Walnut Street, Reading, Berks County, Pennsylvania. This bridge is an example of a single king post truss.



3-4a. Elevation view.



3-4b. Oblique through view.

Figure 3-5. Humpback Covered Bridge (1857), Humpback Bridge spanning Dunlap Creek, Covington vicinity, Alleghany County, Virginia. This bridge is a good example of a multiple king post used for a covered bridge.



3-5a. *Oblique view.*



3-5b. *Interior view shows king post truss in the center (shown by arrow) with multiple panels to either side formed by vertical posts with diagonal counters matching the angle of the diagonals in the center truss, and a horizontal upper chord that is parallel with the lower chord.*

3.1.2 *Queen Post Truss*

History and Description: Like the king post, the queen post (or queenpost) truss dates to the medieval era, if not earlier. The queen post truss may be thought of as a king post truss lengthened by the addition of a horizontal top chord member, thus creating a rectangular panel between the two triangles that face the center king post in the king post design. Because the rigidity of the center panel suffers without bracing, the middle floor beam was sometimes supported by a tensile member extending from the middle of the top chord, by braces between the corners of the middle panel, or by a pier under the middle of the span. This design enabled the construction of greater span lengths than possible with the king post truss. As with the king post truss bridge, metal versions of the queen post truss were constructed, but extant examples are usually of wood and most are covered. The metal queen post was superseded by the Pratt truss, which was very similar visually but very different in scale and function due to the incorporation of diagonal cross-bracing to handle forces in tension.

Significance Assessment: As illustrated in the examples above, the queen post truss was used through the nineteenth century (primarily the second half) and into the twentieth century. The queen post was a simple, easy-to-frame form that economically addressed the need for short spans of 30 to 40 feet.

Like the king post, the queen post is among the least common of this study's 45 common bridge types. The character-defining feature of the queen post truss is its form, a rectangular center panel with a parallel top and bottom chord, which is flanked by triangular panels with inclined end posts. Queen post trusses from the Antebellum period, if they retain their character-defining features, would be considered significant within the context of this study. Intact late nineteenth century examples of the queen post truss are also considered significant. Twentieth century examples would possess less significance within the context of this study, but examples of queen post bridges from this era have been identified as significant, particularly through the Section 106 process and subsequent HAER recordation as a mitigative strategy for proposed demolition.

Examples of Queen Post Truss

1. Greenbanks Hollow Covered Bridge (1886), Caledonia County, VT. NRHP listed 1974.
2. Copeland Covered Bridge (1879), Saratoga County, NY. NRHP listed 1998.
3. Jediah Hill Covered Bridge (1850, rebuilt in 1956 and 1981), Hamilton County, OH. NRHP listed 1973.
4. North Fork of the Yachats Bridge (1938), Lincoln County, OR. NRHP listed 1979 in Oregon Covered Bridges Thematic Resource Nomination.
5. Mercer County Bridge No. 2631 (circa/ca. 1894), spanning Pine Run at Cribbs Road, Mercer vicinity, Mercer County, PA. HAER PA-225.
6. Hortense Bridge (1880), spanning Chalk Creek on State Highway 162, (1880) Nathrop vicinity, Chaffee County, CO. HAER CO-49.

7. Zurich Road Bridge (1920s, 1940s), spanning Southern Pacific, Chicago & St. Louis Railroad, Joliet vicinity, Will County, IL. HAER IL-130.

Figures 3-6 through 3-8 provide a drawing and photographs of examples of the queen post truss.

Figure 3-6. Elevation drawing of queen post truss.

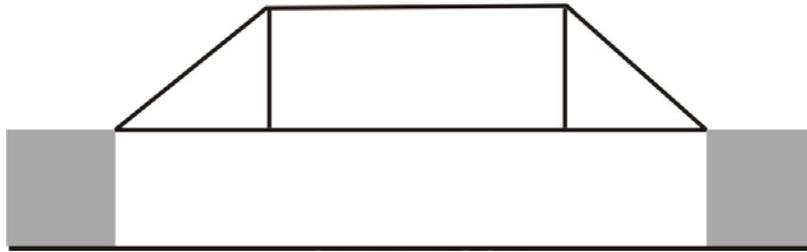


Figure 7. Hortense Bridge, spanning Chalk Creek on State Highway 162 (1880), Nathrop vicinity, Chaffee County, Colorado. This bridge is an example of a queen post truss built by Denver South Park & Pacific Railroad.



Figure 8. Mercer County Bridge No. 2631 (ca. 1894), spanning Pine Run at Cribbs Road, Mercer vicinity, Mercer County, Pennsylvania. This small structure is a late nineteenth century metal queen post truss.

3.1.3 Burr Arch Truss

History and Description: In 1804, Theodore Burr (1771-1822) built a four-span truss bridge with additional arch segments over the Hudson River between Waterford and Lansingburg (now part of Troy), New York. By pegging the arch ribs to the truss, the entire bridge was stiffened throughout its length. This bridge, considered to be Burr's masterpiece, was destroyed by fire in 1909. It is often described as a combination multiple king post truss and arch design, but in fact it had two diagonals in each panel. This arrangement was also illustrated in the Burr patent of 1817, although in practice the Burr arch was usually expressed with a single counter in each panel. The type of truss used was the most variable element in Burr's designs, and not all were of the multiple king post truss type. It was the combination of an arch rib with a truss that was the defining characteristic of the Burr arch. This bridge type was used extensively on highways and railroads primarily during the middle of the nineteenth century. It was suitable for span lengths of approximately 100 to 120 feet.

Significance Assessment: Theodore Burr created a highly successful timber truss system whose most important characteristic, compared to other truss types, was its stiffness. It was used throughout the 1850s, though some examples date from the late nineteenth century, such as the 1892 Raystown Covered Bridge. The Burr arch is considered amongst the highest developed of all-wood bridge types. Today, it is commonly found in wood covered bridges in many regions of the country, particularly in the eastern United States.

Examples of nineteenth century Burr arch bridges are considered significant within the context of this study if they retain their character-defining features. The combination of an arch rib with a truss, the attachment of the arch rib to the truss with pegs, the parallel top and bottom chords of the truss, and the verticals and diagonal members are the primary character-defining features of the Burr arch truss. They may or may not be covered. The roofing and/or exterior covering of a covered Burr arch truss is of secondary importance, since in most, if not all cases, these features are modern replacements. No twentieth century examples of this bridge type were identified during the study process.

Examples of Burr Arch Truss

1. Forksville Covered Bridge (1850), Sullivan County, PA. NRHP listed 1980 in Covered Bridges of Bradford, Sullivan and Lycoming Counties Thematic Resource Nomination.
2. Quinlan's Covered Bridge (1849), Chittenden County, VT. NRHP listed 1974.
3. Perrine's Covered Bridge (1844), Ulster County, NY. NRHP listed 1973.
4. Bridgeton Bridge (1868), Parke County, Indiana. NRHP listed 1978
5. Utica Covered Bridge (ca. 1850), Frederick County, MD. NRHP listed 1978 in Covered Bridges in Frederick County Thematic Resource Nomination.

6. Raystown Covered Bridge (1892), Township Route 418 spanning Raystown Branch, Manns Choice vicinity, Bedford County, PA. HAER PA-351.

Figures 3-9 and 3-10 provide a drawing and an example of the Burr arch truss.

Figure 3-9. Elevation drawing of Burr arch truss.

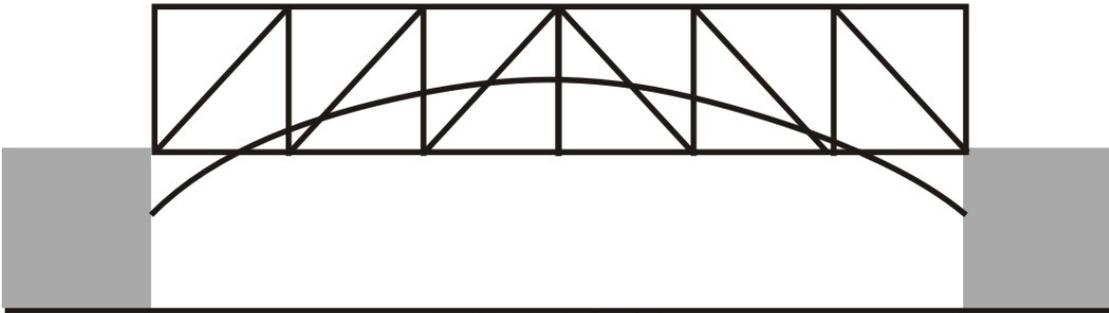


Figure 3-10. Raystown Covered Bridge (1892), Township Route 418 spanning Raystown Branch, Manns Choice vicinity, Bedford County, Pennsylvania. The uncovered sides of this structure reveal the Burr arch.



3.1.4 Town Lattice Truss

History and Description: Connecticut architect Ithiel Town (1784-1844) patented the Town lattice truss in 1820. This type of truss has intersecting diagonals forming a web between the top and bottom chord with no verticals or posts. The diagonals act in compression and in tension. Whereas earlier wood truss designs had relied upon heavy timbers connected with mortise-and-tenon joints, the Town lattice truss used planks cut to standard sizes, connected by round wood pins called “trenails.” Due to the lack of posts and the thinness of the original web design, however, this type was subject to increased twisting of the truss as the length increased. To improve on his design, Town patented a double lattice version featuring a heavier web in 1835 (*I*, p. 40). Town’s system had a number of very appealing features: no preparatory labor; no large timbers or intricate joints; no straps or ties of iron; connections that could all be made with trenails; and chord and web members that could all be made from members of the same size (usually 4-inch x 10-inch planks).

The Town lattice truss was relatively easy to erect and suitable for spans in excess of 200 feet. The longest wood covered bridge in the United States and the longest two-span covered bridge in the world is a Town lattice truss, the Cornish-Windsor Bridge between Cornish, New Hampshire, and Windsor, Vermont. It has a total length slightly in excess of 449 feet, with one span of 204 feet in length and another span of 203 in length. The American Society of Civil Engineers (ASCE) declared it a National Historic Civil Engineering Landmark in 1970.

The type was used extensively for aqueducts, highways, and railroads. The definitive work on the Town lattice is Gregory Dreicer’s dissertation “The Long Span, Intercultural Exchange in Building Technology: Development and Industrialization of the Framed Beam in Western Europe and the United States, 1820-1870,” Cornell University, 1993. It is unknown who, Ithiel Town or a European, first developed the lattice truss (it was known as a trellis in Europe). There is evidence, however, that the Town lattice was taken back to Europe in the mid-1850s and was promoted for use on European railways in iron. Plowden (*I*, p. 40), however, states that the metal lattice truss was invented in Europe and widely used there before appearing in America.

The Town lattice truss is also associated with an important development in business practice as the first bridge design for which licensees wishing to use the type had to pay a royalty to the patent holder. This practice came to dominate iron bridge building a half century later.

Significance Assessment: Most Town lattice trusses are found in wooden covered bridges dating from the 1840s up until the 1870s. In its metal form used by the railroads, bridges would have been built as early as the 1850s, but surviving examples date primarily from the 1890s. Iron and steel lattice trusses for vehicular use are less common. The Upper Bridge at Slate Run, Lycoming County, Pennsylvania, is a wrought iron lattice truss in vehicular service, built by the Berlin Iron Bridge Company, and dating from 1890.

Wooden Town lattice trusses dating from the 1840s up to the period immediately following the Civil War are significant within the context of this study if they retain their character-defining features. The primary character-defining features of this truss are the lattice configuration of the truss (intersecting diagonals forming a web between the top and bottom chord with no verticals or posts), parallel top and bottom chords, end posts and trenail connections. Town lattice trusses may or may not be covered. The roofing and/or exterior covering of a covered Town lattice truss is of secondary importance, since in most, if not all cases, these features are modern replacements. Early metal examples from the Antebellum period are not common and, if intact, would be considered highly significant. Late nineteenth century examples, whether built for the railroad or vehicular use, are more common than the earlier examples, but are still considered significant.

Examples of Town Lattice Truss

1. Cooley Covered Bridge (1849). Rutland County, VT. NRHP listed 1974.
2. Mull Road Covered Bridge (1851). Sandusky County, OH. NRHP listed 1974.
3. Eagleville Covered Bridge (1858). Washington County, NY. NRHP listed 1978.
4. Ashuelot Covered Bridge (1864), Chesire County, NH. NRHP listed 1981.
5. Ashland Covered Bridge (1870), Red Clay Creek-Barley Mill Road, Ashland, New Castle County, DE. NRHP listed 1973. HAER DEL-162.
6. Upper Bridge at Slate Run (1890), spanning Pine Creek at State Route 414, Slate Run vicinity, Lycoming County, PA. HAER PA-460.
7. Cornish-Windsor Covered Bridge (1866), spanning Connecticut River, Bridge Street, between, Cornish, Sullivan County, New Hampshire and Windsor, Vermont. National Civil Engineering Landmark.

Figures 3-11 and 3-12 provide a drawing and an example of the Town truss.

Figure 3-11. Elevation drawing of the Town lattice truss.

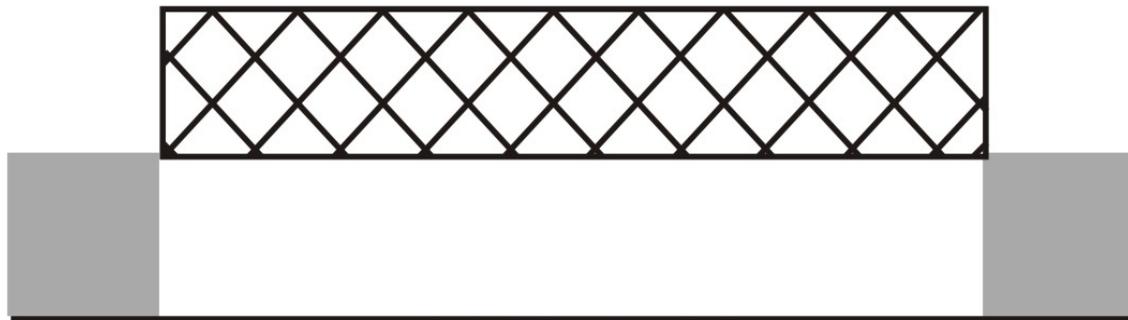


Figure 3-12. Cornish-Windsor Covered Bridge (1866), spanning Connecticut River, Bridge Street, between, Cornish, New Hampshire and Windsor, Vermont. This National Civil Engineering Landmark bridge is an example of the Town lattice truss.



3-12a. Three-quarter view of Cornish-Windsor covered bridge.



3-12b. Interior view of Cornish-Windsor covered bridge showing the intersecting diagonals that form a web between the top and bottom chords.

3.1.5 *Howe Truss*

History and Description: First patented by Massachusetts millwright William Howe (1803-1852) in July and August of 1840, the Howe truss featured heavy wood diagonal members in compression and lighter, vertical iron members in tension. The use of iron to stiffen parallel chord trusses had been used in Europe as early as 1823, but there is no evidence that Howe knew of this precedent. The use of threaded, adjustable iron tension members, secured at the ends by nuts, was the main difference between the Long truss and the Howe truss. This feature made Howe the first bridge designer to devise a method of adjusting a wood truss, the members of which have the tendency to pull apart under live loads and shrinkage (*I*, p. 57).

Howe arrived at a simple, elegant solution to a problem that had confounded several generations of wooden bridge builders, the solution to joining in tension two wooden members. The classic weakness of a timber truss is not the individual members, but the connections. Tension connections proved particularly difficult to detail to insure minimum joint movement and maximum efficiency in transferring tensile loads to a joint. The genius of the Howe system is that the timber verticals, which pose the most difficult problem in forming an effective connection, were neatly replaced with an iron rod. Eliminating the complex mortise and tenon connection simplified the work of millwrights, resulting in a truss that was not only easy to erect, but could be adjusted and parts replaced while remaining in service.

Like the king post truss, the Howe truss was apparently first used as a roof truss, appearing in a church in Brookfield, Massachusetts. Its first use in bridge construction was in 1838 on the Western Massachusetts Railroad (later the Boston and Albany Railroad) over the Quaboag River in Warren, Massachusetts. In 1839, Howe hired his brother-in-law, Amasa Stone, Jr., as a foreman to oversee construction of several buildings in Warren, Massachusetts. When Howe later won a contract with the Western Railroad Company to bridge the Connecticut River at Springfield using his newly patented truss design, he hired Stone to assist in supervision of bridge construction (2). In 1841, Howe revised his patent of the previous year by reducing the diagonals to two in each panel (3, p. 61). Soon thereafter, Stone purchased the rights to build the Howe truss in New England and set up a bridge building company with Azariah Boody in 1842 to market the design. In August 1846, Howe won an additional patent for a timber arch design that he hoped would make his basic truss more widely adaptable for use by the railroads.

In 1847, the first company set up by Howe and Stone was reorganized, with Stone retaining the southern New England rights and younger brother Andros claiming the remainder. Along with Boody, Andros established the Stone and Boomer bridge-building partnership with Lucius Boomer of Chicago, Illinois. That company built a large number of Howe trusses for railroads in Illinois, Wisconsin and Missouri, but not always with success. A Stone and Boomer-built Howe truss bridge erected over the Gasconade River in Missouri collapsed in 1855, killing forty-three people and injuring another seventy, including some of the most prominent citizens of St. Louis. The

following year, the partners also built the first railroad bridge across the Mississippi River, which was located between Davenport, Iowa, and Rock Island, Illinois. Howe trusses were a prominent feature of this bridge, which was widely reviled by steamboat interests as a hazard to navigation until it burned down shortly after completion.

The Howe truss marked the beginning of the transition from wood to iron as a material for bridge construction, but attempts to express the design in iron structures often met with disaster. In 1876, a cast and wrought iron Howe truss bridge designed by Amasa Stone and built in 1865 at Ashtabula, Ohio, collapsed, killing 85 people. An investigation by the ASCE condemned combination cast and wrought iron bridges in favor of all wrought-iron designs, but the real problem may have been the unsuitability of the Howe truss for all-metal construction.

Bridge scholars generally agree that the wood Howe truss was the crowning achievement of the wood bridge era, and Howe's patent was probably the most profitable wood truss patent ever granted due to the popularity of the type with railroads during a period of great expansion of the nation's rail network. The Howe truss became the most widely used wood type for railroad use and dominated the bridge-building industry until all-iron bridges gained greater popularity in the 1850s. The Howe truss is commonly found in covered bridges in several states. For example, it is by far the most represented type among the covered highway bridges of Oregon.

Significance Assessment: The Howe truss, a composite truss of wooden diagonal compression members, iron junction boxes, and threaded vertical wrought-iron rods to carry tension, was the dominant bridge type during the transition of bridge building materials from wood to iron. As stated above, the Howe truss is considered the crowning achievement of the wooden bridge era and the most profitable bridge patent ever granted. The Howe truss also represents the beginning of the transition from wood to iron.

The Howe truss became the most popular bridge for railroads in American until the appearance of the all-metal bridges in the 1840s and 1850s. Thousands were built until the all-iron truss curtailed its popularity. Highly significant within the context of this study are examples of the Howe truss railroad bridges from the early development period, the 1840s and 1850s, as they are less common and are significant in the evolution of bridge building technology associated with the railroads and with the transition from timber to iron. Wooden Howe truss covered bridges of the second half of the nineteenth century and the first quarter of the twentieth century are relatively common, but are considered significant within the context of this study if they retain their character-defining features. The Howe truss featured heavy wood diagonal members in compression and lighter, vertical iron members in tension. The intersecting wood diagonal members, the vertical metal rods, the parallel top and bottom chords and the struts are the primary character-defining features of the Howe truss. Like the previously discussed timber trusses, the roofing and/or exterior covering of a Howe truss is of secondary importance, since in most, if not all cases, these features are modern replacements.

Examples of Howe Truss

1. Buskirk Covered Bridge (1857), Washington and Rensselaer Counties, NY. NRHP listed 1978.
2. Adams Mill Bridge (1872), Carroll County, IN. NRHP listed 1996.
3. Mt. Orne Covered Bridge (1911), Coos County, NH. NRHP listed 1976.
4. Fisher School Bridge (Five Rivers Bridge) (1919); Lincoln County, OR. NRHP listed 1979 in Oregon Covered Bridges Thematic Nomination.
5. Manning-Rye Covered Bridge (Harpole Bridge) (1928), Whitman County, WA. NRHP listed 1982 in Historic Bridges/Tunnels in Washington State Thematic Resource Nomination.
6. Doe River Bridge (1882), spanning Doe River, Third Avenue, Elizabethton, Carter County, TN. HAER TN 41.
7. Jay Covered Bridge (1857), County Route 22, spans East Branch of AuSable River, Jay, Essex County, NY. HAER NY-170.

Figures 3-13, 3-14, and 3-15 include a drawing and examples of the Howe truss.

Figure 3-13. Elevation drawing of Howe truss.

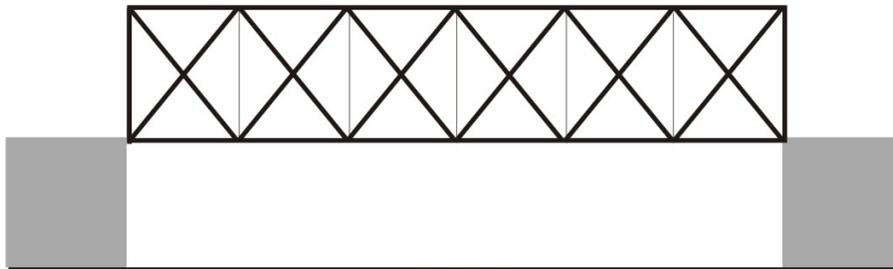


Figure 3-14. Jay Covered Bridge, County Route 22, spans East Branch of AuSable River, Jay, Essex County, New York. This 1857 Howe truss was altered in 1953.



3-14a. Interior of bridge.



3-14b. Detail of the lower joint of the tension/compression members at the

cast iron shoe.

Figure 3-15. Doe River Bridge (1882), spanning Doe River, Third Avenue, Elizabethton, Carter County, Tennessee. This scenic structure is a well-preserved example of a Howe truss covered bridge.



3-15a. Three-quarter view.



3-15b. The interior of the structure. Note the Howe truss's heavy wood diagonal members (in compression) and lighter, vertical cylindrical iron members (in tension).

3.1.6 *Metal Bowstring Arch Truss*

History and Description: In 1840, Squire Whipple (1804-1888), a graduate of Union College in Schenectady, New York, and a surveyor for railroad and canal companies, built an approximately 82 foot-long, tied-arch “bowstring” truss bridge over the Erie Canal at Utica, New York. It was the second all-metal truss bridge constructed in the United States. The following year he obtained a patent for his design (#2,064), which had arches of cast iron functioning as the primary compression members, and vertical and diagonal rods of wrought iron. The “string” (or lower member) tying the ends of the arch acted in tension.

Even before Whipple’s patent expired in 1869, bridge builders copied his design, some with slight variation to avoid infringement, and many without any respect of the patent. This type proved very popular over the next forty years for train sheds, other curved vault structures and short highway and canal spans of 50 to 100 feet, although some bowstring trusses were much longer. During the last quarter of the nineteenth century, it was one of the most generally adapted truss forms in bridge design. Whipple’s patent was adopted by Zenas King, David Hammond and other builders who secured patents for the configuration of the upper chord and other details. These men established bridge-fabricating companies to manufacture bridges by the thousands to meet the overwhelming demand for economic, short to moderate span, bridges for burgeoning farm-to-market road systems.

The King Iron Bridge Company of Cleveland (<http://www.kingbridgeco.com/>) and the Wrought Iron Bridge Company of Canton, Ohio, founded by King and Hammond, were two of literally hundreds of bridge fabricating companies established throughout the east and Midwest to meet demands. The companies employed agents who operated out of larger cities, covering territories and selling their bridges to county commissioners through catalogs, hence the name “catalog” bridges. Whipple himself operated one of the earliest bridge-fabricating companies, building hundreds of iron bridges.

One such example is the Aldrich Change Bridge (1858), formerly at Macedon-Palmyra Creek over the Erie Canal in Wayne County, New York. This span was recently restored to become part of the New York State Erie Canal National Heritage Corridor and the Canalway Trail system, and is now in Wayne County’s Aqueduct Park in Upstate New York.

Metal bowstring arch spans from the nineteenth century, whether built of iron or steel (most were iron), may generally be distinguished from steel tied arch spans of the twentieth century by differentiation of historic context. The events, people (designers and builders) and technology for nineteenth-century bridges are far different than those for more modern structures. This reality is reflected by a statement in “Structural Study of Iron Bowstring Bridges,” the HAER narrative history prepared as part of the Iowa Historic Bridges Recording Project Phase II in 1996 (4, p. 13), which stated that, “the history of the bowstring truss is inextricably linked to the nineteenth century bridge

companies.” Steel tied-arch spans of the twentieth century, therefore, which may occasionally be called “bowstrings,” are examined in the arch category of this study.

Significance Assessment: The number of Whipple bowstring trusses is known, but the number of other surviving bowstring arch trusses is not. The bowstring arch truss is one of the more important nineteenth century bridge forms and dates primarily from the 1870s and 1880s. Bowstring bridges that retain their integrity (i.e., their character-defining features) are highly significant within the context of this study. Character-defining features include a relatively heavy arched top chord, a series of boxed “X” panels, and an outer, basically triangular panel at each end. Character-defining elements include the members that form the ‘X’s” within each panel and the end panels, the slender vertical rods, the bottom chord, floor beams, and method of connection.

The small number of intact Whipple bowstring trusses that remain possess the highest level of significance within this type.

Examples of Metal Bowstring Arch Truss

1. Whipple Cast and Wrought Iron Bowstring Truss Bridge (1867, moved and re-erected 1900). Albany County, NY. NRHP listed 1971.
2. Mill Road Bowstring Bridge (1870s) Knox County, OH. NRHP listed 1979.
3. White Bridge (1877). Mahoning, OH. NRHP listed 1983.
4. Freeport Bowstring Arch Bridge (1878), Winneshiek County, IA. NRHP listed 1984 in Highway bridges of Iowa MPS.
5. North Platte River Bowstring Truss Bridge (1875), spanning North Platte River, Fort Laramie vicinity, Goshen County, WY. HAER WY-1.

Figures 3-16 and 3-17 depict a drawing and an example of the bowstring arch truss.

Figure 3-16. Elevation drawing of bowstring arch truss bridge.

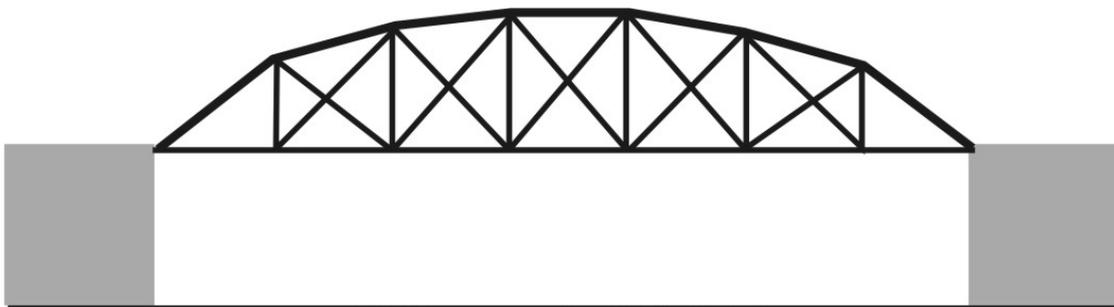


Figure 3-17. Tivoli Island Bridge (ca.1877), spanning the Rock River Channel from the mainland, Watertown, Jefferson County, Wisconsin. The bridge is an example of the metal bowstring arched truss fabricated by King Iron and Bridge Company of Cleveland, Ohio.



3-17a. Three-quarter view.



3-17b. Through view.

3.1.7 *Pratt Truss*

History and Description: Thomas Pratt (1875), an engineer who studied at Rensselaer Polytechnic Institute in Troy, New York, and worked for the U. S. Army and several New England railroads, designed the first Pratt truss in 1842. In 1844 a joint patent (#3,523) was granted to Thomas and his father, Caleb, a Boston architect. As originally conceived, this design used vertical compression members of wood and wrought iron diagonals in tension, a reverse of the earlier Howe truss, which used diagonals in compression and verticals in tension. The great advantage of the Pratt truss over many earlier designs was the relative ease of calculating the distribution of stress throughout the structure.

Because this design demanded a greater use of the more expensive metal than the Howe truss, it initially was not popular; however, as the nation's railroads gradually began to favor all iron bridges, the Pratt truss became widely adopted (5, p. 11). Not only was the design simple, relatively economical, and easily erected in the field, it was also more trustworthy than the Howe. As an iron or steel bridge, the Pratt truss became the most popular span in America in lengths of less than 250 feet for highways and railroads. The Pratt truss was erected in large numbers during the last quarter of the nineteenth century and into the first decades of the twentieth century, when it began to be superseded in popularity by the Warren truss.

The Pratt truss form may be found in through, pony, deck and bedstead spans. Pratt trusses generally have horizontal and parallel chords connected by inclined endposts, but Pratt trusses with vertical endposts were also constructed. In the bedstead variation, the endposts extend below the plane of travel surface, thus serving as components of both the superstructure and substructure. There are a number of Pratt variations, which are discussed as separate truss types in this study (i.e., Whipple, Baltimore, Parker and Pennsylvania).

One popular sub-type of the Pratt is the half-hip pony truss, in which the hip vertical is eliminated and the inclined end post is made more perpendicular to the upper and lower chords, thus requiring less metal. It was limited to lengths of no more than about 60 feet, however. This type was used extensively by county road departments throughout the country for small stream crossings.

Significance Assessment: When fabricated entirely of iron, and later steel, with riveted connections, the Pratt truss became the American standard for bridges of moderate spans well into the 20th century. In 1916, bridge engineer J.A.L. Waddell claimed that the Pratt truss was the most commonly used truss for spans less than 250 feet. Pratt trusses are among the most common nineteenth and early twentieth century bridge types discussed in this study. They are, however, significant in the evolution of bridge technology, particularly the early examples of the type. Early examples of the type that retain their character-defining features are highly significant within the context of this study, while later, more common examples are less significant. The later

examples can still be significant if they retain character-defining features and are very good examples of the type.

Character-defining features vary, as there are number of different subtypes of Pratt trusses. Because the vertical members and endposts of the Pratt truss handle compressive forces under load, they tend to be relatively heavy and visually prominent, and are usually composed of angles, channels or rolled sections. The diagonal members function mainly in tension and are relatively thin (the ones toward the center handle some compressive forces), and are often composed of square or round bars. The interior diagonals all slant down and in, at a pitch of 45 degrees, the optimal angle calculated by the Pratts, while the inclined end posts slant outward at the same angle. Although the patent drawings illustrate a design option featuring a curved top chord, the basic design was for a truss with a straight top chord, and this became a common characteristic of the Pratt truss. Character-defining features include the truss form, method of connection, top and bottom chords, vertical and diagonal members, floor beams and stringers. For through trusses, the lateral top bracing and features of the portal (e.g., struts, bracing) are also character-defining features.

Examples of Pratt Truss

1. Kennedy Bridge (1883), Blue Earth County, MN. NRHP listed 1989 in Iron and Steel Bridges in Minnesota MPS.
2. Sixth Street Bridge (1886), Grand Rapids, MI. NRHP listed 1976.
3. Raritan Bridge (1886), Somerset County, NJ. NRHP listed 1992 in Metal Truss Bridges in Somerset County MPS.
4. Neligh Mill Bridge (1910), Antelope County, NE. NRHP listed 1992 in Highway Bridges in Nebraska MPS.
5. EDL Peloux Bridge (1913), Johnson County, WY. NRHP listed 1985 in Vehicular Truss and Arch Bridges in Wyoming Thematic Resource Nomination.
6. Daphna Creek Pratt Truss Bridge (1900), State Route 1414, Holly Hill Street, spanning Broadway, Rockingham County, VA. HAER VA-33.
7. Burrville Road Bridge (1887), spanning Toti Creek at Burrville Road, Fort Recovery vicinity, Mercer County, OH. HAER OH-35.

Figures 3-18 through 3-21 depict, respectively, a drawing of a Pratt truss, and examples of the pony, through, and bedstead Pratt trusses.

Figure 3-18. Elevation drawing of Pratt Truss.

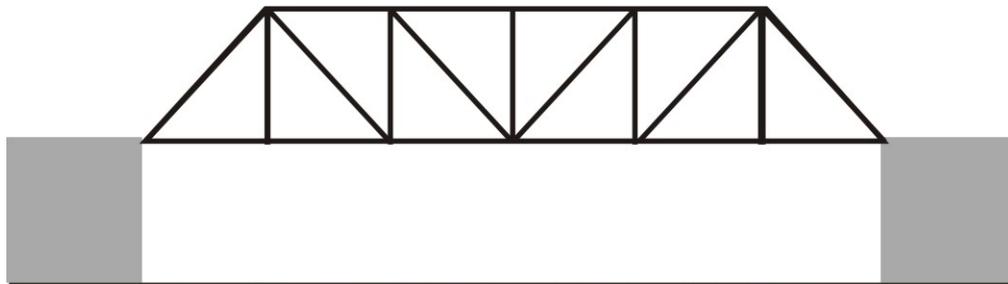




Figure 3-19. Daphna Creek Pratt Truss Bridge (ca. 1900), Rockingham County, Virginia. This Canton Bridge Company structure is an example of the pony Pratt.



Figure 3-20. Runk Bridge (n.d.), Shirleysburg, Huntingdon County, Pennsylvania. This structure is an example of a through Pratt truss.



Figure 3-21. Burrville Road Bridge (1887), spanning Toti Creek Mercer County, Ohio. This structure is an example of the bedstead Pratt truss.

3.1.8 Whipple Truss

History and Description: In 1847, Squire Whipple developed what he called a trapezoidal truss that was similar to a Pratt truss, and has been described as “double-intersection Pratt.” He determined that by extending the diagonal members over two panel lengths, the depth of the panel was increased without altering the optimal angle of 45 degrees; thus, the span length could be increased. The first bridge erected of this type was completed in 1853, on the Albany and Northern Railroad (later the Rensselaer and Saratoga Railroad), about seven miles northwest of Troy, New York. The span, of about 146 feet, had a top chord and end posts of cast-iron, while the lower chord was made of wrought iron.

Whipple published his seminal work on scientific bridge design in 1847, *A Work on Bridge Building*. In this and subsequent books, Whipple explained that truss members could be analyzed as a system of horizontal and vertical components whose forces are in equilibrium. His method of analysis permitted the determination of stresses in all truss members, when the two forces are known. In this, he provided a scientific basis for bridge building, a practice that previously had depended on empirical knowledge. His trapezoidal truss was a manifestation of this theory. Although research by former Professor Francis E. Griggs, Jr. and Associate Professor Anthony J. DeLuzio of Merrimack College (6) suggested that Stephen Long probably preceded Whipple in developing scientific designs for truss bridges, the impact of Whipple’s written work cannot be denied.

Six years after erection of the first Whipple truss, John W. Murphy, chief engineer for the Lehigh Valley Railroad, completed a 165-foot span over a canal near Phillipsburg, New Jersey, in which he substituted wrought-iron pins for the cast iron, oblong trunnions of the Whipple design. This bridge featured wrought iron main web bars and counter bars that were looped at the end. This is considered the first truss bridge in which pin connections were used throughout (5, p. 15). The use of pin connections was a major step forward in the advancement of bridge construction practice in the United States, requiring less time, equipment, and skilled labor to erect than fully (shop) riveted connections (7). It wasn’t until the introduction of reliable and cost-effective pneumatic field riveting equipment at the end of the nineteenth century that the use of pin connections began to fade. The transition from pinned to field-riveted and bolted connections in the first decade of the twentieth century eventually led to the use of heavier and more rigid members than eyebars, which, in turn, led to the use of laced angles for endposts, counters, and lower chord members (8, p. 56).

In 1861, Jacob H. Linville, chief engineer for the Pennsylvania Railroad, built a 192-foot Whipple truss bridge over the Schuylkill River, in which forged wrought iron eyebars and posts were used for the first time. Two years later, John Murphy built a railroad bridge over the Lehigh River at Mauch Chunk, in which he used wrought iron for both the posts and top chord members. Even though he also used cast-iron for the joint blocks and pedestals, this is the first pin-connected bridge in which both the tension and compression members were of wrought iron. This was a major step forward in use of

materials because cast iron is a brittle metal that has high compressive strength but low tensile strength (it doesn't stretch well) and a lack of ductility (it doesn't react well to shocks). Wrought iron, on the other hand, is equally strong in compression and tension. Changes in temperature affect cast iron more adversely than wrought iron, and the force required to cause rupture of cast iron members is small compared to that for wrought iron. Although wrought iron was the more expensive metal, its use ensured a certain degree of reliability.

The Lehigh River Bridge also featured diagonals that crossed two panels, thus making it a Whipple, or, as some would call it, a double intersection Pratt. This truss type, perhaps best described as a Murphy-Whipple, became very popular for use in long-span, nineteenth-century railroad bridges. Linville used the Murphy-Whipple truss extensively for long-span bridges with top chord and posts of cast iron for the Pennsylvania Railroad, and later with all wrought iron main members for the Keystone Bridge Company. He patented certain design variations that came to be known as "Linville" trusses, although in function these were basically Murphy-Whipple trusses.

Significance Assessment: Also known as a Murphy-Whipple truss when made entirely of wrought iron, the Whipple truss was used from 1860 to 1890 for both rail and vehicular bridges with spans capable of reaching 250 to 300 feet. Whipple trusses are less common than many of the bridge types discussed in this study. (Triple intersection Whipple trusses are rare and possess the highest level of significance within this type. Only one surviving example is known, the Laughery Creek Bridge in Indiana.) When Whipple trusses possess their character-defining features, they are considered highly significant within the context of this study. Whipple's trapezoidal truss was similar in configuration to the Pratt with its parallel top and bottom chords, but had a double intersection web system and inclined end posts as illustrated in Figure 3-22, both character-defining features of the type. Character-defining features include the parallel top and bottom chords, intersecting diagonals, vertical members, method of connection, inclined end post, floor beams and stringers, and portal features (e.g., struts, bracing).

Examples of Whipple Truss

1. O Street Viaduct (ca. 1885), Douglas County, NE. NRHP listed 1992 in Highway Bridges of Nebraska, 1870 – 1942 MPS.
2. Whipple Truss (1875) spanning White Lick Creek south of State Route 36, Hendricks County, IN. Labeled as NRHP candidate in *Iron Monuments to Distant Prosperity* by James L. Cooper, 1987.
3. Laughery Creek Bridge (1878), Dearborn County, IN. NRHP listed 1976. HAER IN-16.
4. Kentucky Route 49 Bridge (1881), Marion County, KY. HAER KY-17.
5. Emlenton Bridge (1883), Venango County, PA. HAER PA-101.
6. Carroll County Bridge No. 119 (Wise's Ford Bridge) (1888), Carroll County, IN. HAER IN-70.

Figures 3-22 through 3-24 provide a drawing and an example of the double and triple intersection Pratt truss.

Figure 3-22. Elevation drawing of double intersection Whipple Truss.

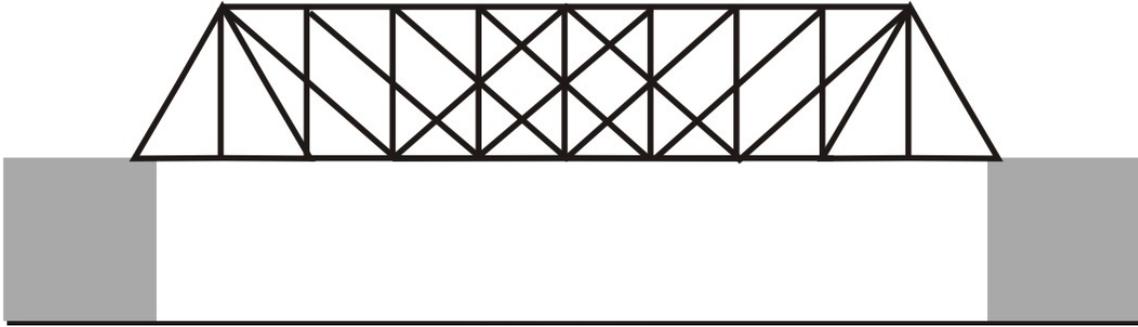


Figure 3-23. Kentucky Route 49 Bridge (1881), spanning Rolling Fork River, Bradfordsville, Marion County, Kentucky. This bridge is an example of the double intersection Whipple truss.



Figure 3-24. Laughery Creek Bridge (1878); Dearborn County, Indiana. This bridge is the only known example of the triple-intersection Whipple truss.



3-24a. Oblique view of bridge.



3-24b. Through View of bridge.

3.1.9 Baltimore Truss

History and Description: This truss (along with Pennsylvania truss) was the product of two of the early eastern trunkline railroads developed during the 1870s for heavy locomotives. The Baltimore truss, specifically, was designed by engineers of the Baltimore and Ohio (B & O) Railroad in 1871.

The truss was adapted for highway use as early as the 1880s, often for spans of modest lengths. When steel replaced wrought iron and rigid, riveted connections replaced pins in the early decades of the twentieth century, the Baltimore truss was used for longer span highway bridges until the 1920s.

The Baltimore truss is basically a parallel chord Pratt with sub-divided panels in which each diagonal is braced at its middle with sub-diagonals and vertical sub-struts. This type is sometimes referred to as a “Petit” truss. The logic leading to subdivided panels stems from the need to maintain an economic spacing of floor beams in longer span bridges. As the distance between chords increases, so does the width of panels. In order to maintain optimum slope of diagonals (45 – 60 degrees) and, an economic spacing of floor beams, the panels were subdivided at intermediate points between the main vertical members. This increases the number of floor beams but reduces the overall cost and weight of the bridge since the whole deck system can be designed with smaller members. Larger members use more metal resulting in an heavier and often more expensive bridge. This is a subtlety of bridge design that is hard to visualize (8, p. 68).

Significance Assessment: The Baltimore truss is significant for its association with the railroad. Nineteenth century examples of such bridges are considered significant within the context of this study, and the earliest examples along the B&O Railroad are highly significant. Highway bridges built using the Baltimore truss are not amongst the more common bridge types in this study and are considered significant if they retain their character-defining features. Such features include the elements that comprise its form— basically it is Pratt with parallel top and bottom chords, but with generally wide, sub-divided panels in which each diagonal is braced at its middle with sub-diagonals and sub-struts. The end posts are inclined. Character defining features include its parallel top and bottom chords, verticals and diagonals (including substruts or sub-ties), floor beams, stringers, struts, form of connection, and portal features (e.g., struts, bracing).

Examples of Baltimore Truss

1. Loosveldt Bridge (1888), Sheridan County, NE. NRHP listed 1992 in Highway Bridges in Nebraska MPS.
2. Tippecanoe River Bridge (1890), Fulton County, IN. NRHP candidate in *Iron Monuments to Distant Prosperity* by James L. Cooper, 1987.
3. Walnut Street Bridge (1890), Dauphin County, PA. NRHP listed 1972.
4. Colclessor Bridge #SH00-42 (1888), Sheridan County, NE. NRHP listed 1992 in Highway Bridges in Nebraska MPS.
5. Post Road Bridge (1905), State Route 7A, Havre De Grace Vicinity, Harford County, MD. HAER MD-44.

Figures 3-25 and 3-26 present a drawing and an example of a Baltimore truss bridge.

Figure 3-25. Elevation drawing of a Baltimore truss bridge.

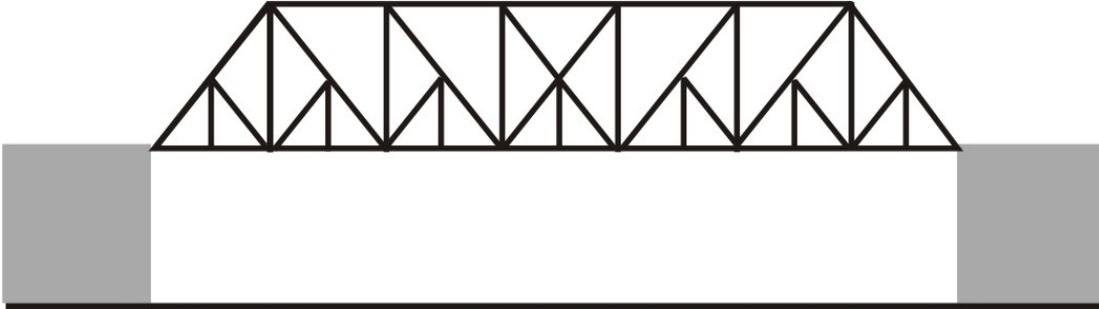


Figure 3-26. Post Road Bridge (1905), State Route 7A, Havre de Grace vicinity, Harford County, Maryland. This bridge is an example of the Baltimore truss type.



3.1.10 Parker Truss

History and Description: On February 22, 1870, Charles H. Parker, a mechanical engineer with the National Bridge and Iron Works of Boston, Massachusetts, was awarded a patent (#100,185) for what was essentially, according to most bridge historians, a Pratt truss with a polygonal or inclined top chord. Parker, it is claimed, recognizing that the depth of truss required at the ends was less than that required at mid-span, simply inclined the top chord, thus also progressively shortening the vertical and diagonal members from the center to the ends of the truss. The Parker truss therefore uses less metal than a parallel chord Pratt truss of equal length, and the longer the span the greater the economy of materials. Unlike the parallel chord Pratt, however, the Parker required different length verticals and diagonals at each panel. This increased fabrication and erection costs. Because bridge prices were usually driven by the weight of the materials used to construct the superstructure, the lighter weight of the polygonal chord truss tended to offset the increased labor costs for spans over a certain length.

According to bridge engineer and historian Victor Darnell, however, the Parker design could not claim the curved top chord as a feature because it was already in common use. Even Thomas and Caleb Pratt, who illustrated a curved top chord in their truss patent of 1844, could not claim a curved top chord as a feature of their patented design. The Parker patent claimed three improvements over earlier designs. The first claim was that minor changes in bridge lengths could be accommodated by changing the slope of the inclined end post or extending it to the top chord to a point behind the first vertical web member. Second, the design of the top and bottom connections of the web posts to the chords was new. And third, the casting at the bottom of the end post simplified the connection joining the top and bottom chords (*10*, p. 12). What set the Parker truss aside from earlier designs was not so much the continuously sloping top chord, but the use of simple, cast iron connections and the inclined end post. Yet, the Pratt patent also had inclined end posts, although these were placed very near the verticals of the end panel and did not function in the same way as in the Parker design.

In 1998, Darnell could only find one extant bridge that was built according to the original design patented in 1870; the Vine Street Bridge (1870) in Northfield, Vermont. This bridge has all the characteristics evident in the 1870 patent application: sloping wrought iron endposts, continuously curved wrought iron top chord, wrought iron I-beam web posts, cast iron web post connections, and a bottom chord that forms a loop around the endposts. The trusses that we now commonly identify as “Parkers” use inclined endposts, but generally have inclined top chords composed of straight members, with the degree of inclination changing at the panel points. Virtually all of these bridges are constructed of steel.

In the highly competitive bridge market, the economy of materials directly affected profit, and the Parker trusses superseded Pratt trusses for long span bridges after the turn of the century, as less materials were needed in their construction. The form was adopted by highway departments as standard designs for pony trusses (30 to 60 feet) and through trusses (100 to 300 feet).

The camelback is a variation of the Parker truss. Most camelback trusses are essentially Parker trusses with exactly five slopes in the upper chord and end posts.

Significance Assessment: A selection of wrought iron Parker pony trusses with pinned connections survive from the nineteenth century, but the majority date from the twentieth century. The Parker pony truss was built as late as 1950. These bridges are characterized by rigid riveted connections and steel construction.

Parker trusses are significant within the context of this study. At the highest level of significance within this type are nineteenth century, pin-connected Parker trusses, as the numbers of these bridges are dropping as they are replaced with modern structures. A well-preserved twentieth century Parker truss that exemplifies a standard bridge type of a state department of transportation also is significant within the context of this study. Examples dating after the first two decades of the twentieth century are substantially less significant than the above-discussed examples, possessing low to moderate significance. Primary character-defining features include the polygonal top chord; inclined end posts; diagonals in each panel; and different length verticals, shortening in length outward from the central panel. Other character-defining features include the floor beams, stringers, struts, method of connection and portal features (e.g., struts, bracing)

Examples of Parker Truss

1. Bridge No. 5721 (1890, 1937), Koochiching County, MN. NRHP listed 1998 in *Iron & Steel Bridges in Minnesota MPS*.
2. Walnut Street Bridge (1891), Chattanooga, Hamilton County, TN. NRHP listed 1990.
3. Rifle Bridge (1909), Garfield County, CO. NRHP listed 1985 in *Vehicular Bridges in Colorado Thematic Resource Nomination*.
4. Gross State Aid Bridge (1918), Knox County, NE. NRHP listed 1992 in *Highway Bridges in Nebraska MPS*.
5. Enterprise Bridge (1924-25), spanning Smoky Hill River on K-43 Highway, Enterprise, Dickinson County, KS. HAER KS-5.
6. Sparkman (Shelby) Street Bridge (1907-09), spanning the Cumberland River, Nashville, Davidson County, TN. HAER TN-38.

Figures 3-27 through 3-29 include a drawing and examples of the Parker truss.

Figure 3-27. Elevation drawing of Parker truss.

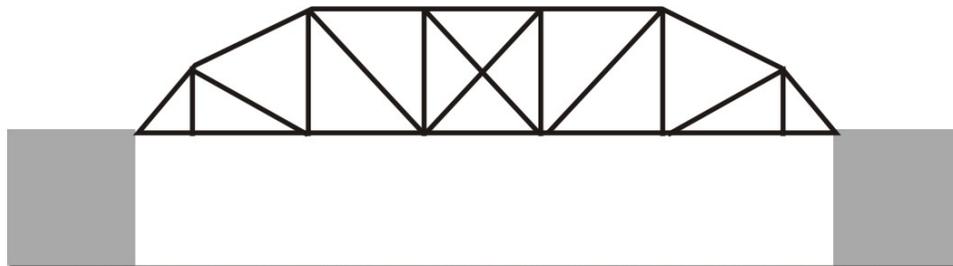


Figure 3-28. Enterprise Bridge (1924-25), spanning Smoky Hill River on K-43 Highway, Enterprise, Dickinson County, Kansas. This structure is an example of a Parker truss.



Figure 3-29. Sparkman (Shelby) Street Bridge (1907-09), spanning the Cumberland River, Nashville, Davidson County, Tennessee. This span is an example of the camelback variation of the Parker truss. Note the characteristic five slopes in the upper chord and end posts.



3.1.11 Pennsylvania Truss

History and Description: The Pennsylvania truss, like the Baltimore truss sometimes referred to as a “petit,” was developed by engineers of the Pennsylvania Railroad in 1875. The Pennsylvania truss (along with the Baltimore truss) was the product of two of the early eastern trunkline railroads developed during the 1870s for heavy locomotives. This truss is similar to the Baltimore truss in that it has sub-divided panels, but it also has a polygonal or inclined top chord.

As with the Baltimore truss, the Pennsylvania truss was originally developed for use in relatively long span railroad bridges, but became a common type for shorter span lengths. The truss was adapted for highway use as early as the 1880s. When steel replaced wrought iron and rigid riveted connections replaced pins in the early decades of the 20th century, the Pennsylvania truss was used for longer span highway bridges until the 1920s.

Significance Assessment: The Pennsylvania truss is significant for its association with the railroad. Nineteenth century examples of such bridges are considered significant within the context of this study, and the earliest railroad-built examples are highly significant. Highway bridges built using the Pennsylvania truss are not amongst the more common bridge types in this study and are considered significant if they retain their character-defining features.

This truss is a form of the Pratt, similar to the Baltimore truss in that it has sub-divided panels, but unlike the Baltimore truss, it has a polygonal top chord. This heavy top chord and the panel configuration, as shown in Figure 3-30, comprise the primary character-defining features of this type. Character-defining features include the top and bottom chords, vertical and diagonal members (including sub struts or sub ties), floor beams, stringers, struts, method of connection and portal features (e.g., struts, bracing).

Examples of Pennsylvania Truss

1. Leaf River Bridge (1907), Green County, MS. NRHP listed 1988 in Historic Bridges of Mississippi MPS.
2. Rifle Bridge (1909), Garfield County, CO. NRHP listed 1985 in Vehicular Bridges in Colorado Thematic Resource Nomination.
3. Third Street Bridge (1910), Goodhue County, MN. NRHP listed 1989 in Iron and Steel Bridges in Minnesota MPS.
4. Four Mile Bridge over Big Horn River (1927-28), Hot Springs County, WY. NRHP listed 1984 in Vehicular Truss and Arch Bridges in Wyoming MPS.
5. Old Colerain Pennsylvania Through Truss Bridge (1894), spanning Great Miami River at County Route 463, Ross vicinity, Hamilton County, OH. HAER OH-54.
6. Scioto Pennsylvania Through Truss Bridge (1915), spanning Scioto River at State Route 73, Portsmouth, Scioto County, OH. HAER OH-53.

Figures 3-30 and 3-31 include a drawing and an example of the Pennsylvania truss.

Figure 3-30. Elevation drawing of a Pennsylvania truss.

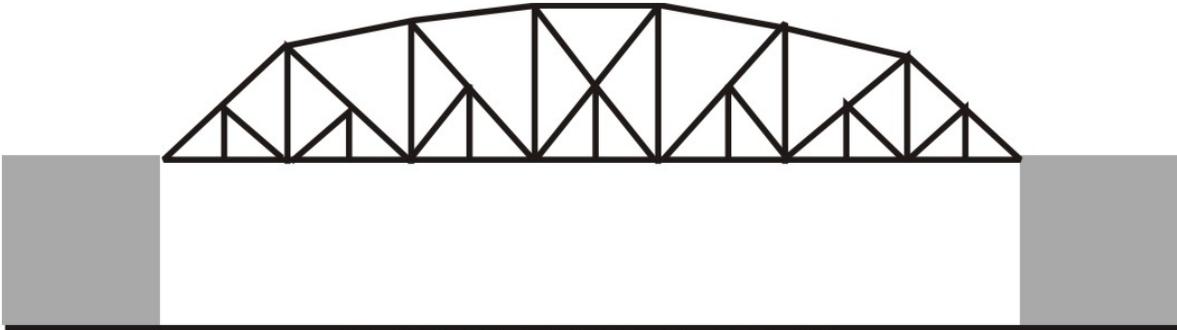


Figure 3-31. Old Colerain Bridge (1894), spanning Great Miami River at County Route 463, Hamilton County, Ohio. Detail of panel configuration, bottom chord, floor beams, and stringers of Pennsylvania truss bridge.



3.1.12 Warren Truss

History and Description: The Warren truss is a highly efficient form developed by an obscure Belgian engineer named Neville and a British engineer named Francis Nash. The form has only diagonal members connecting the two chords, with no verticals. The basic design is based on combining a series of equilateral triangles to form an efficient truss in which the diagonals act in compression and tension. Usually this truss type was altered by the addition of verticals or additional alternating diagonals. The main diagonals, endposts, and top or bottom chord members tend to be thick and visually prominent. Verticals or additional diagonals, when present, are much thinner. As was the case with the Pratt truss, the distribution of stress throughout the structure was easily analyzed in the Warren truss by mathematical calculation.

The Warren truss was theoretically a rational design. Since the structure's diagonals took both tensile and compressive stresses, they were constructed of wrought iron, thus introducing all wrought-iron bridge construction to Europe. In the Warren truss, every part of the truss equally bears its share of the stresses, while in the lattice, Pratt and other truss forms, stresses in the members vary, hence differently sized members.

As a pin-connected iron truss, this type was never very popular, either as a railroad or a highway bridge. Many steel, field-riveted or bolted Warren pony trusses, however, were erected by counties throughout the country beginning in the 1890s, by state highway departments in the 1920s and 1930s, and by railroads into the 1930s. Warren trusses were also built, occasionally, with polygonal top chords as a through or pony truss; with vertical endposts as a pony truss; or as a bedstead pony truss.

Significance Assessment: Few Warren trusses survive from the nineteenth century, but the form dominated twentieth century bridge design, used in many different configurations by highway departments for short span pony trusses and through trusses for intermediate spans, from the 1900s to the present.

The Warren truss is significant within the context of this study if they retain their character-defining features, which include parallel top and bottom chords, inclined end posts (or vertical end posts for bedsteads), diagonals, floor beams, stringers, method of connections, and for through trusses, struts and portal features (e.g., struts, bracing). Intact nineteenth century examples are the most significant within this type as they are no longer common. Most significant amongst the twentieth century examples are the bridges built by state departments of transportation according to their standardized plans. Warren trusses built after the first two decades of the twentieth century are substantially less significant than the aforementioned significant examples, possessing low to moderate significance.

Examples of Warren Truss

1. Clear Creek Bridge (1891), Butler County, NE. NRHP listed 1992 in Highway Bridges in Nebraska MPS.
2. Bridge No. 12 (1908), Goodhue County, MN. NRHP listed 1989 in Iron and Steel Bridges in Minnesota MPS.
3. Romness Bridge (1912), Griggs County; ND. NRHP listed 1997 in Historic Roadway Bridges of North Dakota MPS.
4. ERT Bridge over Black's Fork (1925), Unita County, WY. NRHP listed 1985 in Vehicular Truss and Arch Bridges in Wyoming Thematic Resource Nomination.
5. Williams River Bridge (1929), Windham County, VT. NRHP listed 1991 in Metal, Truss, Masonry and Concrete Bridges in Vermont MPS.
6. Virgin River Warren Truss Bridge, spanning Virgin River at Old Road, Hurricane vicinity, Washington County, UT. HAER UT-76.
7. Boylan Avenue Bridge (1913), Raleigh, Wake County, NC. HAER NC-20.
8. Fifficktown Bridge (1910), spanning Little Conemaugh River, South Fork, Cambria County, PA. HAER PA-233.
9. Spavinaw Creek Bridge (1909), Benton County Road 29 spanning Spavinaw Creek, Gravette vicinity, Benton County, AR. HAER AR-29.

Figures 3-32 through 3-36 show, respectively, a drawing, and examples of the through, pony, deck and bedstead Warren trusses.

Figure 3-32. Elevation drawing of Warren truss.

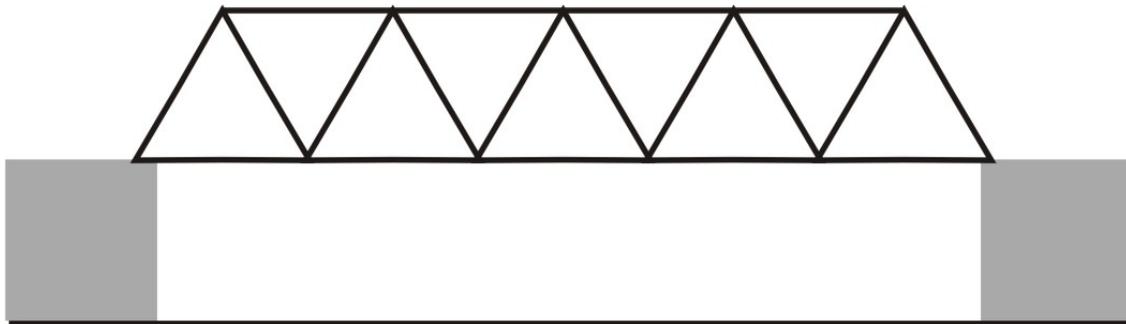


Figure 3-33. Boylan Avenue Bridge (1913), Raleigh, Wake County, North Carolina. This through Warren truss serves as a grade separation.



Figure 3-34. Virgin River Warren Truss Bridge, spanning Virgin River at Old Road, Hurricane vicinity, Washington County, Utah. This undated pony Warren truss bridge is in Zion National Park.



3-34a. Oblique view.



3-34b. Side panel.

Figure 3-35. Fifficktown Bridge (1910), spanning Little Conemaugh River, South Fork, Cambria County, Pennsylvania. This structure is an example of the Warren deck truss.



Figure 3-36. Spavinaw Creek Bridge (1909), Benton County Road 29 spanning Spavinaw Creek, Gravette vicinity, Benton County, Arizona. This structure is an example of the Warren bedstead truss.



3.1.13 Subdivided and Double Intersection Warren Truss

History and Description: An adaptation of the Warren truss is the double intersection Warren, also called a quadrangular, or multiple-intersection Warren truss. It has a distinctive crosshatched appearance, and when viewed in profile it seems that one triangular web system has been superimposed upon another. This type of truss may have verticals but usually does not. The main structural members act in compression and in tension (depending on specific configuration). The purpose of overlapping the diagonals was to increase stiffness and load carrying capacity.

The quadruple intersection Warren through truss is sometimes called a “Hilton” truss, after bridge designer Charles Hilton, an apprentice of Howard Carroll, a builder of riveted metal lattice truss bridges for the New York Central Railroad. The “lattice” truss of Carroll appeared similar to the quadruple Warren truss when viewed in profile, however, Hilton extended and adapted the system that he had learned under Carroll to create a design suitable for longer span lengths. Hilton’s longest bridge was the seven span, 180-foot long bridge over the Connecticut River at Springfield, Massachusetts, completed in 1874 (5, p. 16). He is also known for having developed bridge specifications for the Lake Shore and Michigan Southern Railway in 1877 (9, p. 29). A good extant NRHP example of the quadruple intersection Warren truss bridge is the Rice Farm Road Bridge (1892) in Windham County, Vermont.

Significance Assessment: Few subdivided or double intersection Warren trusses survive from the nineteenth century. Extant subdivided, double intersection, and quadruple intersection Warren truss bridges have been identified during the last twenty years in North Carolina, Colorado, Kansas, Oklahoma, Connecticut, Vermont, Ohio, Pennsylvania, and West Virginia. Subdivided, double intersection, and quadruple intersection Warren truss bridges are among the least common bridge types in this study and examples that retain their character-defining features are highly significant within the context of this study. Character-defining features include the parallel top and bottom chords, diagonal members, floor beams, stringers, struts, method of connection and portal features (e.g., struts, bracing). Vertical members are an additional character-defining feature of the subdivided Warren truss.

Examples of Subdivided and Double Intersection Warren Truss

1. Georgetown Loop Railroad Deck Truss Bridge (ca. 1870s): Clear Creek County, CO. NRHP listed in 1970 as part of Georgetown Loop Railroad, Structure #70000909.
2. Rice Farm Road Bridge (Green Iron Bridge) (1892); Windham County, VT. NRHP listed in 1995 in Metal Truss, Masonry, and Concrete Bridges in Vermont MPS.
3. Tauy Creek Bridge (ca. 1895); Franklin County, KS. NRHP listed in 1990 in Metal Truss Bridges in Kansas 1861-1939 MPS.

4. Norwalk River Railroad Bridge (1896); Fairfield County, CT. NRHP listed 1987 in Movable Railroad Bridges on the Northeast Corridor in Connecticut Thematic Resources Nomination.
5. Blackledge River Railroad Bridge (ca. 1907); New London County, CT. NRHP listed 1986. HAER CT-7.

Figures 3-37 and 3-38 present a drawing and an example of the subdivided and double intersection Warren truss.

Figure 3-37. Elevation drawing of the subdivided Warren truss (with verticals).

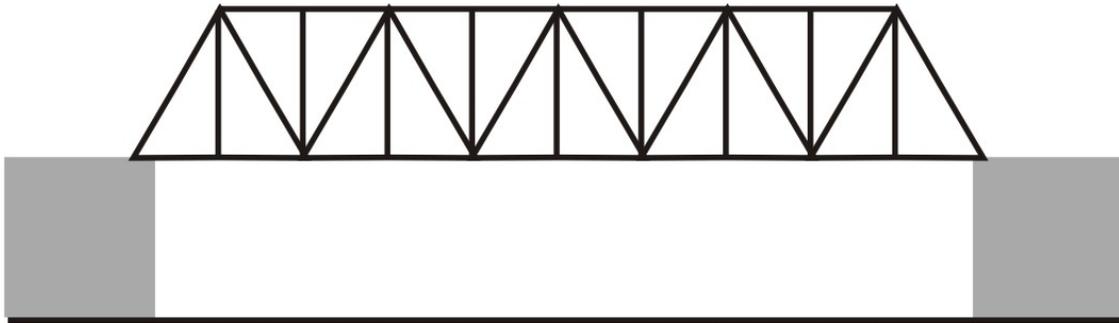


Figure 3-38. Bridge spanning Blackledge River (1907), Solchestes, New London County, Connecticut. This abandoned railroad bridge is an example of a double intersection Warren truss.



3.1.14 Lenticular Truss

History and Description: The lenticular truss may be thought of as a Pratt truss with the top and bottom chords curved over the entire length of the structure, thus creating the appearance of a lens. This type of truss is sometimes referred to as a “parabolic” truss.

Friedrich August von Pauli, a German engineer, patented the lenticular form in 1856, twenty-two years before William Douglas received his United States patent in 1878. We have no evidence whether Douglas knew of von Pauli’s precedent. Historically, the lens-shaped profile probably was derived from Laves beam. The earliest parabolic can be traced back as far as Faustus Verantius who in 1617 published *MACHINAE NOVAE*, a review of the structural arts at the end of the Renaissance where he discussed and illustrated several concepts that later become standard bridge designs: the tied arch and the lenticular truss in wood, a form that recognized the concept of bending. In 1820, a French engineer named Debia designed bridges with a curved top chord and an iron-chain bottom chord with vertical and diagonal bracing in the web attempting to equalize the stresses in the upper and lower chords.

Known as the Pauli truss in Europe and as the “lenticular truss” in the United States, the Berlin Iron Bridge Company of Connecticut adapted it as a standard design. Except for the Smithfield Street Bridge in Pittsburgh, Pennsylvania (1883), all of the lenticular trusses built in the United States were fabricated by the Berlin Iron Bridge Company of East Berlin, Connecticut, or by its predecessor company, the Corrugated Metal Company. Although this company built other types of trusses, it is best known for proliferating the lenticular design patented by William O. Douglas in 1878. From that date to about 1900, the company erected hundreds of bridges in the Northeastern and Midwestern states. A smaller, but significant number of bridges were also erected in California, Montana, Kansas, Texas and Virginia. Foreign sales included Germany, Mexico, Haiti, and much of South America (*11*, p. 10).

Significance Assessment: There are fifty-five known lenticular truss bridges in the United States today, which have been identified through the research (“Lenticular Truss Bridges of Massachusetts”) of Allen Lutenecker, a professor of civil engineering at the University of Massachusetts-Amherst. His research paper on lenticular truss bridges can be found at http://www.ecs.umass.edu/cee/cee_web/bridge/1.html. This type is one of the least common types in this study and is highly significant. Lenticular bridges have been identified in Massachusetts (9), Vermont (2), New Hampshire (4), Connecticut (11), New York (13), New Jersey (2), Rhode Island (2), Pennsylvania (5) and Texas (9). Character-defining features of this truss are its parabolically curved top and bottom chords, its vertical and diagonal members, floor beams, stringers, and method of connection. For through trusses, the portal elements (e.g., struts, bracing) are also character-defining features.

Examples of Lenticular Truss

1. Washington Avenue Bridge (ca. 1880); New Haven County, CT. NRHP listed 2001. HAER CT-18.
2. Smithfield Street Bridge (1883); Allegheny County, PA. NRHP listed 1974.
3. Nicholson Township Lenticular Bridge (1881), spanning Tunkhannock Creek at State Route 1029, Nicholson vicinity, Wyoming County, PA. HAER PA-468.
4. Lover's Leap Lenticular Bridge (1895), spanning Housatonic River on Pumpkin Hill Road, New Milford, Litchfield County, CT. HAER CT-17
5. Neshanic Station Bridge (1896); Somerset County, NJ. HAER NJ-31.

Figures 3-39 through 3-41 depict, respectively, a drawing of a lenticular truss and an example of a through and pony lenticular truss.

Figure 3-39. Elevation drawing of the lenticular truss.

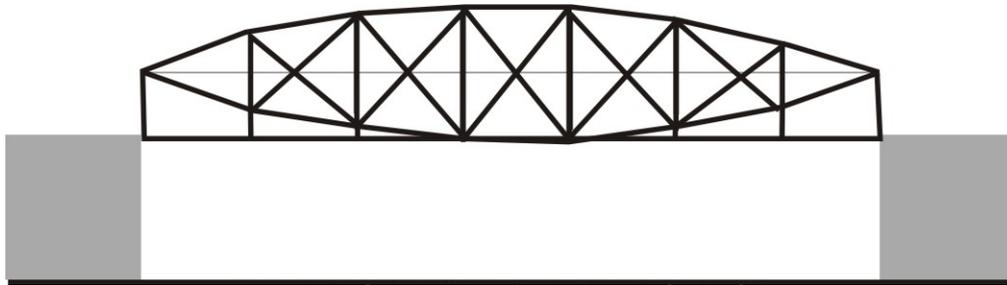


Figure 3-40. Nicholson Township Lenticular Bridge (1881), spanning Tunkhannock Creek at State Route 1029, Nicholson vicinity, Wyoming County, Pennsylvania. This bridge is an example of the through lenticular truss.



Figure 3-41. Nicholson Bridge (1888), Cemetery Road spanning Black Creek, two miles Southwest of Salem, Washington County, New York. This bridge is an example of the pony lenticular truss.



3.2 Arch Types

The types of arch bridges may be differentiated by the location of the deck or travel surface in relation to the rest of the superstructure. In a deck bridge the superstructure is entirely below the travel surface of the bridge. In a through-arch bridge the travel surface passes through all or a portion of the superstructure, which is sometimes connected above the deck and travel surface by cross bracing.

3.2.1 Stone Arch

History and Description: The immigrants who settled America came from European countries where masonry arch bridge construction was well established. Though our earliest stone arch bridge dates from 1697, and there is a scattering of early stone arch bridges in the original thirteen colonies, consistent stone arch construction did not appear until the third decade of the nineteenth century and was limited to major public work projects such as the canals, turnpikes, railroads and water supply systems.

Our most distinctive collection of stone arch bridges are found on the early, eastern trunkline railroads such as the B&O (Thomas Viaduct) and Erie (Starrucca Viaduct) railroads, and intrastate railroads such as the Providence & Boston (Canton Viaduct). These railroad structures are the American equivalent of Roman stone arch aqueducts.

Early turnpikes such as the National Road had impressive stone arch bridges in Maryland. Along the road in Ohio, the famous S-bridges were built.

Canals such as the Erie and the Chesapeake & Ohio had stone arch aqueducts. Early water supply systems such as the Croton Aqueduct (1837 - 1842) had stone arches carrying the conduit over roads in Westchester County, New York, including the massive Croton Aqueduct High Bridge over the Harlem River between the Bronx and Manhattan. America's greatest stone arch is the 220-foot span Cabin John Aqueduct Bridge (1864) over Cabin John Creek in suburban Maryland outside Washington, DC. It was the longest arch bridge in the world until 1905.

Masonry arch bridges can be composed of either stone or brick, or both, but most are entirely of stone, and the oldest extant vehicular bridge type in the United States is likely the stone arch. Stone and wood were often the most readily available building materials for bridges long before fabricated metal was introduced towards the middle of the nineteenth century, and of the two, stone was by far the preferred choice where durability and permanence were required. The technology of stone arch construction is ancient, and from the seventeenth century through the early nineteenth century, the skills necessary for erection of falsework to support arch construction (carpentry) and for the laying of stones (masonry) were commonly found within the local labor pool, although this was somewhat truer of Colonial America and the new Republic than it was for the railroad-expanded nation of the mid-to-late 1800s.

Stone arch bridges were generally more expensive to build than were timber bridges, but their use for roads and highways was favored for heavily traveled routes or locations of high visibility and importance; otherwise, the cost savings of timber bridges tended to offset their relative lack of permanence.

The oldest known stone arch highway bridge in the United States is the Frankford Avenue Bridge in Philadelphia, Pennsylvania, which crosses Pennypack Creek. Built in 1697 as part of the King’s Road, this National Civil Engineering Landmark has been extensively altered through the years and has suffered considerable loss of its original integrity (*1*, p. 10). A better example of an early stone arch structure is the Choate Bridge (1764), spanning the Ipswich River in Ipswich, Massachusetts. Although widened in 1838, this two span, 75 foot-long bridge is listed in the NRHP and is the oldest known extant bridge in the state. This important structure was documented by the Historic American Buildings Survey (HABS) and the Historic American Engineering Record (HAER), respectively, in 1934 and 1986.

Increased use of metal truss bridges on highways from the late 1800s into the early twentieth century, coupled with a decrease in the number of skilled masons, and advancements in reinforced concrete construction technology in the early decades of the twentieth century, led to a decline in stone arch bridge construction. A brief resurgence in construction of this type occurred during the Great Depression due to the availability and low wage rates for both skilled masons and unskilled labor.

One good example of a masonry arch bridge built during the later stages of this period is the Possum Kingdom Bridge, constructed across the Brazos River on State Highway 16 near the town of Graford, Texas. This eighteen-arch bridge was built by the Works Progress Administration between 1940 and 1942, using unemployed coal miners who had acquired stone cutting skills in the underground mines. It is the longest and most substantial masonry arch bridge in Texas, and like many earlier masonry highway bridges built in the 1800s, it was constructed to withstand floodwaters from an upstream dam.

Some states have an abundance of stone arch highway bridges, while others do not. For example, the NRHP Inventory—Nomination Form for “Masonry Arch Bridges of Kansas” (*12*) states that “stone arch bridges were popular in Kansas for many reasons, a major one being that the stone was often available locally.” The NRHP Multiple Property Documentation Form for “Minnesota Masonry Arch Highway Bridges, 1870-1945” (*13*) similarly found that there were 45 masonry arch bridges in the state, all of which appeared to be constructed of local stone. In contrast, the NHRP Multiple Property Documentation Form for “Historic Highway Bridges of Michigan, 1875-1948” (*14*) states that “despite an abundance of stone in various forms through the state and an indigenous tradition of masonry construction, stone bridges were never built in abundance in Michigan.” The NRHP Multiple Property Documentation form for “Highway Bridges in Nebraska: 1870-1942” (*15*) noted that stone arch bridges were never popular in that state, and lists only two bridges of that type as possibly eligible for the NRHP. However, despite variation in frequency from state to state and region to

region, stone arch bridges were constructed in most states, even if there are only a few extant examples in any one state.

The strength and durability of stone arch bridges made them popular for non-highway transport systems, such as canals, aqueducts, and railroads. Although stone arch canals and aqueducts no longer exist in great numbers, there are a number of stone arch railroad bridges, including grade separation structures, still scattered about the country. The oldest stone arch bridges are viaducts, which are addressed in Section 3.6.

Significance Assessment: Generally, stone arch bridges built during the nineteenth century are found today in areas where good stone was available. Stone arches were common in the first half of the nineteenth century, and a number of these structures still exist. There were flourishes of stone arch construction in the late nineteenth and early twentieth centuries, as in park bridges built during the City Beautiful movement and in the work projects of the Great Depression.

Stone arch bridges from the late eighteenth and first half of the nineteenth century are highly significant within the context of this study if they retain their character-defining features. Character-defining features include the arch ring with keystone, barrel, spandrel wall, parapet, headwalls and abutments/wingwalls. Piers may also be a character-defining feature.

Many of these stone arch structures possess both engineering and historical significance, the latter for associations with early and important infrastructure projects, such as the turnpikes, railroads and canals. Also significant are the Depression-era stone arch bridges, constructed up to the early 1940s by government work programs. The structures may possess both engineering and historical significance for their associations with the work programs of the Great Depression of the 1930s. Bridges associated with parks may be significant. Stone arch bridges that do not fit within these areas (early, Depression-era, association with parks) generally possess less significance, but are still significant within the context of this study.

Examples of Stone Arch

1. Goose Creek Stone Bridge (Ashby's Gap Turnpike Bridge) (ca. 1810s), Loudoun County, VA. NRHP listed 1974.
2. Wade Park Avenue Bridge (1899), Rockefeller Park, Cleveland, OH. NRHP listed 1982.
3. Park Avenue Bridge (1907), El Paso County, CO. NRHP listed 2000 in Vehicular bridges in Colorado Thematic Resource Nomination.
4. Cedar Creek Bridge (1935), Conway County, AR. NRHP listed 1990 in Historic Bridges of Arkansas MPS.
5. "S" Bridge (first quarter nineteenth century), West of Cambridge, Cambridge vicinity, Guernsey County, OH. HABS recorded 1933.
6. Cabin John Aqueduct Bridge (1853-1864), MacArthur Boulevard, spanning Cabin John Creek at Cabin John, Montgomery County, MD. HAER MD-51.

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

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

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

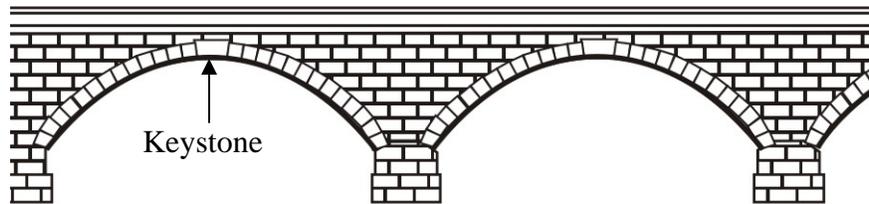


Figure 3-43. Gulph Creek Stone Arch Bridge (1789), Old Gulph Road, Upper Merion, Montgomery County, Pennsylvania. This eighteenth century stone arch bridge is one of the oldest surviving bridges in Pennsylvania.



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

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



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



3.2.2 Reinforced Concrete Melan/von Emperger/Thacher Arch

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

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

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

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

In 1902, Henry C. Turner, a former Ransome assistant, founded the Turner Construction Company and began fully exploiting the Ransome System. Apparently Turner had acquired some rights to the Ransome patent. Ransome continued to work on his own, however, and the Foster-Armstrong piano factory in Rochester, New York, was built in 1905 according to the “Ransome-Smith reinforced concrete method.” The “Smith” in the name referred to borax king Francis M. Smith, who, along with Ransome,

formed the Ransome & Smith Contracting Company and built an addition to the Pacific Coast Borax Company factory in Alameda, California, in 1889, and a warehouse for the Pacific Coast Borax Company facility in Bayonne, New Jersey, in 1898, using Ransome's method. Ransome also designed an elegant little arched footbridge over a pond at Presdeleau, Smith's estate at Shelter Island, New York. This structure, which still exists, and the two bridges erected in San Francisco, are the only bridges known to have been designed by Ransome. Other engineers and builders eventually propagated his design for use in buildings, but in the late 1890s and well into the twentieth century there were other reinforcing systems for concrete bridges that were better promoted by their designers and much more widely used in bridge construction.

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

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

In 1897, von Emperger patented a system of reinforcing concrete arches with steel ribs consisting of a pair of parallel, curved, rolled I-beams, each beam placed near one surface of the concrete, with secondary members connecting the beams (#583,464). Both bars extended into the abutments of the arch. This system was enough of a refinement of the one developed by Melan to win a patent, but it still followed the ideas espoused by

the Austrian engineer. With confidence in the future of the Melan system, von Emperger had earlier founded the Melan Arch Construction Company in New York City, and went on to build several Melan-style bridges. One small Melan-system bridge that may have been built by von Emperger's company was the Doan Brook Bridge over Jephta Road in Cleveland (1900). By the turn of the century, however, von Emperger had left his company in the care of his design engineer, William Meuser, who formed a new partnership about 1900 with a western agent for the von Emperger firm, Edwin Thacher (1840-1920), who had built the first large Melan arch bridge in 1896 over the Kansas River in Topeka, Kansas. In 1901, Meuser and Thacher renamed their firm the Concrete Steel Engineering Company, and under this name built more than 200 Melan arch bridges across the country by 1912, with Thacher acting as the chief engineer and dominant partner.

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

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

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

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

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

Examples of Reinforced Concrete Melan/von Emperger/Thacher Arch

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

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

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



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



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



3.2.3 Reinforced Concrete Luten Arch

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

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

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

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

establishment finally washed over Luten in 1918, and his patents, along with some of Thatcher's, were invalidated.

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

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

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

Examples of Reinforced Concrete Luten Arch

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

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

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



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



3-51a. Three-quarter view.



3-51b. Detail of open spandrel.

3.2.4 Reinforced Concrete Marsh and Rainbow (Through) Arch

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

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

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

demolished, have been documented across the Little Wabash River at Carmi, Illinois (1917); and across the Cannonball River at Mott, North Dakota (1921). The greatest number of extant Marsh Arch Bridges, however, may be found in Kansas, Iowa and Ohio.

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

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

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

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

records. Kansas has completed a study of its Marsh arches, which can be found at <http://midwestbridges.com/marsharch.html>.

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

Examples Reinforced Concrete Marsh or Rainbow (Through) Arch

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

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

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



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



3.2.5 Reinforced Concrete Closed Spandrel Arch

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

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

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

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

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

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

Examples of Reinforced Concrete Closed Spandrel Arch

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

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

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



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

3.2.6 Reinforced Concrete Open Spandrel Arch

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

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

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

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

Examples of Reinforced Concrete Open Spandrel Arch

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

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

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

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



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



3.2.7 Steel Tied Arch

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

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

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

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

Examples of Steel Tied Arch

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

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

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



3-58a. Three quarter view.



3-58b. Detail of connection.

3.2.8 Reinforced Concrete Tied Arch

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

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

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

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

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

Examples of Reinforced Concrete Tied Arch

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

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

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



3-59a. View from below.



3-59b. Through view.

3.2.9 *Steel Hinged Arch*

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

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

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

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

Significance Assessment: Hinged steel arches built during the historic period covered in this study (through 1955) are not among the most common bridge types in this study. Due to this fact and the fact that most are monumental structures, they are highly significant within the context of this study if they retain their character-defining features,

which include curved girder or truss top chord, bottom chord, suspenders, ties and piers, hinges and hinges, and abutments (buttresses). Most possess historic as well as engineering significance, as through their construction they solved transportation problems encountered at major river crossings. Many also have important scenic qualities.

Examples of Steel Hinged Arch

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

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

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

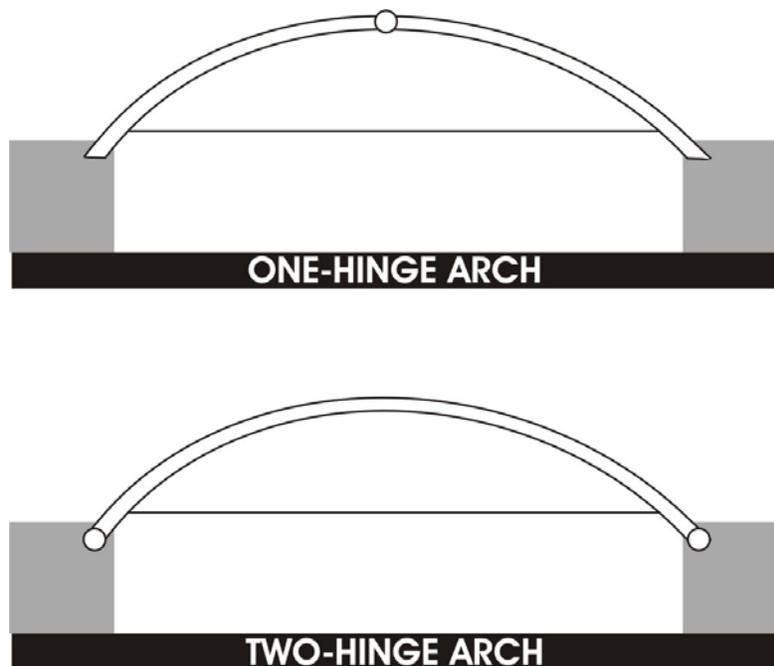


Figure 3-61. Washington (Heights) Bridge (1889), Bronx County, New York. This bridge is an example of a two-hinged steel arch.

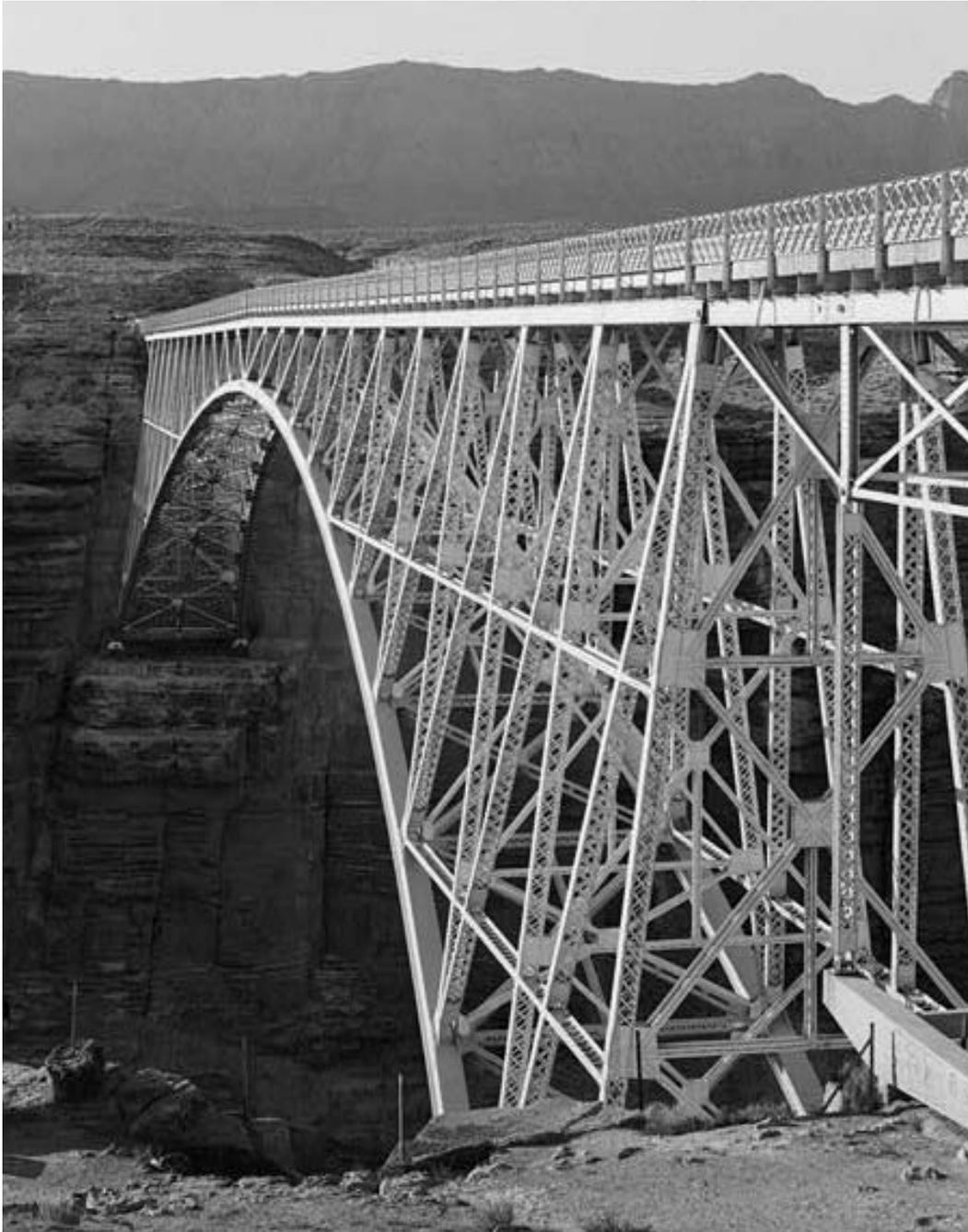


3-61a. View towards Manhattan.



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

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



3.2.10 Reinforced Concrete Hinged Arch

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

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

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

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

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

The earliest extant three-hinged reinforced concrete arch bridge in the nation is the Ross Drive Bridge in Rock Creek Park, Washington, DC. Originally built in 1907,

this NRHP-listed bridge was widened in 1968. It is a rare example of a hinged concrete arch bridge in which the hinges were left exposed. Most hinged concrete arch bridges have hinges that are imbedded in the concrete.

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

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

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

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

Examples of Reinforced Concrete Hinged Arch

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

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

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



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



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

3.3 Slab, Beam, Girder and Rigid Types

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

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

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

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

3.3.1 *Timber Stringer*

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

In the early twentieth century, a design for a timber stringer was included in the standardized designs of a number of the state departments of transportation. The Montana Highway Commission, for example, developed a standard design for simple-span timber bridges in 1915. By the 1920s it became necessary to modify this design, due to higher vehicle weights, using creosote-treated timbers. In 1933, the Maryland State Roads Commission issued plans for “Standard Timber Beam Bridges for Secondary Roads.” The Montana Highway Department built hundreds of timber stringer

bridges up to the mid-1950s, when prestressed concrete and steel bridges began to be used (26). In New Jersey, timber stringer bridges were reportedly built as late as the 1990s, particularly in the southern portion of the state (27). In Maryland, timber beam bridges were once found in abundance in the Tidewater region. In Colorado, they have historically been the most common bridge type and there are seven timber stringer bridges in the state that are NRHP listed or eligible. In West Virginia, there are currently 24 timber stringer bridges on the Department of Transportation state inventory (not all of historic age). In Georgia, the State Highway Department adopted a standard design for timber beam bridges in 1919, and more than 100 pre-1956 examples were identified during research for the *Historic Bridge Inventory Update* (28).

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

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

Examples of Timber Stringer

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

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

Figure 3-65. Elevation drawing of timber stringer.

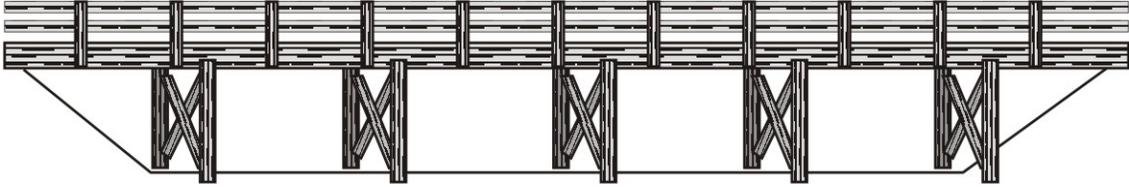


Figure 3-66. Fishing Bridge (1937), spanning Yellowstone River at East Entrance Road, Yellowstone National Park, Park County, Wyoming. This NPS-built rustic timber bridge was erected on pile bents.



3-66a. Elevation view.



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

3.3.2 Reinforced Concrete Cast-in-Place Slabs

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

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

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

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

buildings, or was simply a progression and adaptation of earlier systems that had been applied to reinforced concrete arch bridge construction.

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

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

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

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

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

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

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

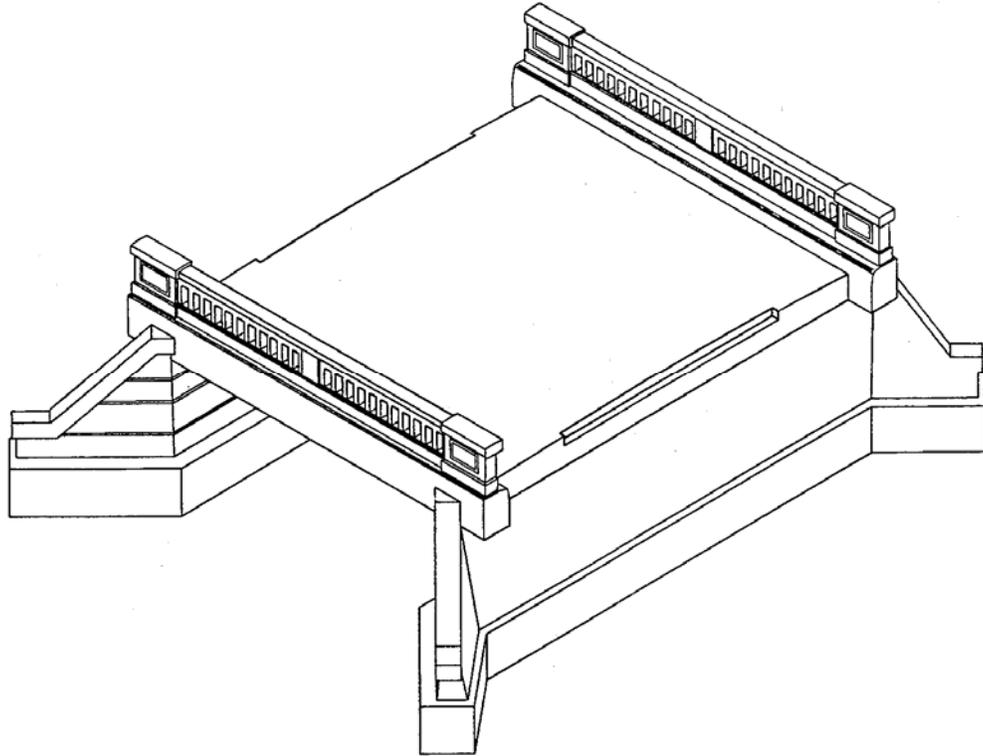
Significance Assessment: A number of pre-1955 slab bridges remain, many because they have thick slabs and are often located in rural areas not subject to roadway salting. Pre-1955 concrete slabs possess significance within the context of this study if these are intact. The most significant types of slab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

Examples of Reinforced Concrete Cast-in-Place Slabs

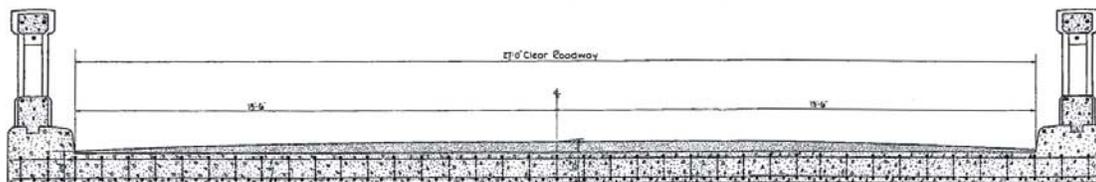
1. Dry Creek Bridge (1929), Pierce County, WA. NRHP listed 1997 in Mt. Rainier National Park MPS.
2. Chester County Bridge No. 225 (1907), spanning Tweed Creek at Hopewell Road, Oxford vicinity, Chester County, PA. HAER PA-415.
3. Coop Creek Bridge (1940), Broadway Street (CR 236), Sebastian County,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

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

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



3-67a. Isometric view.



3-67b. Roadway cross section.

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



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



3-69a. Elevation view.



3-69b. Detail of bridge “plaque.”

3.3.3 Reinforced Concrete T-Beams

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

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

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

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

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

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

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

Examples of Reinforced Concrete T-Beam

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

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

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

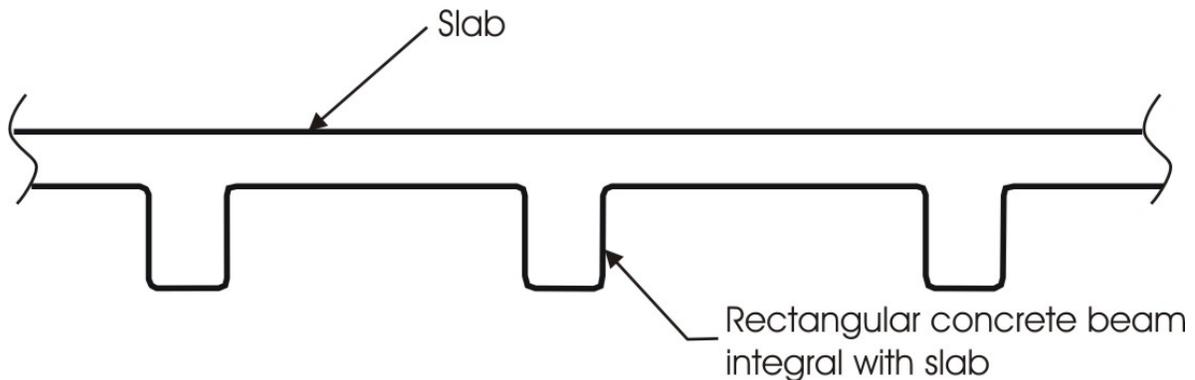


Figure 3-71. Fullersburg Bridge (1924), spanning Salt Creek at York Road, Oak Brook, Du Page County, Illinois. This is an example of a T-beam concrete bridge.



3-71a. Elevation view



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

3.3.4 Reinforced Concrete Channel Beams

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

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

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

Example of Reinforced Concrete Channel Beams

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

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

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



3.3.5 Reinforced Concrete Girders

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

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

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

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

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

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

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

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

Examples of Reinforced Concrete Girders

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

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

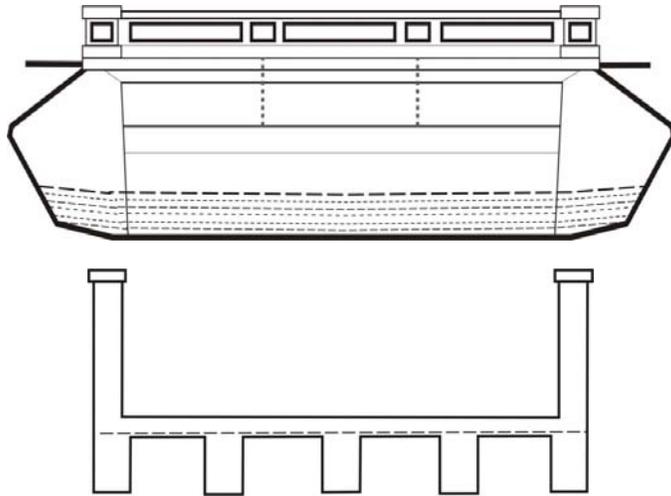


Figure 3-73. Drawings of elevation and section of concrete girder. Adapted from Maryland State Roads Commission's 1919 "Standard Girder Bridges General Plan."

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



3-74a. Elevation view.



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

3.3.6 Reinforced Concrete Rigid Frames

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

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

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

This type was considered to be an efficient use of material in its time, and was well suited to parkways and other locations where aesthetics were important. It also worked well for river and valley crossings because the horizontal or diagonal (in V-shaped frames) pier sections, when tilted at an angle, can straddle crossings very

effectively. The junction of the pier and the beam can be difficult to fabricate, however, and it takes an extensive amount of formwork to erect the rigid frame, which is particularly problematic for river crossings. After the introduction of pre-stressing in the 1950s, the rigid frame span began to lose popularity in comparison to more economical types of reinforced concrete bridges.

Significance Assessment: Rigid frame structures, primarily built between the early 1920s and 1950, possess significance within the context of this study if they possess their character-defining features, which include a monolithic substructure and superstructure of one continuous fabric, and a parapet railing. The more highly-significant rigid frames are those that possess integrity and date early in the period of the structure’s development in the United States (1920s) and those that can be documented as a representative example of a department of transportation’s standard bridge design. Also significant are those built on parkways, as they possess both engineering significance and historic significance for their association with the development of the parkway.

Examples of Reinforced Concrete Rigid Frames

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

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

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

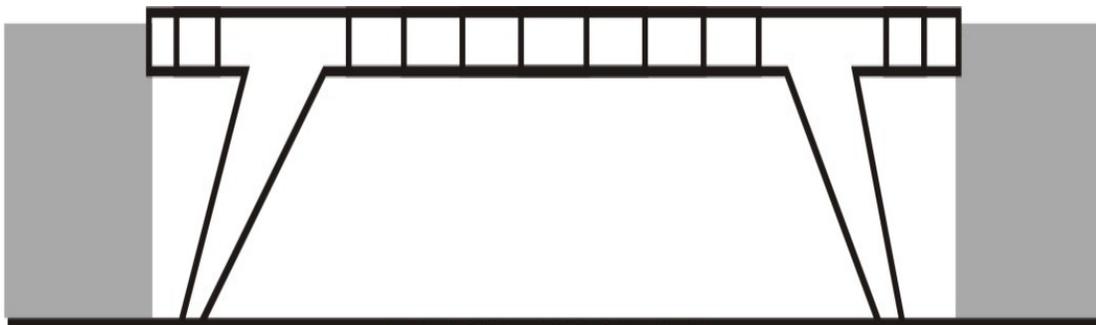


Figure 3-76. Dodge Street Overpass (1934) over Saddle Creek Road, Omaha, Nebraska. This structure was built as part of a federal aid project. Salvaged stone curbing was reused as facing for the structure. (Photograph from <http://www.fhwa.dot.gov/ndiv/bridges/histbrdg.htm>.)



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



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



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

3.3.7 Reinforced Concrete Precast Slabs

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

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

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

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

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

NRHP examples of Reinforced Concrete Precast Slabs

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

3.3.8 Prestressed Concrete I-Beams

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

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

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

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

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

used efficiently in crossover structures over depressed freeways. As confidence in longer spans increased along with the demonstrated ability of the prestressing industry to produce high-strength concrete, spans of 150 feet could be constructed economically, though transporting them to the construction site could pose problems.

Highway construction began to escalate approaching the interstate boom spurred by the 1956 Federal Aid Highway Act, and thus, the arrival of prestressing was very timely. Nothing has been as beneficial to the economy and durability of American highway bridges as precast, pretensioned concrete I-beams. In the early years of interstate highway construction, prestressed beam spans were offered to contractors as alternates to continuous steel I-beam units. It soon became obvious that steel could not compete economically. Prestressed beams became the best choice for many crossover structures and stream crossings.

Although pre-stressing was first used in the United States in application to an I-beam bridge, pre-stressing can also be applied to several other bridge types, including slabs, T-Beams, girders, box beams, and rigid forms. In fact, the first prestressed concrete beam bridge in the United States to be completed was not the Walnut Lane Bridge, but a small “block” beam bridge completed in October 1951, in Madison County, Tennessee. The Duffy’s Creek Bridge (1950), designed by Ross Bryan, is discussed in the following section of this chapter (prestressed box beams).

In prestressed concrete bridges, the tensile forces caused by the application of loads are reduced in the main structural members by inducing internal compressive forces by means of high tensile strength wires, cables or (occasionally) bars. The compressive forces may be applied during fabrication of the member by stretching the steel reinforcement prior to casting and curing of the concrete. After the concrete has cured, the tension on the steel is released, thus transferring the load to the concrete. The concrete is in direct contact with the steel so that bonding of the two materials can occur. When external loads (traffic and the weight of the deck and other bridge components) are applied to the member, tensile forces that are thus created are counterbalanced by the internal compressive forces induced by the pre-tensioning of the steel. This method of pre-stressing is called pre-tensioning.

Another method of pre-stressing, called post-tensioning, involves placing sleeves or ducts in the concrete member during fabrication, into which steel reinforcement is placed after curing of the concrete. The reinforcement is then stretched (stressed) by jacking, and locked in place by anchor plates or other locking devices. If bonding is desired, grout may be injected into the sleeves. In some cases, however, a protective covering is applied to the steel to de-bond it from the concrete in order to control cracking in end sections. Occasionally, though usually in more modern bridges that have not yet achieved “historic age,” a combination of pre-tensioning and post-tensioning is used. But, whatever the method employed, when compressive forces are properly calculated and proper fabrication methodology is followed, the prestressed bridge members will not develop stress cracks.

Significance Assessment: This type of structure was developed late in the historic period covered by this report (through 1955). Because of the influence of prestressed concrete I-beams on modern bridge technology, the early examples (pre-1955) that possess integrity are significant within the context of this study. It is thought that they would be highly significant, but insufficient historic context/scholarship exists for this period of bridge building to confidently assess the significance of this structural type. Character-defining features that contribute to integrity include: the slab, longitudinal beams, floor beams, a parapet or railing if integral, and abutments, piers and wingwalls, when present.

ASCE's History & Heritage Committee, under the leadership of Professor Dario Gasparini, Case Western Reserve University, is seeking assistance identifying early prestressed concrete projects that may merit designation as National Historic Civil Engineering Landmarks. The fact that ASCE is seeking identification of prestressed concrete structures means that this bridge type only recently has been perceived as significant.

Examples of Prestressed Concrete I-Beams: Because of its comparative recent vintage, meaning many of the examples are just reaching 50 years of age, only one NRHP-listed/HAER-recorded example of this type has been identified, the Walnut Lane Bridge.

1. Walnut Lane Bridge (1950); spanning Lincoln Drive & Monoshone Creek at Walnut, Philadelphia County, Pennsylvania. NRHP listed 1984. HAER PA-125.
2. Roseville Bridge (1952), CR 32 over Moxahola Creek, Muskingum County, OH. NRHP eligible 2004 in *Third Ohio Historic Bridge Inventory, Evaluation and Management Plan for Bridges Built 1951 – 1960 and the Development of Ohio's Interstate Highway System*.
3. US 37 Bridge (1960), over Scioto River, Scioto Township, OH. NRHP eligible 2004 in *Third Ohio Historic Bridge Inventory, Evaluation and Management Plan for Bridges Built 1951 – 1960 and the Development of Ohio's Interstate Highway System*.
4. Bridge 39 7301 0000 0013 (1955), 15th Street, Allentown, PA. Determined NRHP eligible in state-wide bridge survey.
5. Bridge 67 3009 0180 0721 (1955), Ridge Avenue south of Philadelphia City border, Delaware County, PA. Determined NRHP eligible in state-wide bridge survey.

Figure 3-78 depicts the Walnut Lane Bridge, a prestressed concrete I-Beam structure.

Figure 3-78. Walnut Lane Bridge (1950), Philadelphia, Pennsylvania. This structure is the first prestressed concrete beam bridge built in the United States.



3-78a. Oblique View.



3-78b. View of underside of superstructure.

3.3.9 Prestressed Concrete Box Beams

History and Description: Prestressed box beams began to appear on highways in the early 1950s, but were not common until the 1960s. According to bridge historian Patrick Harshbarger, the Pennsylvania Highway Department, which may have been the first transportation agency to employ them, began using prestressed box beams in 1951. By 1954, they were building about sixty of them a year, mostly on secondary roads.

Problems with fabrication and construction soon became evident. Even so, box beams (and I-beams) remained popular where speed of construction or minimum section depth was critical. Many state highway departments (e.g., Pennsylvania, Florida, Tennessee, California and Texas) initiated research in an effort to develop economical precast structural shapes. Research resulted in simplified box, (as well as I-beam and double tee) standards and, in 1962, AASHTO and the Prestressed Concrete Institute (PCI) published recommendations for standard shapes. Construction experience improved and more prestressed structural shapes, such as box beams, were built.

Most bridges of this type have a rectangular cross section in which the top and bottom slabs act as the flanges and the side walls act as webs; however, the interior void of many early box beams were circular in section.

A similar type of prestressed structure is the “block” beam bridge. Although begun after the Walnut Lane Bridge, the Duffy’s Creek Bridge (1950) in Madison County, Tennessee, was completed first, thus making it the first prestressed concrete bridge to be put into service in the United States. This bridge features a “block” beam design developed by Ross Bryan (1910-2002). A 1933 graduate of the civil engineering program at the University of Kansas, Bryan worked early in his career at the Kansas Highway Department. He was also a structural design engineer in the Panama Canal Zone before and after World War II, and a structural engineer with Marr and Holman Architects until establishing Bryan and Dozier Consulting Engineers in 1949. Approximately four years later he formed Ross Bryan Associates, Inc., in Nashville, Tennessee; a company that still exists. Bryan led the firm until his retirement in 1977. He also designed a stadium in Fayetteville, Tennessee, which is credited as being the first prestressed concrete non-bridge structure in the country. Like many designers of concrete bridges, he was apparently more interested in building designs than in bridges. A small handful of bridges were designed by Bryan using this method, which does not appear to have been widely used.

According to a 1951 article in the *Engineering News Record* (33), the Duffy’s Creek Bridge consisted of pre-cast concrete standard machine blocks compressed by seven-wire galvanized wires. Each block had three cores. Special end blocks were made for anchoring the prestressed strands, and special depressor blocks held the strands in place. The blocks were strung over the prestressing strands and mortared together. An initial tension was then placed in the strand. After the mortar had been allowed to set for a day, additional force was applied. The unified beams thus formed were lifted onto the substructure to form the superstructure of the bridge. A concrete deck slab and integral

curb was then cast. Transverse strands were then placed and tensioned so that the beams would work together to handle the loads imposed on the bridge.

In 1996 Bryan was awarded the Medal of Honor by the Precast/Prestressed Concrete Institute in recognition of his contributions to the design of prestressed concrete structures (32). The Precast/Prestressed Concrete Institute also recognizes a prestressed block beam bridge built in Michigan by C. L. Johnson in 1950, but little is known about this designer or his work.

Significance Assessment: This type of structure was developed late in the historic period covered by this report (through 1955). Because of its relative commonness, the prestressed concrete box beam possesses a low level of significance within the context of this study. Early examples (pre-1955) that possess integrity are the most significant of this type. However, insufficient historic context/scholarship exists for this period of bridge building to confidently assess the significance of this structural type. Character-defining features that contribute to integrity include the slab, the box-shaped longitudinal beams, parapet or railing if integral and abutments, wingwalls and piers when present.

Examples of Prestressed Concrete Box Beams: Due to the fact that these structures are just reaching 50 years of age, no know examples are listed in the NRHP or HAER-recorded. The only readily identifiable examples that have been labeled as NRHP eligible are listed below.

1. Middle Pike Bridge #0630535 (1956), over Dry Run, AuGlaize County, OH. NRHP eligible 2004 in *Third Ohio Historic Bridge Inventory*.
2. Lippincott Road Bridge #1130234 (1956), over Mad River, Champaign County, OH. NRHP eligible 2004 in *Third Ohio Historic Bridge Inventory*.
3. Middleburg Road Bridge #1130412 (1954), over Branch of Big Darby Creek, Champaign County, OH. NRHP eligible 2004 in *Third Ohio Historic Bridge Inventory*.
4. Suder Avenue Bridge #4860098 (1959), over Ottawa River, Lucas County, OH. NRHP eligible 2004 in *Third Ohio Historic Bridge Inventory*.
5. Hempt Road Bridge (1952), over Hogestown Run, Silver Spring, Cumberland County, PA. NRHP eligible in state-wide bridge survey.
6. Scenic Drive Bridge (1950), over Hickory Run, Kidder, Carbon County, PA. Recommended NRHP eligible in statewide bridge survey.

Figure 3-79 depicts an example of a concrete box beam bridge.

Figure 3-79. Scenic Drive Bridge (1950), over Hickory Run, Carbon County, Pennsylvania. This 24-foot long structure was built as part of improvements at Hickory Run State Park. Photographs courtesy of PENNDOT.



3-79a. West elevation.



3-79b. Underside of box beams at stone abutment.

3.3.10 Metal Rolled Multi-Beams

History and Description: Bridge historians and bridge engineers frequently use the terms “beam” and “girder” interchangeably, however, for the purposes of this report, a distinction will be made between the two. As the FHWA *Bridge Inspector’s Reference Manual* (23, p. 8.2.1) states, “In steel fabrication, the word ‘beam’ refers to rolled shapes, while the word ‘girder’ refers to fabricated members.” Another term that is widely used in discussion of historic bridges is “stringer,” which generally refers to a type of bridge in which a series of parallel, relatively shallow, longitudinal beams (usually I-beams) serve as part of the superstructure in support of the deck or travel surface. The longitudinal beams are the “stringers” in a stringer bridge.

Iron I-beams were available to bridge designers prior to the Civil War, but the limited fabrication capabilities of iron mills in the nineteenth century dictated that metal beams were generally used only in place of timber stringers in short span bridges. In the 1890s, steel began to replace iron as the preferred material for metal bridge members as advances in technology lowered costs, enhanced the consistency, and increased the fabrication capabilities of the steel making industry. This shift was first observable in regard to metal truss bridges, which basically retained their primary design characteristics when expressed in steel rather than iron. Eventually, however, the increased ability of steel plants in the early twentieth century to roll steel I-beams and channels of just about any length and depth required by bridge designers, without warping of the member, facilitated development of the steel beam (stringer) bridge.

Although fabricated in the United States in the 1850s to 1860s, rolled beams were not generally used on highway bridges until the 1920s and 1930s. The earliest known standard drawings of the rolled beam bridge were prepared by the U.S. Government’s Bureau of Public Roads in 1917. The earliest structures were simple I-beam spans with timber decks, but reinforced concrete decks soon became standard. Span length capabilities were eventually increased through the use of cantilever drop-in units. Some of the advantages of continuity could be obtained without the structure being statically indeterminate. Hinges were notched beam seats with bearings first and pin and hangers later.

By the early 1940s, continuous units with riveted splices were being designed. Simple spans still retained popularity because of simpler construction. I-beams, in general, ceased to be economical by the early 1960s, succumbing to rising steel prices and a new and vital prestressed beam industry. There has been a slight resurgence in the use of steel I-beam spans as their cost has become comparable to concrete box beams, and steel is much easier to adapt to severe geometric constraints.

The *Bridge Inspector’s Reference Manual* states that the steel rolled multi-beam bridge is made up of three or more parallel rolled beams with a deck placed on top of the beams. The primary structural members of a rolled multi-beam bridge are the beams, and the secondary members are the diaphragms, when present. This type of superstructure is commonly used for simple spans, but continuous span designs have also been erected.

The “jack arch” is a deck support system comprised of a concrete (or, in rare cases, brick) arch springing from the bottom flanges of adjacent rolled steel beams, with the beams extending from abutment to abutment, or (for continuous spans) from pier to pier. The principle load carrying element is the steel beam. The concrete stiffens and strengthens the beam by preventing buckling of the compression flange while also protecting the beam from corrosion. Concrete was poured into corrugated metal form liners to encase the beams and integrate them with the deck. The concrete often extended up from the deck along both sides of the roadway to form a low curb or a parapet, with metal railings of various types frequently attached to the concrete extensions. In some cases a metal rail was attached to the sides of the deck without any extension of the concrete. This type was constructed from the late 1890s to the early 1930s, usually as simple span bridges on county roads. Examples have been identified in New York, New Jersey, Maine, Pennsylvania, Georgia, and Texas. These structures are very strong, but very difficult to rehabilitate; thus, not many extant NRHP-eligible examples survive in most states. However, more than 100 jack arch deck bridges were found during research for the Georgia *Historic Bridge Inventory Update* (June 2001), and thirty-nine pre-1930s examples were identified during research for the New York State *Final Report: Evaluation of National Register Eligibility* (34).

Significance Assessment: Metal rolled multi-beam bridges possess low significance within the context of this study. The level of significance within this category will depend on the structures’ dates, span lengths, integrity; and use of early, innovative fabricating techniques, such as welded splice connections. Character-defining features that contribute to a structure’s integrity include the rolled longitudinal I-beams or wide flange beams, floor beams, and original rails, piers, wingwalls and abutments.

Examples of Metal Rolled Multi-Beams

1. Twin Bridge (1900), Cherry County, Nebraska. NRHP listed 1992 in Highway Bridges in Nebraska MPS.
2. Brevard Bridge (1913), spanning Westland Run at Ullom Road, Expot vicinity, Washington County, PA. HAER PA-215.
3. South Euclid Road Bridge (ca.1900), spanning Squaconning Creek, Bay City, Bay County, MI. HAER-MI-42.
4. Parryville Bridge (1933), State Route 2008 over Pohapoco Creek, Parryville, Carbon County, PA. HAER PA-480.
5. Bridge 021-0182 (1929), Jefferson Road over Walnut Creek, Bibb County, GA. Determined NRHP eligible in statewide bridge survey.

Figures 3-80 and 3-81 illustrate a metal rolled beam structure.

Figure 3-80. Elevation drawing of a metal rolled beam bridge.

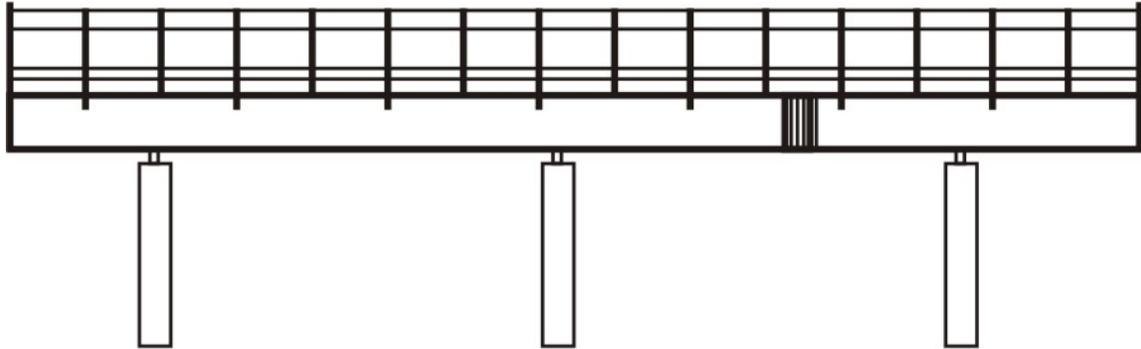


Figure 3-81. Parryville Bridge (1933), State Route 2008 over Pohapoco Creek, Parryville, Pennsylvania. This bridge is an example of the metal rolled multi-beam type.



3.3.11 *Metal Built-up Girder*

History and Description: The first plate-girder bridge in the United States was a single track deck-girder with clear span of 50 feet built for the Baltimore & Susquehanna Railroad by James Millholland at Bolton Station, Maryland, in 1846. Fabricated in the shop, the 14-ton bridge was hauled to the site and set in place. Millholland anticipated by 30 years the standard type girder bridge for short railway spans.

Built-up, riveted plate girders were introduced to highways in the late-nineteenth and early twentieth centuries, but this was rare due to the expense of fabricating built-up plate girder beams. Less expensive alternatives such as rolled girders and the early concrete forms were available.

Since the 1930s, I-shaped plate girders have been used to span beyond the range of rolled beams. Originally, girders were fabricated by riveting flange angles to a web plate and adding cover plates top and bottom. The most common configuration was two girders connected by transverse floor beams with rolled beam stringers parallel to the girders, topped by a one-way deck slab. Built-up steel plate girders remain one of the common bridge types for highway construction.

Welded girders replaced riveted built-up beams as fabrication and welding techniques improved. Design, detailing, and fabrication of welded steel girders became much simpler when welding was accepted as a quality connection technique. However, weld details were shown by numerous laboratory tests to be highly susceptible to fatigue crack failure in bridge girders and I-beams. In the late-1970s, weld flaws were discovered in the first generation (1950s) of welded girders and many states began ultrasonic testing. Numerous welds were found to be outside the limits of acceptable ultrasonic performance. The use of this type of girder on highway bridges was discontinued in favor of bolted connections and splices.

Multi-girder bridges often look similar to rolled multi-beam bridges, but the fabricated girders are generally larger than what rolling mills produce. Older multi-girder bridges use built-up members consisting of angles and plates that are riveted or welded together. This type of superstructure is used for simple and continuous spans, and is widely used for curved portions of bridges.

The two-girder bridge is similar to the multi-girder bridge in most respects, and may have web insert plates and transverse or longitudinal web stiffeners, but is differentiated by having just two primary girders. The floor system may be a girder-floorbeam, or girder-floorbeam-stringer configuration. Two girder bridges may be deck bridges with a floor system that supports the deck, which rests on the top of the flanges of the girders and floor system, or may be through girder bridges in which the deck is located between the girders, which extend above the travel surface. Pin and hanger connections are common features of two-girder deck bridges.

Although two-girder bridges are usually simple span structures, multiple span and continuous span configurations are not uncommon. The majority of older two-girder bridges are likely to feature riveted girders, but welded girders may also be found. Riveted through two-girder bridges, often referred to as “plate-girder” bridges, were once very popular with railroads for watercourse crossings and for grade separation structures where there was a need to achieve maximum vertical clearance between the rail deck and the water feature or the roadway.

Significance Assessment: Metal built-up girders possess moderate significance within the context of this study. Within this type, surviving riveted, built-up girders, dating from the early-twentieth century, of reasonable integrity, are more significant because of their relative rarity. The first generation, welded steel girders that survive from the 1950s are also of higher significance within this bridge type, as these structures have mostly been replaced due to their structural deficiency. Character defining features of this structure include riveted or welded metal plate girders, its floor system and abutments and/or wingwalls, when present.

Examples of Metal Built-up Girder

1. Francis Street Bridge (1894), Providence, Providence County, RI, HAER RI-33
2. North Kinney Road Bridge (c.1910), spanning Brown Creek, Rock City vicinity, Stephenson County, IL, HAER IL-129.
3. Georgetown Loop Plate Girder Bridge (n.d.), Clear Creek County, CO. NRHP listed 1970.
4. Bridge 191-0007-0 (1944), US 17 over Darien River, McIntosh County, GA. Determined NRHP eligible in statewide bridge survey.
5. Peartown Road Bridge (1909), SR 1053 over Cocalico Creek, West Cocalico, Lancaster County, PA. Determined NRHP eligible in statewide bridge survey.

Figures 3-82 and 3-83 contain photographs of metal fabricated girder bridges.



Figure 3-82.
Georgetown Loop
Plate girder Bridge
(n.d.), Clear Creek
County, Colorado.
This railroad bridge is
a metal built-up girder.
Photograph from
*Historic Bridges of the
Midwest*.

Figure 3-83. Francis Street Bridge (1894), near Union Station, Providence, Rhode Island. This structure is a metal, built-up girder.



3-83a. Side Elevation.



3-83b. View of underside of structure.

3.3.12 *Metal Rigid Frame*

History and Description: Steel rigid frame bridges are popular designs used by many state departments of transportation for span lengths of about 50 to 200 feet because they are generally considered to be aesthetically pleasing structures that allow elimination of intermediate supports. The inclined frame sides or “legs” of rigid frame bridges are integral components of the entire structure and combine with the horizontal frame girders to contribute to the overall load-bearing capacity of the bridge. The superstructure can be constructed of two frames, as in a two-girder bridge, or of multiple frames, as in a multiple girder bridge. Moreover, rigid frame bridges can have web stiffeners or diaphragms, and floor systems composed of floorbeams and stringers.

Although most of the rigid frame bridges of the Merritt Parkway in Connecticut were constructed of concrete, not all were. The bridge spanning New Canaan Road/Route 123 in Norwalk, Fairfield County, was built as a single-span deck bridge composed of six steel rigid frames that spanned about 66 feet. This bridge has been widened to accommodate new traffic lanes.

Significance Assessment: Metal rigid frame bridges were developed simultaneously with concrete rigid frames, but they are much less common than the concrete versions. The use of steel would have been a matter of choice, based on economics, or simply to lend some variety to the more typical concrete span. The rigid frame, primarily built between the early 1920s and 1950 and much less common than the concrete rigid frame, possesses significance within the context of this study. The more highly-significant rigid frames are those that possess integrity and date early in the period of the structure’s development in the United States (1920s), and those that can be documented as a representative example of a department of transportation’s standard bridge design. Also significant are those built on parkways, as they possess both engineering significance and historic significance for their association with the development of the parkway.

Character-defining features that contribute to integrity include a monolithic substructure and superstructure of one continuous fabric (legs integral with horizontal girders), parapet or railing and piers, wingwalls and abutments. The outside elevations of these structures may be sheathed in concrete.

Examples of Metal Rigid Frame

1. M-27 Au Sable River bridge (1935), Crawford County, MI. NRHP Eligible in 1999, Highway Bridges of Michigan MPS.
2. New Canaan Road/Route 123 Bridge (1937), Fairfield County, CT. NRHP listed 1991 as part of Merritt Parkway MPS. HAER CT-87.
3. US 1 Bridge (1935), City Line Avenue over Amtrak, Philadelphia, PA. Determined NRHP eligible in statewide bridge survey.

Figure 3-84 shows a historic and current photograph of a metal rigid frame bridge. For a drawing of the type, refer to Figure 3-75, concrete rigid frame structure.

Figure 3-84. Merritt Parkway, New Canaan Road/Route 123 Bridge (1937), spanning New Canaan Road/Route 123, Norwalk, Connecticut. This is an example of a metal rigid frame structure, sheathed in concrete.



3-84a. Historic photograph of Merritt Parkway bridge.



3-84b. Recent photograph of same Merritt Parkway bridge.

3.4 Movable Spans

The machinery for swinging, lifting or opening is the distinguishing feature of moveable bridge spans. The development of reliable electric motors and techniques for counter balancing the massive weights of the bascule, lift, or swing spans marked the beginning of modern moveable bridge construction.

In order to keep navigable waterways free of obstruction, movable bridges or bridges with movable spans are sometimes required when the erection of a non-movable bridge of sufficient clearance is uneconomical or physically difficult. These movable bridges played a crucial role in eliminating many of the great navigable rivers of the nation as barriers to westward expansion, and became distinctive elements of many urban landscapes. There are several different types of movable bridges, but certain types, such as transporter and retractable, are uncommon. The three main types of commonly encountered movable bridges in the United States are the swing, bascule, and vertical lift. Swing spans may be sub-divided into three types: center pivot, rim bearing, and combination (rim bearing and center pivot), with the last constituting an uncommon type.

3.4.1 *Center-Bearing Swing Span*

History and Description: Dating from the 1890s to the 1920s, swing bridges were the earliest of the movable bridge types. They were simpler to build and operate than the other movable forms, but were slow to open and required large piers in the center of the shipping channel.

Although swing spans were once the most popular form of movable bridge in the United States, they were gradually supplanted by bascule and vertical lift designs because with a swing bridge there is always a structure (the pivot pier) in the waterway that serves as an obstruction to navigation, thus somewhat defeating the purpose of the span. Moreover, the clearance required for swinging the span tended to reduce the value of dock-front property in urban areas.

In the center pivot design, the span turns on a central pin or pivot, which bears the entire dead load of the span, and most of the live load. Part of the live load may also be transmitted to adjacent fixed spans through a locking mechanism when the span is in the closed position. Usually there are two trusses making up the swing span, although single truss designs may be found in smaller bridges. Occasionally, the swing span is composed of trusses of unequal mass, but this variation is very rare and most likely found in rim-bearing designs. The motive power of a swing bridge is usually supplied by electric motors or hydraulic motors, although older, smaller bridges are sometimes turned by manual power.

Although Waddell (9, p. 685) wrote in his highly regarded 1916 treatise that the choice between a center-pivot span and a rim-bearing span was “almost entirely a matter of taste; for there is no great difference between them in the cost, what little there is being favor of the latter,” he seemed to contradict himself by also stating that the choice

between types “will often depend upon the character of the pivot pier.” Rim-bearing spans were briefly more popular for use by railroads when rolling stock was increasing in weight because it was believed that they were more rigid than center-bearing spans, but center-bearing spans are somewhat less complex and easier to construct than rim-bearing spans. Whatever the reason one type was selected over the other, the center pivot design is more commonly encountered in extant structures.

Except for the operating mechanisms that provide movement, swing spans tend to resemble fixed spans in that they are likely to be trusses or girders. The operation of a swing span, however, creates stresses that would not occur in a fixed span; therefore, swing spans, particularly trusses, tend to be built more robustly than fixed spans, with heavier structural members and more counters or braces. Connections are usually made with bolts or rivets in older spans, or by welds in newer spans. Pinned connected trusses are very rare in swing spans due to the stress placed upon the points of connection when the span is in operation.

Significance Assessment: Center bearing swing span bridges are among the least common bridge types in this study and are considered significant. Less common than other types of moveable spans, center bearing swing span bridges from the late nineteenth and early twentieth centuries possess a high level of significance within this type if they retain their integrity. Examples built late in the historic period covered by this study would be considered moderately significant, possessing less significance than the early structures. Character-defining features that contribute to integrity include a swing span that possesses the features of its respective type (e.g., truss or beam), central pier of masonry or concrete, pivot, and end rests. Features such as control houses, other operational machinery, and abutments, piers or wingwalls may also be character-defining features.

Examples of Center-Bearing Swing Spans

1. Hargrove Pivot Bridge (1917), Butler County, MO. NRHP listed 1985.
2. Judsonia Bridge (1924), White County, AR, NRHP listed 1990 in Historic Bridges of Arkansas MPS. HAER AR-73.
3. Great Northern Railway Company Bridge (ca. 1915), Cass County, MN. NRHP listed 1980.
4. Colusa Bridge (1901), spanning Sacramento River, Colusa, Colusa County, CA. HAER CA-7.
5. Chester & Delaware River Railroad (1907), spanning Chester Creek at Edgemont Avenue, Chester, Delaware County, PA. HAER PA-525.

Figures 3-85 through 3-87 depict center bearing swing span structures.

Figure 3-85. Elevation drawing of a center bearing swing span.

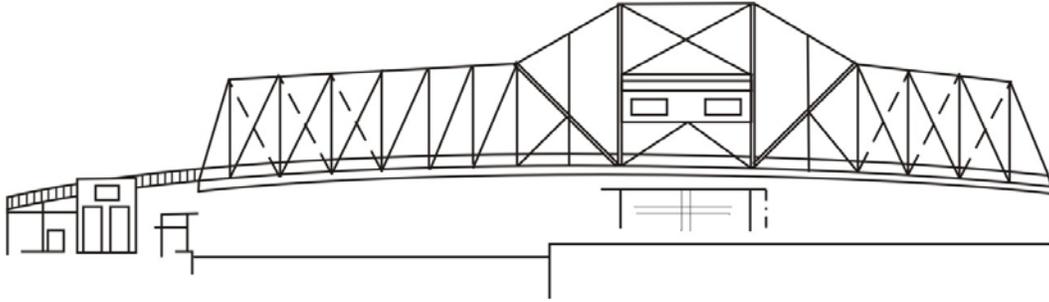


Figure 3-86. Colusa Bridge (1901), spanning Sacramento River, Colusa, California. The swing span of this bridge is pin connected.



Figure 3-87. Chester & Delaware River Railroad (1907), spanning Chester Creek, Chester, Pennsylvania. When built, this swing bridge was hand operated.

3.4.2 *Rim-Bearing Swing Span*

History and Description: Like center bearing swing spans, rim bearing swing spans date primarily from the 1890s to the 1920s. Both type swing spans were once the most popular form of movable bridge in the United States, but they were gradually supplanted by bascule and vertical lift designs because with a swing bridge there is always a structure (the pivot pier) in the waterway that serves as an obstruction to navigation, thus somewhat defeating the purpose of the span. Rim-bearing spans were briefly more popular for use by railroads than center swing spans when rolling stock was increasing in weight because it was believed that they were more rigid than center-bearing spans.

In the rim bearing design, the dead load is borne by a circular drum, which moves upon rollers. Live (traffic) loads are also borne by the drum, but part of the live load may also be transmitted to adjacent fixed spans through a locking mechanism when the span is in the closed position. Rim-bearing swing spans are usually composed of trusses of equal mass, but rare “bob-tailed” bridges with trusses of unequal mass are still extant. The drum of a rim-bearing swing span sits atop tapered wheels or rollers that are evenly spaced around the circumference of the drum. These rollers move within a raceway or track that is situated inside the periphery of the pier, and are held in position by steel radial roller shafts which radiate out from a capstan or center pivot bearing located at the center of rotation. Connections are usually made with bolts or rivets in older spans, or by welds in newer spans. Pinned connected trusses are very rare in swing spans due to the stress placed upon the points of connection when the span is in operation. The motive power is usually supplied by electric motors or hydraulic motors, although older, smaller bridges are sometimes turned by manual power.

Significance Assessment: Less common than other types of moveable spans, rim-bearing swing span bridges from the late nineteenth and early twentieth centuries are considered significant within the context of this study if they retain their integrity. Character-defining features that contribute to integrity include a swing span that possesses the features of its respective type (e.g., truss or beam), pier of masonry or concrete, pivot, and end rest. Features such as control houses, other operational machinery (e.g., drums, rollers, wheels), and abutments, piers or wingwalls may also be character-defining features. Examples built late in the historic period covered by this study would be considered moderately significant, possessing less significance than the early structures.

Examples of Rim-Bearing Swing Spans

1. Center Street Bridge (1901), Cleveland, Cuyahoga County, OH. HAER OH-10.
2. Northern Avenue Swing Bridge (1908), spanning Fort Point Channel, Boston, Suffolk County, MA. HAER MA-37.
3. Romeo Road, Sanitary & Ship Canal Bridge (1899), spanning Sanitary & Ship Canal, Romeoville, Will County, IL. HAER IL-41.

4. New York, New Haven & Hartford Railroad Bridge (1913), spanning Shaw's Cove, New London, New London County, CT. HAER CT-24.

Figure 3-88 contains photographs of a rim-bearing swing span bridge.

Figure 3-88. Northern Avenue Swing Bridge (1908), spanning Fort Point Channel, Boston, Massachusetts. The structure is a pin-connected rim bearing swing span.



3-88a. *Oblique view.*



3-88b. *Span in open position.*

3.4.3 Vertical Lift Span

History and Description: Dating from the late nineteenth century, the vertical lift type flourished for the next thirty years.

In 1872, Squire Whipple patented a vertical lift design that was used to span canals or small streams in New York and other Eastern states. These were modest structures of short span that were not required to elevate more than a short distance. The first vertical lift span of large scale in the United States was designed and patented by J. A. L. Waddell (1854-1938) in 1893 for the City of Duluth, Minnesota, which required a 250-foot wide clear channel and a 140-foot vertical clearance. Although this structure was never built, due to factors unrelated to the suitability of its design, it showed so much promise for addressing the limitations of swing, retractable and bascule bridges that the City of Chicago asked Waddell to design a similar bridge with a clear span of 130 feet and a vertical clearance of 150 feet for erection over the South Chicago River at South Halstead Street. Completed in 1894, the South Halstead Street Bridge was the first large-scale vertical lift bridge constructed in the United States.

Waddell made his principal assistant engineer, Ira G. Hedrick, his partner in 1899, but these men apparently did not design any vertical lift bridges together. In 1907, Waddell formed a new partnership with John Lyle Harrington (1868-1942), and the new firm soon won several contracts for vertical lift bridges of improved design that reflected Harrington's contribution. Before dissolving their partnership about 1915, Waddell and Harrington designed more than thirty bridges together. The Hawthorn Bridge across the Willamette River in Portland, Oregon, completed in 1910 and extensively renovated in 1999, is the oldest bridge designed by the partners that still retains its full functionality.

Harrington's new firm, Harrington, Howard and Ash, was recognized as a leader in vertical lift bridge design for many years. When Harrington left to form a partnership with Frank Cortelyou in 1928, his former company reorganized as Ash, Howard, Needles, and Tammen. The Stillwater Bridge, connecting Houlton, Wisconsin, with Stillwater, Minnesota, is NRHP-listed, Waddell-Harrington design built by this company in 1931. In 1941, there was a further reorganization of the firm as Howard, Needles, Tammen and Bergendoff, now known as HNTB Corporation.

After dissolution of his partnership with Harrington, Waddell was joined by his son, Needham Everett, to form Waddell and Son. Following his son's death in 1919, Waddell moved his office to New York and practiced alone for several years until making his principal assistant, Shorridge Hardesty, his partner in 1927. Hardesty had been an employee of Waddell since about 1908, and undoubtedly made significant contributions to the designs of Waddell well before becoming a partner. The Newark Bay Railroad Bridge, completed in 1925 (demolished in 1980), was one of the most notable works of Waddell during the 1920s. Waddell and Hardesty became widely known for designing a number of vertical lift railroad bridges in the New York metropolitan area, and also expanded their practice to include many non-movable highway bridges.

The great majority of historic-age vertical lift bridges are composed of two towers located on either side of a waterway, with a truss span between. The truss span is lifted by cables that are attached at the ends of the span and run over pulleys at the tops of the towers down to counterweights on vertical runways within the towers (8, pp. 103-4). The truss remains in a horizontal position throughout the operating cycle, and can be raised far enough to provide clearance for the largest ships or boats. (There is a newer vertical lift design that operates differently, but this sub-type does not fall within the parameters of this study.)

The vertical lift type was developed to replace the swing span because it was less obstructive of the channel and quicker to operate. Vertical lifts usually are found in flat terrain where the cost of long approaches to gain high-level crossings is prohibitive. Advantages included rapidity of operation, adjustable openings depending on the size of the vessel, and the ability to build in congested areas adjacent to other bridges. Many of the surviving vertical lift structures are railroad bridges.

Significance Assessment: Most vertical lift bridges are works of late nineteenth and early twentieth century civil and mechanical engineering and tend to dominate both urban and rural landscapes with their distinctive towers. These bridges are less common than many of the bridge types described in this study and, if the structures possess their character-defining features, they possess a high level of significance within the context of this study. Character defining features include two towers, the lift span (which will possess the character-defining features of the relevant span type), drive machinery, cables, pulleys, counterweight and piers or abutments. Another feature that may be considered character-defining is the operator's house.

Examples of Vertical Lift Spans

1. Snowden Bridge (1913), Richland County, MT. HAER MT-27.
2. City Waterway Bridge (1911), Pierce County, WA. NRHP listed 1982 in Historic Bridges/Tunnels in Washington State Thematic Resource. HAER WA-100.
3. White River Bridge at De Valls Bluff (1924), Prairie County, AR. NRHP listed in 1990, Historic Bridges of Arkansas MPS.
4. Meridian Bridge (1924), Cedar County, NE. NRHP listed 1993 in Highway Bridges in Nebraska MPS.
5. Sacramento River (Tower) Bridge (1936), Sacramento County, CA. NRHP listed in 1982. HAER CA-73.

Figures 3-89 and 3-90 depict, respectively, a drawing and a photograph of a vertical lift bridge.

Figure 3-89. Elevation drawing of a vertical lift bridge.

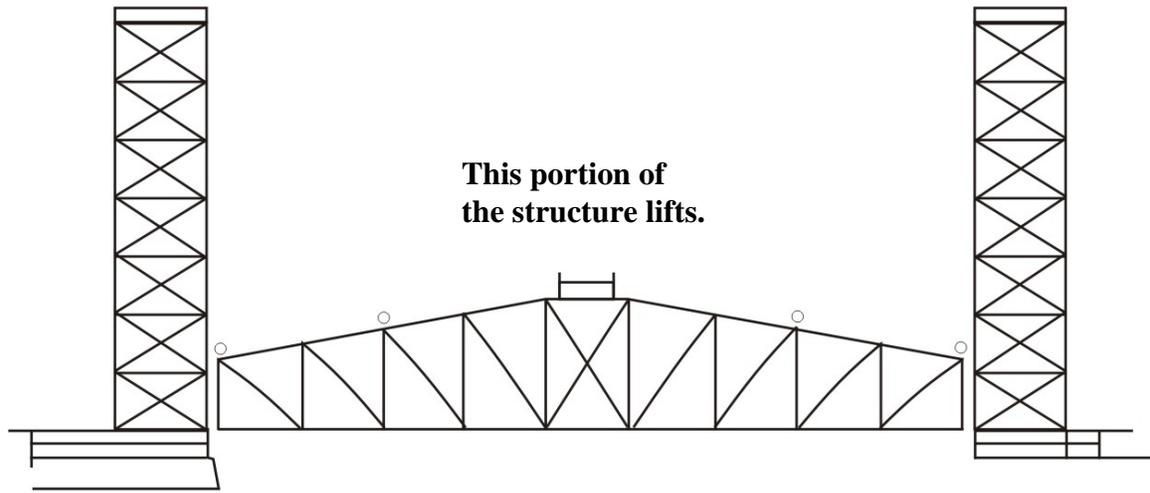


Figure 3-90. Snowden Bridge (1913), spanning Missouri River, Nohly vicinity, Richland County, Montana. This structure is an example of a vertical lift.



3.4.4 *Simple Trunnion (Milwaukee, Chicago) Bascule*

History and Description: Bascules were developed in the United States to replace its predecessor, swing spans, thus eliminating the central pier from the waterway. It was less obstructive of the channel and quicker to open. Engineers in Chicago and Milwaukee pioneered solutions at the turn of the century improving the mechanics of the lift and locking mechanisms resulting in an efficiently operating movable bridge in tight, constricted areas. Bascules quickly replaced swing spans.

Waddell (9, p. 700) states in *Bridge Engineering* that the first important bascule bridge in the United States was the Michigan Avenue Bridge at Buffalo, New York. He does not, however, provide a date for this bridge, which replaced a swing span that had been erected in 1873. Some authors have cited a completion date of 1897, which would seem to bring Waddell in contradiction with himself and others who cite construction of the rolling lift bascule, Van Buren Street Bridge in Chicago, Illinois, (opened to traffic in February 1895), as the beginning of the modern age of bascule bridges in America. Another date sometimes given for the Michigan Avenue Bascule Bridge is 1891, which seems to make more sense. But whatever the date of completion, it was certainly a version of the type first designed by Bernard Forest de Belidor in France about 1729 (35). It had cables attached to the free end of the span, which ran diagonally to pulleys at the top of the tower and then down to cast iron counterweights rolling on curved tracks that were designed so that the tension on the cables decreased as the lever arm of the center of gravity of the leaf diminished. This was supposed to address one of the main drawbacks of the simple trunnion design; it was difficult to balance and control the forces produced by operation, thus making it difficult to start and stop the motion of the leaf. Although Waddell claims that several examples of this particular type of bridge were built, they proved to be less efficient than other types and fell out of favor.

By the end of the nineteenth century there were independent movements in Chicago and Milwaukee to develop simpler bascule bridge designs. The Bridge Division of the Chicago Department of Public Works led the way by undertaking a study in 1899 to select a type of bridge most suitable for erection over the Chicago River and its tributaries. This study led to a juried competition the following year that was won by City Engineer John Erickson. The first simple trunnion bridge over the Chicago River was completed at Clybourn Place (now Cortland Street) in May 1902. A refined version of the design submitted by Ericson, this double-leaf structure provided a clear channel of about 115 feet. Typical of the eight other bascule highway bridges built by the city in the first decade of the twentieth century, this bridge was composed of trusses supported by trunnions located in line with the bottom chord, placed slightly behind the center of gravity of the span. Counterweights were attached to the shorter, shore arm, and descended into a pit in the pier when the bridge was open. The leaves were operated by a pinion and segmented, curved rack at the rear of the short arm. Refined over a period of thirty years, the “Chicago type” bascule bridge has become a symbol of the city and the most known type of simple trunnion bascule bridge. There was, however, another type of simple trunnion bascule developed at about the same time as the Chicago type.

A simple trunnion bascule bridge built by the Wisconsin Bridge Company at Grand (Wisconsin) Avenue in Milwaukee opened for traffic in March 1902, approximately two months before the Cortland Street Bridge, which is often erroneously credited with being the first of its type. In 1904 the Muskego Avenue (Emmber Lane) Bridge over the Menominee River was completed, incorporating several improvements to the design used for the Grand Avenue Bridge and establishing the basic design that would be followed in all thirteen bascule spans built by the City of Milwaukee before World War II. The distinctive features of this design that differentiated it from the Chicago-style bascule bridge were plate girder construction and a bottom mounted segmental rack. According to Hess and Frame, this design may have been more popular than the Chicago-style simple trunnion bascule bridge due to increased ease of construction and maintenance. The lack of a comprehensive national historic bridge inventory makes this claim difficult to prove, but it is certain that the Milwaukee design should deserve at least equal credit with the better known Chicago design as representative of the simple trunnion type of bascule bridge. This is confirmed by illustration of the Milwaukee type in the U. S. Department of Transportation *Bridge Inspector's Manual for Movable Bridges* (1977), which presents the plate girder bascule span with bottom mounted segmented rack as a “typical” type of trunnion bascule bridge (36, p. 46).

The word “bascule” comes from the old French word “bacule,” which means “seesaw,” and denotes a type of bridge so balanced that when one end is lowered the other is raised. The simplest type of bascule bridge is the single trunnion, in which the truss or girder (leaf) rotates vertically on a single, fixed-axis (or nearly fixed) horizontal shaft or pivot at or near the center of gravity of the rotating leaf. In the often-used example of the simple castle drawbridge, virtually all of the mass of the rotating leaf is located on one side of the pivot point. Since the drawbridge is unbalanced, however, it is not a true representation of type. In most modern versions of the bascule span there is a long arm on one side of the pivot point and a shorter arm, which is called the tail, and some means of countering the weight of the long arm to achieve balance, usually with a metal or concrete mass.

Significance Assessment: Simple trunnion bascule bridges are significant within the context of this study if they retain integrity. Of the highest significance within this type would be the early examples of the type (early twentieth century up to around 1930) and examples with historic associations with the Chicago Department of Public Works and the City of Milwaukee. The defining characteristic of the bascule is the upward rotating leaves, which can be single or double. Character-defining elements that contribute to the type’s integrity include the trunnions, integral counterweight, cables, pulleys, counterweight, and piers.

Examples of Simple Trunnion (Milwaukee, Chicago) Bascule Spans

1. West Jefferson Avenue-Rouge River Bridge (1922). Wayne County, MI. NRHP listed 2000.
2. Bridge of Lions (1927), St. Johns County, FL. NRHP listed 1982.

3. University Avenue Bridge (1927-33), spanning Schuylkill River at University Avenue, Philadelphia, Philadelphia County, PA. HAER PA-503.
4. West Adams Street Bridge (1926), West Adams Street, Chicago, Cook County, IL. HAER IL-51.
5. Jackson Boulevard Bridge (1916), spanning Chicago River, Chicago, Cook County, IL. HAER IL-55

Figures 3-91 and 3-92 contain photographs of a Chicago simple trunnion bascule and an example in Philadelphia.



Figure 3-91. Chicago River Bascule Bridge (1916), Jackson Boulevard, Chicago, Illinois. This simple trunnion, double leaf bascule was a product of the Strauss Bascule Bridge Company.



Figure 3-92. University Avenue Bridge (1927-33), spanning Schuylkill River, Philadelphia, Pennsylvania. This bridge has historical significance through its association with noted Philadelphia architect Paul Philippe Cret.

3.4.5 *Multiple Trunnion (Strauss) Bascule*

History and Description: Another type of trunnion bascule bridge was developed by Joseph B. Strauss (1870-1938), builder of the Golden Gate Bridge. Strauss founded his own company in 1902 after having been a draftsman for the New Jersey Steel and Iron Company and the Lassig Bridge and Iron Works, and an apprentice of famed Chicago bridge engineer Ralph Modjeski.

The distinctive feature of the Strauss trunnion is the pivoting of the counterweight at the end of the short arm. This enables the counterweight to move parallel to itself thus avoiding the counterweight pit which is required for other bascules such as the Chicago and Scherzer rolling lift types. Strauss claims to have introduced the use of concrete rather than iron for the counterweight. The counterweight could either be placed overhead or underneath the plane of the longer arm, and the longer arm could be a truss or a plate girder. The overhead counterweight version of this design was first patented in 1905, and the underneath version was first patented in 1906, although the same basic designs were also covered by later patents. A modification of this concept, in which the main fixed pivot point is located at the end pin of the bottom chord of the truss and the counterweight trunnion is a fixed pivot point at the top of a stationary tower that is supported by the main pier and an auxiliary pier, is known as the “heel trunnion” bascule. Although Strauss bascule bridges were built in great numbers across the United States, this type is now rare in relation to highways, but may exist in greater numbers, though fixed in place and inoperable, on railroad lines.

Significance Assessment: Multiple trunnion bascule spans are rare on highways and intact examples would possess a high level of significance within the context of this study. Early examples of the type are highly significant within the context of this type. All other intact examples are also considered significant. Character-defining features that contribute to the structure’s integrity include the trunnions, the integral counterweight, struts, and possibly, the control house and mechanical equipment. Since these structures may be built in any number of bridge types, they must also possess the features of the respective bridge type (e.g., truss, girder).

Examples of Multiple Trunnion (Strauss) Bascule Spans

1. Hoquiam River Bridge (1928), Grays Harbor County, WA. NRHP listed 1982 in Historic Bridges/Tunnels in Washington State Thematic Resource Nomination. HAER WA-93.
2. Philadelphia, Baltimore & Washington Railroad (1917-18), spanning Darby Creek, South of Essington Avenue, Eddystone, Delaware County, PA. HAER PA-526.
3. Henry Ford (Badger Avenue) Bridge (1924), spanning Cerritos Channel, Los Angeles-Long Beach, Los Angeles, Los Angeles County, CA. HAER CA-156.
4. NJ-127 Route 7 Bridge (1925), Route 7 (1AG) over Passaic River, Belleville, Essex County, NJ. HAER NJ-127.

5. Congress Street Bascule Bridge (1929-31), spanning Fort Point Channel at Congress Street, Boston, Suffolk County, MA. HAER MA-38.

Figures 3-93 through 3-95, depict, respectively, a drawing and photographs of the multiple trunnion lift type.

Figure 3-93. Elevation drawing of a multiple trunnion lift.

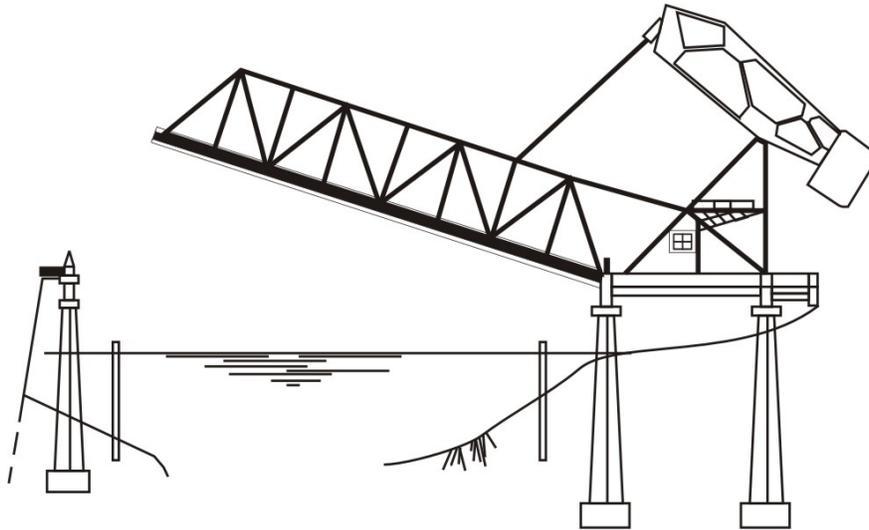


Figure 3-94. Philadelphia, Baltimore & Washington Railroad, spanning Darby Creek, Eddystone, Pennsylvania. This Strauss Bascule Bridge Company-designed structure was fabricated and built by Bethlehem Steel.



Figure 3-95. NJ-127 Route 7 Bridge (1925), Route 7 (1AG) over Passaic River, Belleville, New Jersey. This Strauss Bascule Company structure is a heel trunnion bascule.



3-95a. Oblique view.



3-95b. Detail of counterweight.

3.4.6 *Rolling Lift (Scherzer) Bascule*

History and Description: This bridge design was first patented by William Scherzer (1858-1893) in 1893, but following his death the patent was taken over by his brother Albert (1865-1916), who also founded the Scherzer Rolling Lift Bridge Company. Over a number of years the design was improved in a number of ways, including substitution of concrete for iron in the counterweight and an option of moving the counterweight to an overhead position. Scherzer rolling lifts were popular from the early 1900s well into mid-century because of their simplicity and the fact that they were quick to open and required a small amount of power for operation.

The Scherzer rolling lift bascule bridge became the favored replacement for swing spans in many parts of the United States, and was a design widely used by railroad companies. It was not a perfect design, however, because the point of pressure where the segmented girder encounters the horizontal track constantly changed as the span was in motion, thus tending to weaken bridges that were not securely founded on bedrock. This shortcoming had much to do with the eventual preeminence of simple and multiple trunnion types of the bascule bridge.

The rolling lift Van Buren Street Bridge (1895) was a double leaf bridge that exhibited two types of movement. As the leaves rose vertically they also moved horizontally away from the Chicago River. The leaves were girders segmented at the bottom that moved along a segmented horizontal track. A fixed cast iron counterweight located on the rear of the girder dropped down into a pit in the bridge's base as the girder "rocked" back along the horizontal track. In the Scherzer rolling lift form, the center of gravity moves in a horizontal line constantly shifting the point of application of the load to the pier or abutment. As the bridge lifted, the weights shifted back to the pier.

Until engineers were able to design good, solid foundations, the design was flawed because the rolling action caused piers to shift position. Engineers were eventually able to resolve this problem, which had afflicted the earlier bridges. Scherzer rolling lifts continued to be built into the 1940s because they were quick to open. Primarily used by railroads, Scherzer rolling lifts are less common in the context of the bascule type for vehicular spans.

Significance Assessment: Scherzer lift bridges are not common amongst bascule vehicular bridges. Intact examples of rolling lift bascule bridges are highly significant within the context of this study. Of the highest level of significance within this category are early (late nineteenth to early twentieth century) examples of the type. The character defining features are steel trusses or girders across the navigable channel that retain the features of their respective bridge type, and rigidly connected large steel rollers or rockers that have a weight at the rear to counterbalance the truss span. The rollers are cast in the form of a segment of a circle describing an arc of ninety degrees.

Examples of Rolling Lift (Scherzer) Bascule Spans

1. Blossomland Bridge (1949), Berrien County, MI. SHPO determined NRHP eligible.
2. DesPlaines River Bridge (1932), Jefferson Street, Joliet, Will County, IL. HAER IL-58.
3. Rehoboth Avenue Bridge (1926), State Route 1A (Rehoboth Avenue), Rehoboth Beach, Sussex County, DE. HAER DE-22.
4. New York, New Haven & Hartford Railroad Bridge (1907) spanning Niantic River, East Lyme, New London County, CT. HAER CT-27.
5. Seddon Island Scherzer Rolling Lift Bridge (1906), spanning Garrison Channel from Tampa to Seddon Island, Tampa, Hillsborough County, FL. HAER FL-3.
6. Pennsylvania Railroad "Eight-track" Bascule Bridge (1901), spanning Sanitary & Ship Canal, west of Western Avenue, Chicago, Cook County, IL. HAER IL-99.

Figures 3-96 and 3-97 contain photographs of Scherzer rolling lift bascule bridges.

Figure 3-96. DesPlaines River Bridge (1932), Jefferson Street, Joliet, Illinois. This bridge is an example of the Scherzer rolling lift bascule.



Figure 3-97. New York, New Haven & Hartford Railroad Bridge (1907), spanning Niantic River, East Lyme, Connecticut. This Scherzer rolling lift bridge is a through girder built for railroad use.



3-97a. Scherzer rolling lift in open position.



3-97b. Detail of control house and lift in open position.

3.5 Suspension

History and Description: In 1801, James Finley (1756-1828), a justice of the peace and judge in Fayette County, Pennsylvania, constructed the first metal suspension bridge in the United States over Jacob's Creek near Mt. Pleasant, on the highway between Uniontown and Greensburg, Pennsylvania. It had a clear span of about 70 feet and featured a wood truss-stiffened vehicular deck suspended from wrought iron chains. Although forty or more chain bridges were built according to Finley's 1808 patent, they tended to fail after only a few years of use. Some critics felt that the Finley design was only as good as the weakest link in one of the chains. This fear was addressed by the introduction of metal cables.

In 1816, wrought iron wire manufacturers, Josiah White (1780-1850) and Erskine Hazard (1790-1865), erected a wire pedestrian suspension bridge spanning about 410 feet across the Schuylkill River near Philadelphia, Pennsylvania. Although short-lived, this is believed to be the first wire suspension bridge in the country.

The first wire cable suspension bridge to carry vehicular traffic was the bridge over the Schuylkill River at Fairmont Park in Philadelphia, which is sometimes referred to as the Callowhill Street Bridge. Charles Ellet, Jr. (1810-1862) designed this bridge, which opened on January 1, 1842. The bridge had a clear span of 358 feet between the towers, supported by five cables on each side, and a generous deck width of 25 feet. This structure utilized the abutments of Lewis Wernwag's Colossus Bridge, a wood arched truss design completed in 1812 that was destroyed by fire in 1838. The bridge at Fairmont was well regarded, and encouraged the construction of other wire cable suspension bridges. It also established Ellet as a leading designer of suspension bridges, and led directly to his involvement in the planning for two important bridges, one at Wheeling, West Virginia, and the other across the Niagara Gorge between New York and Canada (37, p. 19).

In 1847, Ellet won the contract to design and build a bridge over the Ohio River at Wheeling, West Virginia. According to Emory Kemp, this victory may well have led to Ellet's success in beating out three other competitors, including John Roebling, for the right to construct a bridge over the Niagara Gorge. Completed in 1848, the first Niagara Suspension Bridge was designed to only carry pedestrian and carriage traffic. It was the unauthorized taking of tolls for this traffic that caused Ellet to have a falling out with the bridge owners. He quickly turned his full attention to the Wheeling Bridge, which was completed in 1849. Spanning 1,010 feet, this was the longest bridge in the world for many years after its completion and proved to be Ellet's greatest and last triumph as a bridge engineer.

The mantle of leading suspension bridge engineer soon passed from Ellet to John Roebling, who won the contract to build the second suspension bridge, and the first railroad bridge, across the Niagara Gorge. Completed in 1855, this bridge had a span slightly longer than 821 feet, and was the longest railway bridge in the world. Despite the success of the Niagara Bridge, and Roebling's confidence in the suspension type for

use by railroads, railroad company executives were not convinced that suspension bridges were capable of bearing the live loads imposed on them by heavy rail traffic. Their skepticism was not unjustified because the Niagara Bridge needed substantial repair in 1877 and 1880, and was declared inadequate in 1890. It would be 133 years before the next suspension bridge designed for railway traffic was built (*J*, p. 17).

Of greater longevity is the suspension bridge built by Roebling over the Ohio River between Cincinnati, Ohio, and Covington, Kentucky. Officially opened on January 1, 1867, this bridge has a main span of 1,057 feet. It had the longest clear span of any bridge in the world when completed, and was the first suspension bridge in the United States to use both vertical suspenders and diagonal stays fanning out from the towers. Concerns over the adequacy of the deck truss led to redesign by Wilhelm Hildenbrand and complete reconstruction in the late 1890s. In 1984 this structure was renamed the John A. Roebling Suspension Bridge.

Few suspension bridges in the world built since the time of the Roeblings can claim to stand entirely clear of the shadow cast by the Brooklyn Bridge. The plan involved two towers, cables and suspenders, anchorages and a stiffening truss - the character-defining features of a suspension bridge. Beginning with Ellet and significantly advanced by the Roeblings, Othmar Ammann, Leon Moiseiff, David B. Steinman, and others, America led the world in suspension bridge design and construction until completion of the Veranzano Narrows Bridge (1964) when design precedent revolved back to Europe.

The deck of a suspension bridge is hung from vertical suspenders that are affixed to ropes, chains, eyebars or cables that are in tension, passing over towers that are in compression. Usually the ends of the cables are anchored in large masses of stone or concrete, but a rare form of suspension bridge is “self-anchored.” Suspension bridges are particularly suited for spanning great distances, and some of the most monumental and historically significant bridges in the United States are of this type. At one time, however, a great number of suspension bridges of very modest span length were built across the country due to the type’s basic simplicity and ease of erection. But in some states, such as Oklahoma, the once common small suspension bridge has virtually disappeared.

Significance Assessment: Suspension bridges are the quintessential statement for elegant, vehicular, long-span bridges. The monumental examples often symbolize an urban gateway and many have become symbols of the cities for which they provide ingress. Most nineteenth century suspension bridges that retain integrity are highly significant within the context of this study and most have been determined NRHP eligible. Twentieth century examples are also considered significant; some possess high significance for the engineering challenges faced or for association with significant bridge designers.

Also significant are the short-span and/or vernacular suspension bridges found in smaller communities or the rural countryside of the United States, Appalachia for

example. Unlike the more monumental spans, many of these structures have been lost, rendering them increasingly less common.

Character defining features of suspension spans include the towers, cradles, cable or chain, suspenders, anchors, stays and piers.

Examples of Suspension Bridges

1. Brooklyn Bridge (1883), Kings County, NY. NRHP listed 1966. HAER NY-18.
2. Covington & Cincinnati Suspension Bridge (1867), Kenton County, KY. NRHP listed 1975. HAER KY-20.
3. Wheeling Suspension Bridge (1849), Wheeling, WV. NRHP listed 1970. HAER WV-2.
4. Dresden Bridge (1914), Muskingum County, OH. NRHP listed 1978. HAER OH-93.
5. Regency Suspension Bridge (1939), Mills County, Texas. NRHP listed 1976. HAER TX-61.
6. Mid Hudson Suspension Bridge (1930), spanning Hudson River, Poughkeepsie, Dutchess County, NY. HAER NY-160.
7. Seventh Street Bridge (1924-26), spanning Allegheny River at Seventh Street, Pittsburgh, Allegheny County, PA. HAER PA-490.
8. Clear Fork of Brazos River Suspension Bridge (1896), spanning Clear Fork of Brazos River, Albany vicinity, Shackelford County, TX. HAER TX-64.

Figures 3-98 through 3-102 provide examples of suspension bridges.

Figure 3-98. Covington & Cincinnati Suspension Bridge (1856-67), spanning Ohio River, between Covington, Kentucky and Cincinnati, Ohio. This Roebling bridge is a landmark structure across the Ohio River.



Figure 3-99. Mid Hudson Suspension Bridge (1930), spanning Hudson River, Poughkeepsie, New York. This suspension bridge was designed by noted bridge engineer Ralph Modjeski.



Figure 3-100. Seventh Street Bridge (1924-26), spanning Allegheny River at Seventh Street, Pittsburgh, Pennsylvania. One of the Three Sisters bridges, this self-anchored suspension bridge was designed by the Allegheny Department of Public Works and built by the American Bridge Company.





Figure 3-101. Clear Fork of Brazos River Suspension Bridge (1896), Shackelford County, Texas. The original cables have been replaced and the towers encased in concrete on this 312-foot long bridge.

Figure 3-102. Middle Bridge (1913), spanning Osage River, Warsaw, Missouri. This bridge is an example of a locally built and designed suspension bridge.



102a. Detail of tower.



102b. Through view.

3.6 Trestles and Viaducts

History and Description: In *Bridge Engineering* (1916), Waddell (9, p. 534) struggled to differentiate between trestles, viaducts and bridges, and noted that there was a tendency in the engineering profession to use the terms “trestle” and “viaduct” interchangeably, even though a trestle is a viaduct, but a viaduct is not necessarily a trestle. Both, of course, are bridges, even though all bridges are not viaducts or trestles. Dictionary definitions do not completely clear the matter up, as it is common to define a trestle as “an open braced framework to support a bridge,” which seems to ignore the fact that the supporting framework is an integral *part* of the bridge. Waddell’s perspective is more useful, in that he states, “a trestle consists of a succession of towers of steel, timber, or reinforced concrete, supporting short spans, while the piers of a viaduct may be of masonry, steel, or timber, and the spans may be either long or short.” If we add to this that a viaduct is a bridge-like structure, especially a large one composed of arches, carrying a roadway or railway across a valley or ravine, we begin to arrive at useful definitions of these types of bridges. We might also note that the term “trestle” has often been used for timber approaches to bridges.

The reason for considering trestles and viaducts as separate from other types of bridges is that they both have design attributes that were generated by the need of railroad engineers to maintain easy gradients, especially when crossing deep ravines or depressions, to compensate for the limited traction of railroad engines. As Eric DeLony (38, p. 29) has noted, “Viaducts and trestles were the engineering solution for maintaining a nearly straight and horizontal line where the depth and width of the valley or gorge rendered embankments impracticable.”

The earliest stone arch railroad bridge built in the United States, and the world’s oldest stone railroad span still in service, is the Carrollton Viaduct over Gwynn’s Falls on the old B & O Railroad line near Baltimore, Maryland. Completed in 1829, this National Historic Landmark and National Civil Engineering Landmark was designed by B&O engineer Casper Weaver and built by James Lloyd, a mason from Chambersburg, Pennsylvania, whose family built many stone arch highway bridges in Maryland (39). This 312-foot long bridge has a centered arch with a clear span length of 80 feet and clearance of about 51 feet above the stream, and has a small arched passageway through one of the approaches that accommodated an old wagon road.

The first multi-span stone arch railroad bridge in the United States was the Thomas Viaduct, completed in 1835 over the Patapsco River near Relay, Maryland. Designed by B&O Chief Engineer Benjamin Henry Latrobe II, and built by John McCartney, a master mason from Ohio, this structure includes eight Roman arches built on a four-degree curve. This 612-foot long bridge is a National Historic Landmark. Latrobe (1807-78) became famous within the engineering profession for executing the very difficult task of extending the B&O across the Allegheny Mountains. He formed Smith, Latrobe & Company with Charles Shaler Smith in 1866, and that firm became the Baltimore Bridge Company in 1869. Smith, Latrobe & Company built the Zoarville

Station Bridge in Ohio, which is the only Fink through truss known to exist in the country.

The Starrucca Viaduct on the New York & Erie Railroad (1848) rises 110 feet above Starrucca Creek between Lanesboro and Susquehanna, Pennsylvania. It is approximately 1,200 feet long, with eighteen arches, each spanning about 50 feet. The piers, arch rings and parapet walls are of blue stone obtained from a quarry about three miles above the creek. The engineer who built the viaduct, James P. Kirkwood (1807-77), was a Scotsman trained at Edinburgh College who gained practical experience working for the Stonington Railroad and the Boston & Albany Railroad. He is said to have accepted the challenge of bridging the very deep and wide valley of the Starrucca with the stipulation that the railroad company owners not be too averse to incurring the high cost of construction. When completed, the viaduct was the most expensive railroad bridge yet built, and the longest stone rail viaduct of its era. This bridge has been listed on the NRHP since 1975.

According to Waddell (9, p. 21), the first wood railroad trestle was built on the Philadelphia and Reading Railway in 1840. This type of structure used widely in the west during construction of the various transcontinental rail lines (although usually the wood had to be shipped to the site on rail cars), and was frequently used by railroads in the South where wood was more plentiful and easier to use for the erection of bridges than stone. Although often replaced by metal structures, wood railroad trestles may still be found in scattered locations across the country. One notable example is the Mexican Canyon Trestle near Cloudcroft, New Mexico. In the first half of the twentieth century, wood approach trestles were sometimes built to serve metal and even concrete highway bridges, but extant wood highway trestles are very rare.

Significance Assessment: The stone railroad viaducts of the early days of the railroad (second quarter of the nineteenth century) possess a high level of significance within the context of this study. Of slightly lesser significance are other, intact nineteenth century masonry, timber and steel viaducts, mainly constructed for railroads. In the twentieth century, viaducts built to carry roadways over the railroad may possess significance, but they are generally evaluated under the bridge type in which they fit. For example, to name a few types, concrete viaducts of the twentieth century can be built as concrete arches, girders or steel beam structures. Viaducts should possess integrity. Character defining features that define integrity include the features of the respective bridge type (e.g., concrete arch, girder).

Also significant within the context of this study are nineteenth century trestles that retain their integrity. It is important to note, however, that timber structures often have undergone substantial replacement of materials, a factor that may damage the structure's integrity. Twentieth century trestles are less significant within the context of this study, but may possess significance for factors such as a great length or solving a topographical engineering problem. Trestles should possess their character defining features, which include beams, abutments and timber or steel piers or bents.

Examples of Trestles and Viaducts

Viaducts

1. Carrollton Viaduct (1828-29), Baltimore County, MD. HAER MD-9. National Historic Landmark and National Civil Engineering Landmark.
2. Starrucca Viaduct (1848), Erie Railway spanning Starrucca Creek, Susquehanna County, PA. HAER PA-6.
3. Fourteenth Street Viaduct (1899), Fourteenth Street at Wazee Street, Denver, Denver County, CO. HAER CO-52.
4. Brownson Viaduct, Cheyenne County, NE. NRHP listed 1992 in Highway Bridges in Nebraska MPS.
5. Long Bridge, Baltimore & Ohio Railroad (1860-69), Keedysville Vicinity, Washington County, MD. HAER MD-37.
6. Dallas-Oak Cliff Viaduct (1910-12), spanning Trinity River at Houston Street, Dallas, Dallas County, TX, NR Listed. HAER TX-33.

Trestles

1. Mexican Canyon Trestle (Cloudcroft Railroad Trestle) (1899), NRHP listed 1979.
2. Mahoning Creek Trestle (1899), spanning Mahoning Creek, 1 mile West of Goodville, Goodville vicinity, Indiana County, PA. HAER PA-266.
3. Adelaide Bridge/Trestle (1894), Phantom Canyon Road over Eightmile Creek, Fremont County, CO. NRHP listed 1985.
4. West James Street Bridge (1924), over the Union Pacific Railroad on West James Street in Redfield, Jefferson County, AR. NRHP listed 1995
5. Promontory Route Railroad Trestle 790B (1872), 11 miles west of Corrine, Box Elder County, UT. HAER UT-64E.
6. Marquette Ore Dock No. 6 Timber Trestle (1931-32), Between East Lake Street and Ore Dock No. 6, Marquette City, Marquette County, MI. HAER MI-45.

Figures 3-103 through 3-108 depict examples of viaducts and trestles.

Figure 3-103. Baltimore & Ohio Railroad Carrollton Viaduct (1828-29), spanning Gwynn's Falls near Baltimore, Maryland. This stone railroad viaduct is a National Civil Engineering Landmark and a National Historic Landmark.



Figure 3-104. Fourteenth Street Viaduct (1899), Fourteenth Street at Wazee Street, Denver, Colorado. This structure is a typical concrete viaduct built to carry traffic over the railroad.



Figure 3-105. Dallas-Oak Cliff Viaduct (1910-12), spanning Trinity River at Houston Street, Dallas, Texas. This early twentieth century viaduct is a concrete open spandrel arch.





Figure 3-106. Promontory Route Railroad Trestles 790B (1872), Corinne vicinity, Box Elder County, Utah. This nineteenth century structure was built by the Central Pacific Railroad Company.



Figure 3-107. Marquette Ore Dock No. 6 Timber Trestle (1931-32), between East Lake Street & Ore Dock No. 6, Marquette City, Marquette County, Michigan. This structure is an example of a high timber trestle.



Figure 3-108. Mahoning Creek Trestle (1899), spanning Mahoning Creek, Goodville vicinity, Indiana County, Pennsylvania. This high steel structure was built to carry the railroad.

3.7 Cantilevers

History and Description: If you hold your arm straight out from your shoulder, it is acting as a cantilever. The equivalent engineering definition of the extended-arm analogy is that a cantilever is a continuous girder with hinges at the points of zero moments (the extended-arm theory is much easier to understand). The form was statically determinant, which meant that it was easy to calculate and the members did not have the inherent deficiency of the continuous beam or girder developing indiscernible internal stresses and possibly failing should one of the piers or abutments subside. Unstable soil conditions plagued foundation, pier, and abutment design, so the ability of a bridge's superstructure to adjust should one of the piers or abutments sink, was a significant design breakthrough.

The form originated in the Far East with the fourth century AD Shogun's Bridge, which still spans 84 feet over the Daiya-gawa River in Nikko, Japan. Another ancient example is the Wandipore Bridge (ca. 1643) high in the Himalayan Mountains in Bhutan, a cantilever of layered timbers projecting forty feet and carrying a simple timber platform--the suspended span. It was illustrated in Thomas Pope's *Treatise on Bridge Architecture*, the first American book on bridges published in 1811. The book was a summary of world bridge building and featured Pope's own "Flying Pendant Lever Bridge." Though never built, Pope proposed to span the Hudson River with a flying pendant of 3,000 feet and the East River with a span of 1,800 feet. This was the cantilever's first introduction in the United States.

The cantilever was not practical and did not achieve widespread use until the structural behavior of trusses was better understood half a century later. These mathematical issues were resolved by a German engineer, Heinrich Gerber, who built the Hassfurt Bridge over the River Main in Germany in 1867 with a central span of 124 feet, the first modern cantilever.

Cantilever bridges are a modified form of beam bridge. A cantilever is essentially a beam that is unsupported at one end but supported at the other, like diving boards. The cantilever was developed to solve the problem of increasing the length of the bridge to enable crossing wide bodies of water like the Ohio and Mississippi rivers, or wide and deep gorges like the Niagara Gorge separating the United States from Canada. It provided alternatives to beam and arch bridges, which had limited spans not exceeding 200 to 300 feet when constructed of steel or reinforced concrete. This configuration made longer spans possible and wider clearance beneath. The cantilever also eliminated the high cost of building anchorages required by the other long span bridge type, suspension bridges, thus saving money and materials.

Charles Conrad Schneider helped develop the cantilever form in the United States with the design of the counterbalanced cantilever with the arms supporting a simple suspended span. Cantilevers first were used by the railroads (Poughkeepsie, Memphis, High Bridge) and then as highway bridges with many notable examples such as the Lyon's Ferry and Longview bridges in Washington. Cantilever bridges over the Ohio and

Mississippi rivers at Pittsburgh, Cincinnati, Louisville, Cairo, St. Louis, Memphis and New Orleans date from the last quarter of the nineteenth century up until the 1950s and 1960s. One great advantage of a cantilever is that it can be built outwards from the towers without falsework to block the channel below. Then the suspended span can be lifted into place. Another is that it is inherently rigid so that heavy locomotives pulling trains of cars are no threat to the structure if properly designed.

In 1877, American engineer C. Shaler Smith, Baltimore Bridge Company, and Louis Frederic Gustav Bouscaren, chief railroad engineer, built the world's longest cantilever for the Cincinnati Southern Railroad over the 275-foot deep Kentucky River gorge at Dixville. No longer extant, it had three spans of 375 feet each. The bridge was selected by ASCE for the 1878 Paris Exposition as one of the prime examples of American bridge ingenuity.

America's oldest surviving cantilever is a railroad bridge spanning the Hudson River at Poughkeepsie, NY, dating from 1889. This structure was notable for the depth of its foundations, which were constructed in timber caissons using the open dredging method developed in America by James Buchanan Eads for the Eads Bridge (1874) and Washington Roebling for the Brooklyn Bridge (1883). Other early notable bridges by Schneider include the 1883 Niagara River Bridge and the Fraser River Bridge of the Canadian Pacific Railroad located in British Columbia.

The Queensboro Bridge over the East River in New York City was the longest cantilever in the United States when completed in 1909. It had no central suspended span which was unique among cantilevers of its size designed with a single hinge to prevent the reversal of stresses.

Development of the cantilever form led to the Tappan Zee Bridge (1955) over the Hudson connecting Tarrytown and Nyack, New York. It is part of the New York State Thruway System and Interstate I-87/287, and is a superlative example of the bridge type used by highway engineers to span larger rivers when the interstates were being constructed during the 1950s and 1960s. With a cantilever span of 1,212 feet and an overall length of 16,013 feet, the Tappan Zee Bridge is a significant bridge system that turns 50 years old in 2005. It is being considered for NRHP listing at a level of national significance as a bridge achievement of the national defense highway system.

With deep canyons carved by the Columbia River and its tributaries, the state of Washington has more cantilever bridges than any other state: at least fifteen remain. Other states with large rivers have cantilevers, as they are the ideal for intermediate to long span bridges. In the last twenty years, however, cable-stayed suspension bridges have begun to supplant cantilevers because they are visually appealing and sometimes more economical.

Significance Assessment: The cantilever bridge in the U.S. dates from the 1880s to the 1960s and is one of the standard bridge types for intermediate to longer spans, crossing deep, broad river gorges where it was difficult, if not impossible, to erect

falsework. Cantilever bridges are significant within the context of this study. Of the highest level of significance are the early structures of the type and the structures of great length.

Cantilevers include two types of structure, cantilever and suspended span. The character defining features of most cantilever bridges will consist of two towers or piers with a pair of cantilever arms, or beams sticking out from the support towers. The beams taper in depth as they project from the towers and usually are truss-like in appearance. These well-secured arms carry a central span suspended over the water way. The cantilevers and suspended span are counterweighted by truss-like back spans that complete the connection to land. Unlike a simple beam supported at both ends, the cantilever must resist tension in its upper half and compression in its lower.

Examples of Cantilevers

1. Poughkeepsie Bridge (1889), spanning Hudson River, Poughkeepsie, Dutchess County, NY. HAER NY – 131.
2. Memphis Bridge (1892), spanning Mississippi River, Memphis, Shelby County, TN. HAER TN-14.
3. Queensboro Bridge (1909), spanning the East River & Blackwell's Island, New York City, New York County, NY. HAER NY- 19.
4. High Bridge (1910, double tracked 1929), spanning Kentucky River, 4 miles Southwest of Wilmore, High Bridge, Jessamine County, KY. HAER KY-37.
5. Longview Bridge (1930), spanning the Columbia River at State Route 433, Longview, Cowlitz County, WA. HAER WA-89.

Figures 3-109 through 3-111 depict examples of cantilever structures.

Figure 3-109. Queensboro Bridge (1909), spanning the East River and Blackwell's Island, New York City, New York.



Figure 3-110. Memphis Bridge (1892), spanning Mississippi River, Memphis, Tennessee.



Figure 3-111. Longview Bridge (1930), spanning the Columbia River at State Route 433, Longview, Washington.



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4.0 CONCLUSIONS, ISSUES AND RECOMMENDATIONS

This chapter presents a summary of the conclusions regarding the significance of the individual bridge types within the context of this study. It also identifies the issues encountered in preparing the study, and lastly, it offers recommendations for future study.

4.1 Summary Findings

Chapter 3 provided a statement of significance for each of the common bridge types addressed in this study. The context for the significance evaluation is the most common historic bridge types in the United States. This significance evaluation is geared primarily toward the engineering significance of the bridge types, that is, National Register of Historic Places (NRHP) Criterion C. Factors such as technological importance and relative rarity played a role in the significance evaluation. Some of the evaluations also touch upon NRHP Criterion A, for example, a bridge associated with events such as the State Departments of Transportation's (DOTs) standardization of bridge designs that began in the early twentieth century.

Some bridges have subtypes or eras of construction in which they are highly significant, and other subtypes within the same category that are of substantially lower significance. If a type or subtype is denoted as highly significant within the context of this study (common historic bridge types in the United States), it will likely be eligible for the NRHP if it retains a high or medium level of integrity. If a type or subtype is noted as significant, it may be eligible for the NRHP if it retains a high level of integrity. Types or subtypes that have moderate significance would need to have a very high level of integrity and may need added elements of significance to be considered NRHP eligible. Examples of elements that may increase the significance of a bridge within the context presented in this study, include association with an important designer or historic event. Types or subtypes labeled as having low significance are very common types that either played no important technological role in the context of this study or bridges that are more recent and their relative significance cannot yet be determined because of the lack of scholarship or shortage of scholarship on these types.

Table 4-1 summarizes the significance level recommendations that have been derived from the conduct of this study. The second column provides the highest significance level of any bridges within the type, the second column identifies the most significant bridge or subtypes within the type and the last column identifies bridges or subtypes with lower levels of significance.

Table 4-1. Summary of Bridge Type/Subtype Significance Evaluations			
Truss Type	Highest Level of Significance Within Type	Subtypes with Highest Significance Level Within Type	Subtypes With Lower Significance Level Within Type
CATEGORY 1: TRUSS			
King Post Truss	Significant	Pre Civil War examples are of the highest significance.	Late 19 th century examples are significant and 20 th century examples are of moderate significance.
Queen Post Truss	Significant	Pre Civil War examples are of the highest significance.	Late 19 th century examples are significant and 20 th century examples are of moderate significance.
Burr Arch Truss	Significant	All 19 th century examples are considered significant.	N/A
Town Lattice Truss	Significant	Wood examples dating before 1870 and all metal railroad bridges of the 19 th century are of the highest significance.	N/A
Howe Truss	Highly Significant	Highly significant are the railroad bridges of the 1840s and 1850s.	Wooden Howe truss covered bridges from the 19 th century and 20 th century are significant.
Bowstring Arch Truss	Highly Significant	Whipple bowstring trusses of are the highest level of significance.	Non-Whipple bowstrings are highly significant, but less significant than the Whipples. An exception would be examples such as King Iron or Wrought Iron company-fabricated bowstrings, or rare one-of-kind examples such as the Avery-Bartholomew or Glass Rezner Schneider patented bowstrings.
Pratt Truss	Significant	Early examples (19 th century) are of the highest significance, especially multiple-span truss bridges spanning larger rivers.	Later examples are of moderate significance.

Table 4-1. Summary of Bridge Type/Subtype Significance Evaluations			
Truss Type	Highest Level of Significance Within Type	Subtypes with Highest Significance Level Within Type	Subtypes With Lower Significance Level Within Type
Whipple Truss	Highly Significant	Whipples are relatively rare within the context of this study and are of the highest level of significance.	N/A
Baltimore Truss	Significant	Early examples associated with the B&O Railroad are of the highest significance.	Baltimore truss bridges on highways are not common and are considered significant.
Parker Truss	Significant	Pin-connected 19 th century examples are of the highest significance.	Twentieth century examples are of moderate significance.
Pennsylvania Truss	Significant	Early examples associated with the railroad are of the highest significance.	Pennsylvania truss bridges on highways are not common and are considered significant.
Warren Truss	Significant	Nineteenth century examples are of the highest significance.	Trusses built after ca. 1920 are of moderate significance.
Subdivided and Double-intersection Warren Truss	Highly Significant	All examples, as they are among the least common types in this study.	N/A
Lenticular Truss	Highly Significant	All examples, as they are among the least common types in this study.	N/A
CATEGORY 2: ARCH			
Stone Arch	Highly Significant	Late 18 th and early 19 th century examples are of the highest level of significance.	Bridges built under the Depression-era federal work programs are significant. Bridges associated with parks may also be significant.
Reinforced Concrete Melan/ von Emperger Arch	Highly Significant	Documented patented examples of the type are of the highest level of significance.	N/A
Reinforced Concrete Luten Arch	Significant	Documented patented examples of the type are of the highest level of significance.	N/A

Table 4-1. Summary of Bridge Type/Subtype Significance Evaluations			
Truss Type	Highest Level of Significance Within Type	Subtypes with Highest Significance Level Within Type	Subtypes With Lower Significance Level Within Type
Reinforced Concrete Marsh or Rainbow (Through) Arch	Significant	Documented patented examples of the type are of the highest level of significance.	Rainbow arches that cannot be documented as patented are less significant, but still possess significance.
Reinforced Concrete Closed Spandrel Arch	Significant	Early examples and types built according to State DOT standardized bridge plans are of the highest level of significance.	Later examples are less significant, but still possess significance.
Reinforced Concrete Open Spandrel Arch	Significant	Early examples and types built according to State DOT standardized bridge plans are of the highest level of significance.	Later examples are less significant, but still possess significance.
Steel Tied Arch	Significant	Most examples will possess significance.	N/A
Reinforced Concrete Tied Arch	Significant	Most examples will possess significance.	N/A
Steel Hinged Arch	Highly Significant	Most examples will possess significance.	N/A
Reinforced Concrete Hinged Arch	Highly Significant	Most examples will possess significance.	N/A
CATEGORY 3: BEAM, GIRDER & RIGID			
Timber Stringers	Low Significance	Early examples and examples built according to State DOT standard plans are of the highest level of significance.	Timber stringers associated with parks may also possess significance.
Reinforced Concrete Cast-In-Place Slabs	Significant	Early examples and examples built according to early 20 th century State DOT standard plans are of the highest level of significance.	Examples from the 2 nd quarter of the 20 th century are less significant, but still may possess significance.

Table 4-1. Summary of Bridge Type/Subtype Significance Evaluations			
Truss Type	Highest Level of Significance Within Type	Subtypes with Highest Significance Level Within Type	Subtypes With Lower Significance Level Within Type
CATEGORY 3: BEAM, GIRDER & RIGID, Continued			
Reinforced Concrete T-Beams	Moderate Significance	Early examples and examples built according to early 20 th century State DOT standard plans are of the highest level of significance.	Long examples (>30 feet) and examples with decorative features may also possess significance.
Reinforced Concrete Channel Beams	Low to Moderate Significance	Early 20 th century representative examples or those built according to early 20 th century State DOT standard plans are of the highest level of significance.	Examples with decorative features may also possess significance.
Reinforced Concrete Girders	Moderate Significance	Early examples and examples built according to early 20 th century State DOT standard plans, and through girders are of the highest level of significance.	Examples from the 2 nd quarter of the 20 th century are less significant, but still may possess significance.
Reinforced Concrete Rigid Frames	Significant	Early examples and those that can be documented as having been built according to State DOT standard plans are of the highest level of significance.	Also significant are examples built on parkway systems.
Reinforced Concrete Pre-cast Slabs	Low Significance*	The earliest examples of the type possess the highest level of significance.*	N/A*
Pre-stressed Concrete I-Beams	Significant*	Early 1950s examples of the type possess the highest level of significance.*	Other examples possess a low level of significance.*

Table 4-1. Summary of Bridge Type/Subtype Significance Evaluations			
Truss Type	Highest Level of Significance Within Type	Subtypes with Highest Significance Level Within Type	Subtypes With Lower Significance Level Within Type
CATEGORY 3: BEAM, GIRDER & RIGID, Continued			
Pre-stressed Concrete Box Beams	Low Significance*	The earliest examples of the type possess the highest level of significance.*	N/A*
Metal Rolled Multi-Beams	Low Significance	Early examples of the type possess the highest level of significance.	Other examples that use innovative fabricating techniques may be significant.
Metal Fabricated Girders	Moderate Significance	Early 20 th century examples possess the highest level of significance.	First generation, welded steel girders that survive from the 1950s may also be significant.
Metal Rigid Frames	Significant	Early examples and those documented as having been built according to State DOT standard plans possess the highest level of significance.	Also significant are examples built on parkway systems.
CATEGORY 4: MOVABLE SPANS			
Center-bearing Swing Span	Highly Significant	Late 19 th and early 20 th century examples possess the highest level of significance.	Examples built late in the historic period (through 1955) may be significant or moderately significant.
Rim-bearing Swing Span	Highly Significant	Late 19 th and early 20 th century examples possess the highest level of significance.	Examples built late in the historic period (through 1955) may be significant or moderately significant.
Vertical Lift Span	Highly Significant	Most examples will possess significance.	N/A
Simple Trunnion (Milwaukee, Chicago) Bascule Span	Significant	Early examples and examples associated with the Chicago Department of Public Works.	Other examples are less significant, but still considered significant.

Table 4-1. Summary of Bridge Type/Subtype Significance Evaluations			
Truss Type	Highest Level of Significance Within Type	Subtypes with Highest Significance Level Within Type	Subtypes With Lower Significance Level Within Type
CATEGORY 4: MOVABLE SPANS, Continued			
Multi-trunnion (Strauss) Bascule Span	Highly Significant	Most examples will possess significance.	N/A
Rolling Lift (Scherzer) Bascule Span	Highly Significant	Of the highest significance are early examples of the type.	Most other examples will possess significance.
CATEGORY 5: SUSPENSION			
Monumental Suspension Bridges	Highly Significant	Most examples will possess significance.	N/A
Shorter-span and Vernacular Spans	Significant	Most examples will possess significance.	N/A
CATEGORY 6: TRESTLES AND VIADUCTS			
Trestles	Significant	Nineteenth century examples possess the highest level of significance.	Twentieth century examples are of moderate to low significance, but may possess significance for their great length or for solving a topographical problem.
Viaducts	Highly Significant	Stone railroad and other viaducts from the second quarter of the 19 th century are of the highest significance level.	Many viaducts should be evaluated within the bridge type that they fall under, e.g., girder, concrete arch.
CATEGORY 7: CANTILEVERS			
Cantilevers	Significant	Early examples and those of very long length are of the highest significance.	Twentieth century examples are of lower significance, unless they are very long in length or for solving a topographical problem.

*More modern types of bridges for which scholarship is just being developed.

4.2 Issues

A number of issues were encountered in the preparation of this study. These are described below.

4.2.1 *Lack of National Database/Repository for Bridge Studies*

The first issue is the lack of a national database for the nation’s historic bridges and a common repository for the many state bridge survey reports, historic contexts and historic bridge management plans. In addition, the many bridge reports present data in inconsistent formats. Some reports list all of the surveyed bridges and identify which are eligible and ineligible for the NRHP, some only identify the eligible bridges, and some of the glossier reports feature only the most significant and/or interesting examples of a state’s bridges. This caused problems for the Study Team in identifying regional trends for inclusion in this report. In addition, many of the reports were prepared a number of years ago and it is unknown how many of the bridges have been replaced. That made identifying the most common types today difficult.

Secondly, access to online data was of critical importance. The Historic American Engineering Record (HAER) collection at the Library of Congress was highly important to this study and its documentation was accessible. The HAER records were relied upon heavily, particularly for identifying the needed examples. It was, however, difficult to search the HAER collection for several of the bridge types in this study. The HAER documentation was relied on for its accuracy and while most HAER documentation is accurate, a small number of errors were found in the HAER records. The Study Team hopes that they found and identified the errors in the HAER records that were consulted before the information and examples were included in this study.

The NRHP records were not accessible as a rule online. Searches generally came up with no records. And, the nominations are not accessible online. The Study Team was fortunate to obtain a list early in the study process that had online links to many of the NRHP-listed state historic bridge contexts or multiple property submittals. This list is in Appendix A.

4.2.2 *Less than Fifty Common Bridge Types*

Another issue is that the scope of work for this study requested the “fifty most common bridge types.” Since the Study Team was unable to identify fifty types that were moderately to very common, some of the types in this study are, in reality, not very common at all. However, when compared to rare bridge types, such as the Bollman truss, these bridges are not rare, as a number of examples exist.

4.2.3 *Lack of Scholarship and Examples For More Recent Bridge Types*

Post World-War II bridges, and particularly, those types of the 1950s, are just recently reaching the age where they fall within the 50-year NRHP age criterion.

Consequently, State DOTs are just beginning to address the significance of these structures through the preparation of historic contexts and survey reports. An example of a recent report that addresses the significance of structures built during this era is *The Third Ohio Historic Bridge Inventory, Evaluation and Management Plan for Bridges Built 1951 – 1960 and the Development of Ohio’s Interstate Highway System*. This report was prepared in 2004 by Lichtenstein Consulting Engineers for the Ohio Department of Transportation, in Cooperation with the Federal Highway Administration and the Ohio Historic Preservation Office.

In the opinion of the Study Team, a body of scholarship that would place structures of this era in their national context is not yet in existence. It was particularly difficult to obtain examples of NRHP listed or HAER recorded examples from this period, but kindly, Mary McCahon of Lichtenstein Consulting Engineers provided assistance with this, as did Kara Russell of PENNDOT.

4.2.4 Inconsistencies in Terminology

Different studies consulted for this study used different terms and names for both bridge types and bridge members. It was often hard to translate information in some studies for use in this study. In addition, some studies were so general, e.g., simply labeling a bridge as a “concrete arch,” that these examples could not be used to illustrate the defined types used in this study. This occurred in the HAER documentation, NRHP documentation forms and throughout state historic bridge surveys, context reports and management plans.

4.2.5 Inability to Locate Peer Reviewers

Many peers assisted with the development of the list of common bridge types for this study. Throughout the study, historic bridge experts provided information and examples of bridge types. The Study Team had high hopes that members of the historic bridge community would assist in the preparation of this important study through volunteering their time to conduct a peer review of the draft study findings. However, with the exception of Martha Carver at Tennessee DOT who reviewed Chapter 2, and Claudette Stager of the Tennessee State Historic Preservation Office, who reviewed Chapters 1 and 2, the Study Team was unable to locate any peer reviewers.

4.3 Recommendations

One near-term recommendation would improve the significance evaluation of historic bridges as presented in this report:

- Prepare a companion report to this study that would discuss in detail and depict the character-defining features of each of the common bridge types.

Other recommendations of high importance include:

1. The National Park Service (NPS) should improve the accessibility of the NRHP records.
2. The NPS should implement an online system for reporting errors found in HAER documentation.
3. A glossary of historic bridge terms should be created and published.
4. A study should be undertaken that looks at the feasibility of creating a national historic bridge database/repository and presents a suggested methodology for undertaking this task.
5. Encourage FHWA to require the state DOTs to complete historic bridge management plans. Management plans are seminal to saving historic bridges, serving as the umbrella under which other actions (e.g., Programmatic Agreements (PAs), identifying best practices examples, and improving data accessibility) would insure the preservation of the Nation’s historic bridges. Management plans should be “bridge-specific,” rather than a series of vague, general recommendations. Every attempt should be made to identify those bridges where rehabilitation/preservation is appropriate and feasible, and to develop specific treatments for these bridges. This recommendation logically follows completion of the statewide historic bridge surveys and begins to address the question: “Now that we have identified all these wonderful spans, what do we do with them?”
6. The scope of work for this study involved only the development of a context for “common, historic bridge types.” Rare, one-of-a-kind bridges are mentioned in the overview essays in Chapters 3 and 4. There was, however, no effort made to identify surviving examples of rare bridge types, as this was outside the scope of this study. A companion study to this study is needed, one that would be concerned with identifying and protecting rare, one-of-a-kind structures. More than half the historic bridges of the United States have been destroyed in the last twenty years. Most Americans resonate to wooden covered spans and stone arches, but the true bridge heritage most at risk is metal trusses and concrete arches. Identification of all nationally significant bridges, regardless of type, should be a national priority, with FHWA taking the lead and coordinating with state and local governments to identify and protect these structures. These bridges illustrate the bench marks of American bridge design and building technology. Inventories have revealed the wealth of historic bridges remaining. Most states know their rare, one-of-a-kind examples. Hence, it will not be difficult to compile this list. Funds are limited; therefore there can be little argument that they need to be directed to saving the truly outstanding bridges. FHWA, with the backing of the groups mentioned above and funding from Congress, should identify the truly outstanding, nationally significant bridges at the earliest possible moment so they can be protected.



Appendix A

Links to National Register Multiple Property Contexts for Bridges



National Register Multiple Property Contexts for Bridges

Eric DeLony provided this list in 2004. Most, but not all links were checked in 2004.

TR=Thematic Resource

MPS=Multiple Property Submittal

Northeast (ME, NH, VT, MA, RI, CT, NY, NJ, PA)	
Metal Truss, Masonry, and Concrete Bridges in VT MPS	www.nr.nps.gov/multiples/64500692.pdf
Movable Railroad Bridges on the NE Corridor in Connecticut TR	www.nr.nps.gov/multiples/64000097.pdf
Metal Truss Bridges in Somerset County (NJ) MPS	www.nr.nps.gov/multiples/64500404.pdf
Early Stone Arch Bridges of Somerset County (NJ) MPS	www.nr.nps.gov/multiples/64500399.pdf
Bridges of Tewksbury Township (NJ) MPS	(No link)
Highway Bridges Owned by the Commonwealth of Pennsylvania TR	www.nr.nps.gov/multiples/64000726.pdf
Stone Arch Bridge (PA) TR	www.nr.nps.gov/multiples/64000563.pdf
Allegheny County (PA) Owned River Bridges TR	www.nr.nps.gov/multiples/64000703.pdf
Bedford County (PA) Covered Bridges TR	www.nr.nps.gov/multiples/64000704.pdf
Berks County (PA) Covered Bridges TR	www.nr.nps.gov/multiples/64000705.pdf
Covered Bridges of Adams, Cumberland, and Perry Counties (PA) TR	www.nr.nps.gov/multiples/64000707.pdf
Covered Bridges of Bradford, Sullivan and Lycoming Counties (PA) TR	www.nr.nps.gov/multiples/64000708.pdf
Covered Bridges of Chester County (PA) TR	www.nr.nps.gov/multiples/64000710.pdf
Covered Bridges of Columbia and Montour Counties (PA) TR	www.nr.nps.gov/multiples/64000712.pdf
PA Covered Bridges of Erie County (PA) TR	www.nr.nps.gov/multiples/64000713.pdf
PA Covered Bridges of Indiana County (PA) TR	www.nr.nps.gov/multiples/64000714.pdf
PA Covered Bridges of Juniata and Snyder Counties (PA) TR	www.nr.nps.gov/multiples/64000715.pdf
PA Covered Bridges of Lancaster County TR	www.nr.nps.gov/multiples/64000717.pdf
PA Covered Bridges of Northumberland County TR	www.nr.nps.gov/multiples/64000718.pdf
PA Covered Bridges of Somerset County TR	www.nr.nps.gov/multiples/64000719.pdf
PA Covered Bridges of the Delaware River	www.nr.nps.gov/multiples/64000721.pdf

Northeast (ME, NH, VT, MA, RI, CT, NY, NJ, PA)	
Watershed TR	
Covered Bridges of Washington County (PA) TR	www.nr.nps.gov/multiples/64000546.pdf
PA Covered Bridges of Washington and Greene Counties TR	www.nr.nps.gov/multiples/64000720.pdf
Union County (PA) Covered Bridges TR	www.nr.nps.gov/multiples/64000734.pdf

Midwest (OH, IN, IL, MI, WS, MN, IA, MO, NE, KS)	
Masonry Arch Bridges of Kansas TR	www.nr.nps.gov/multiples/64000197.pdf
Metal Truss Bridges in Kansas 1861--1939 MPS	www.nr.nps.gov/multiples/64500222.pdf
Rainbow Arch Marsh Arch Bridges of Kansas TR	www.nr.nps.gov/multiples/64000199.pdf
Highway Bridges in Nebraska MPS	www.nr.nps.gov/multiples/64500389.pdf
Highway Bridges of Iowa MPS	www.nr.nps.gov/multiples/64500160.pdf
Metal Highway Bridges of Fulton County (IL) TR	www.nr.nps.gov/multiples/64000179.pdf
Parke County (IN) Covered Bridges TR	www.nr.nps.gov/multiples/64000193.pdf
Highway Bridges of Michigan MPS	www.nr.nps.gov/multiples/64500271.pdf
Iron and Steel Bridges in Minnesota MPS	www.nr.nps.gov/multiples/64500280.pdf
Minnesota Masonry-Arch Highway Bridges MPS	www.nr.nps.gov/multiples/64500282.pdf
Reinforced-Concrete Highway Bridges in MN MPS	www.nr.nps.gov/multiples/64500291.pdf

South (WV, MD, VA, KY, TN, NC, SC, GA, AL, MS, AR, LA, PR)	
West Virginia Covered Bridges TR	www.nr.nps.gov/multiples/64000967.pdf
Covered Bridges in Frederick County (MD) TR	www.nr.nps.gov/multiples/64000308.pdf
Blount County (AL) Covered Bridges TR	http://www.nr.nps.gov/multiples/64000011.pdf
Historic Bridges of Arkansas MPS	www.nr.nps.gov/multiples/64500021.pdf
Historic Bridges of Mississippi TR	www.nr.nps.gov/multiples/64000410.pdf
Swinging Suspension Bridges (MS) TR	www.nr.nps.gov/multiples/64000423.pdf
Historic Bridges of Puerto Rico MPS	www.nr.nps.gov/multiples/64500544.pdf

High Plains & Mountain West (ND, SD, MT, ID, WY, CO, UT)	
Historic Roadway Bridges of North Dakota MPS	www.nr.nps.gov/multiples/64500380.pdf
Historic Bridges in South Dakota MPS	www.nr.nps.gov/multiples/64500579.pdf

Stone Arch Culverts in Turner County (SD) MPS	www.nr.nps.gov/multiples/64500590.pdf
Metal Truss Highway Bridges of Idaho MPS	www.nr.nps.gov/multiples/64500192.pdf
Pegram Truss Railroad Bridges of Idaho MPS	www.nr.nps.gov/multiples/64500195.pdf
Vehicular Bridges in Colorado TR	www.nr.nps.gov/multiples/64000080.pdf
Highway Bridges in Colorado MPS	(No link)
Vehicular Truss and Arch Bridges in Wyoming TR	www.nr.nps.gov/multiples/64000970.pdf

Southwest (TX, NM, AZ, NV)	
Historic Bridges of Texas MPS	www.nr.nps.gov/multiples/64500638.pdf
Historic Highway Bridges of New Mexico MPS	www.nr.nps.gov/multiples/64500416.pdf
Vehicular Bridges in Arizona MPS	www.nr.nps.gov/multiples/64500050.pdf

West (WA, OR, CA)	
Bridges of Washington State MPS	www.nr.nps.gov/multiples/64500697.pdf
Historic Bridges/Tunnels in Washington State TR	www.nr.nps.gov/multiples/64000902.pdf
Bridges and Tunnels Built in Washington State, 1951-1960 MPS	(No link)
Oregon Covered Bridges TR	www.nr.nps.gov/multiples/64000700.pdf

Appendix B

Bridge Basics

Adapted from <http://pghbridges.com>, and used with the permission of Bruce Cridlebaugh, creator of the pghbridges website, “Bridges and Tunnels of Allegheny County and Pittsburgh, PA.”



Bridge Basics

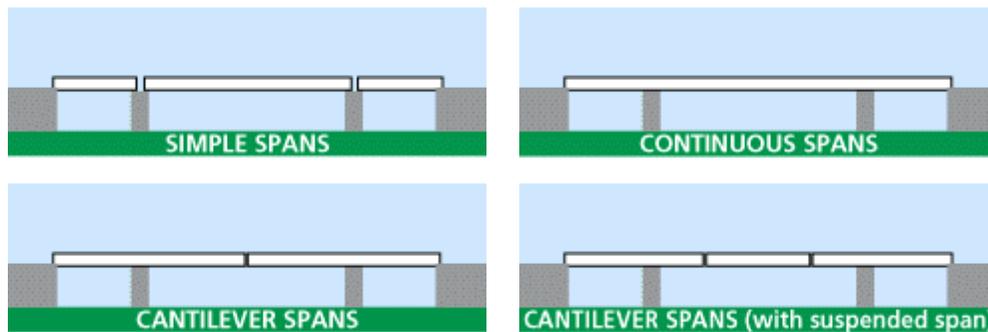
Used with the permission of Bruce S. Cridlebaugh. Bridges and Tunnels of Allegheny County and Pittsburgh, PA [pghbridges.com](http://www.pghbridges.com). From <http://www.pghbridges.com/basics.htm>.

Because of the wide range of structural possibilities, this Spotter's Guide shows only the most common fixed (non-movable) bridge types. Other types are listed in the **Bridge Terminology** page. The drawings are not to scale. Additional related info is found on the other **Terminology** pages which are linked to the left.

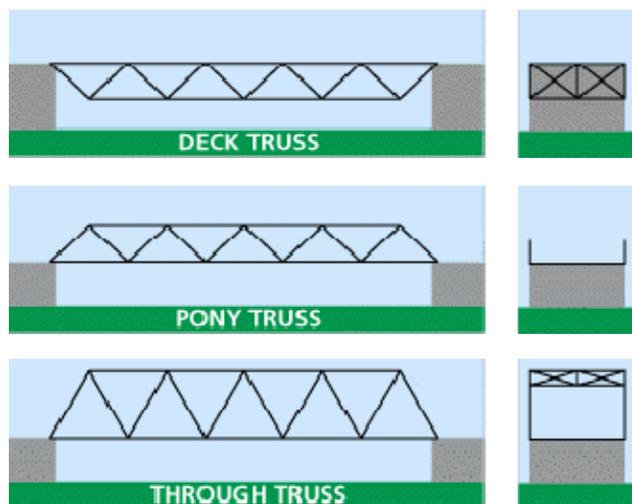
The four main factors are used in describing a bridge. By combining these terms one may give a general description of most bridge types.

- span (simple, continuous, cantilever),
- material (stone, concrete, metal, etc.),
- placement of the travel surface in relation to the structure (deck, pony, through),
- form (beam, arch, truss, etc.).

The three basic types of spans are shown below. Any of these spans may be constructed using beams, girders or trusses. Arch bridges are either simple or continuous (hinged). A cantilever bridge may also include a suspended span.



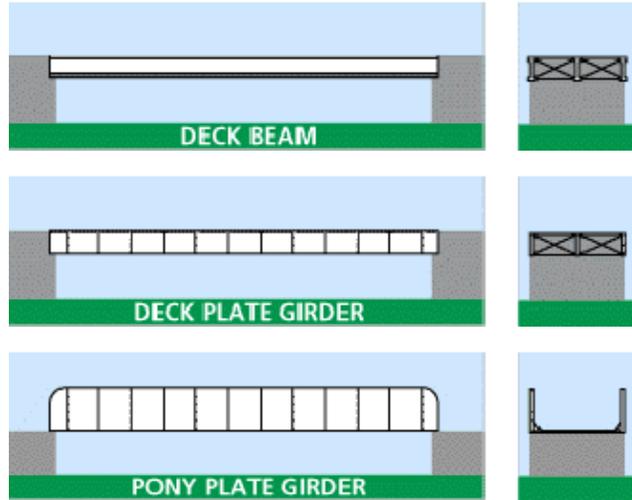
Examples of the three common travel surface configurations are shown in the Truss type drawings below. In a **Deck** configuration, traffic travels on top of the main structure; in a **Pony** configuration, traffic travels between parallel superstructures which are not cross-braced at the top; in a **Through** configuration, traffic travels through the superstructure (usually a truss) which is cross-braced above and below the traffic.



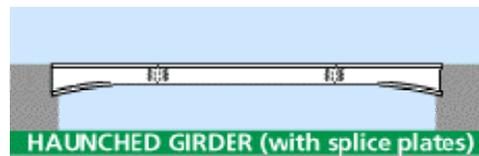
Beam and Girder types

Simple deck beam bridges are usually metal or reinforced concrete. Other beam and girder types are constructed of metal. The

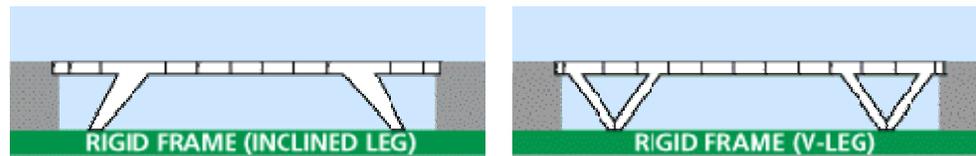
end section of the two deck configuration shows the cross-bracing commonly used between beams. The pony end section shows knee braces which prevent deflection where the girders and deck meet.



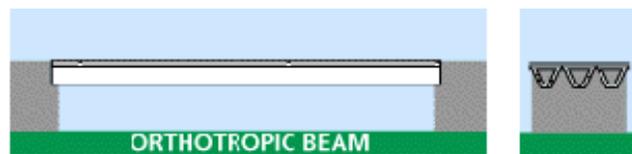
One method of increasing a girder's load capacity while minimizing its web depth is to add haunches at the supported ends. Usually the center section is a standard shape with parallel flanges; curved or angled flanged ends are riveted or bolted using splice plates. Because of the restrictions incurred in transporting large beams to the construction site, shorter, more manageable lengths are often joined on-site using splice plates.



Many modern bridges use new designs developed using computer stress analysis. The **rigid frame** type has superstructure and substructure which are integrated. Commonly, the legs or the intersection of the leg and deck are a single piece which is riveted to other sections.



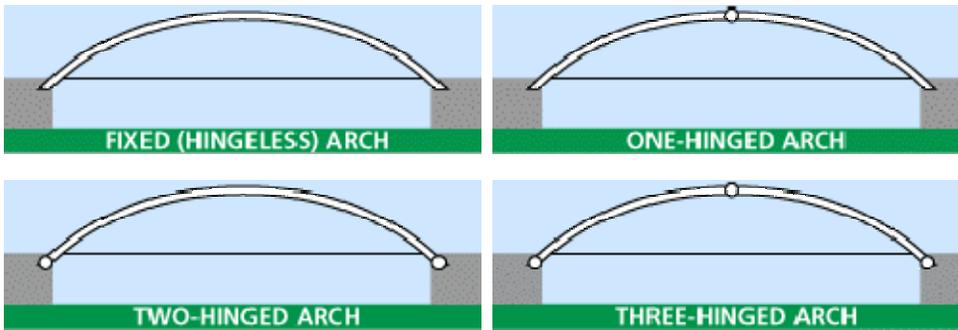
Orthotropic beams are modular shapes which resist stress in multiple directions at once. They vary in cross-section and may be open or closed shapes.



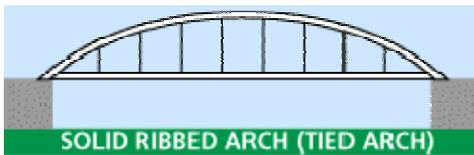
Arch types

There are several ways to classify arch bridges. The placement of the deck in relation to the superstructure provides the descriptive terms used in all bridges: deck, pony, and through.

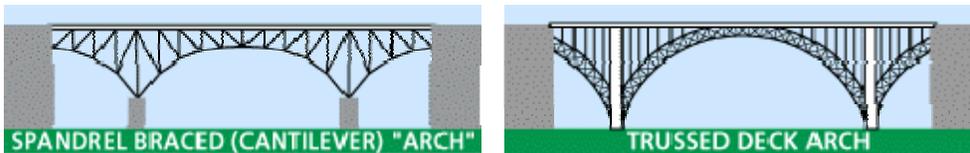
Also the type of connections used at the supports and the midpoint of the arch may be used - - counting the number of **hinges** which allow the structure to respond to varying stresses and loads. A through arch is shown, but this applies to all type of arch bridges.



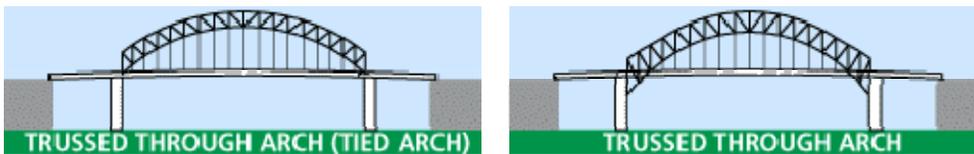
Another method of classification is found in the configuration of the arch. Examples of **solid-ribbed**, **brace-ribbed** (trussed arch) and **spandrel-braced** arches are shown. A solid-ribbed arch is commonly constructed using curved girder sections. A brace-ribbed arch has a curved through truss rising above the deck. A spandrel-braced arch or open spandrel deck arch carries the deck on top of the arch.



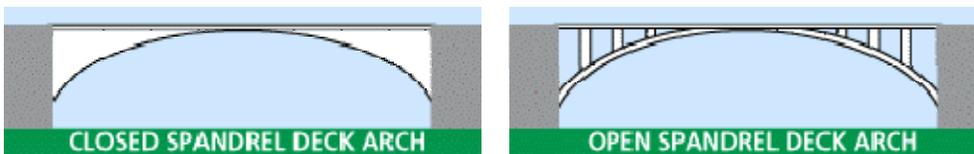
Some metal bridges which appear to be open spandrel deck arch are, in fact, **cantilever**; these rely on diagonal bracing. A true arch bridge relies on vertical members to transmit the load which is carried by the arch.



The tied arch (bowstring) type is commonly used for **suspension** bridges; the arch may be trussed or solid. The trusses which comprise the arch will vary in configuration, but commonly use Pratt or Warren webbing. While a typical arch bridge passes its load to bearings at its abutment; a tied arch resists spreading (drift) at its bearings by using the deck as a tie piece.

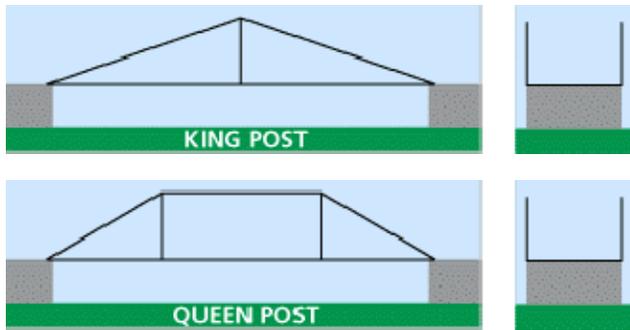


Masonry bridges, constructed in stone and concrete, may have open or closed spandrels. A closed spandrel is usually filled with rubble and faced with dressed stone or concrete. Occasionally, reinforced concrete is used in building pony arch types.



Truss - simple types

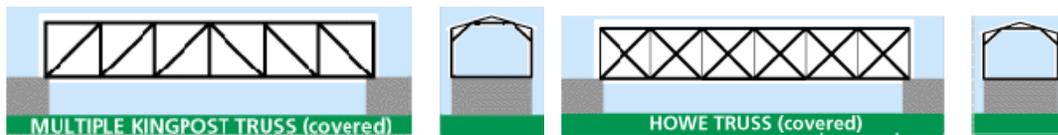
A truss is a structure made of many smaller parts. Once constructed of wooden timbers, and later including iron tension members, most truss bridges are built of metal. Types of truss bridges are also identified by the terms **deck**, **pony** and **through** which describe the placement of the travel surface in relation to the superstructure (see drawings above). The **king post truss** is the simplest type; the **queen post truss** adds a horizontal top chord to achieve a longer span, but the center panel tends to be less rigid due to its lack of diagonal bracing.



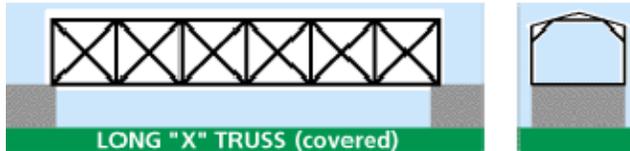
Covered bridge types (truss)

Covered bridges are typically wooden truss structures. The enclosing roof protected the timbers from weathering and extended the life of the bridge.

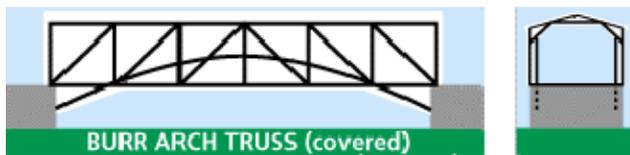
One of the more common methods used for achieving longer spans was the **multiple kingpost truss**. A simple, wooden, kingpost truss forms the center and panels are added symmetrically. With the use of iron in bridge construction, the **Howe truss** - in its simplest form - appears to be a type of multiple kingpost truss.



Stephen H. Long (1784-1864) of the U.S. Army Topographical Engineers may be best known for comments he made after one of his missions to explore and map the United States as it expanded westward. In 1819-20, when he viewed the treeless expanse of the Great Plains, he called it the "American Desert" - and the name stuck. While working for the Baltimore and Ohio Railroad, he developed the X truss in 1830 with further improvements patented in 1835 and 1837. The wooden truss was also known as the **Long truss** and he is cited as the first American to use mathematical calculations in truss design.



Theodore Burr built a bridge spanning the Hudson River at Waterford, NY in 1804. By adding a arch segments to a multiple kingpost truss, the **Burr arch truss** was able to attain longer spans. His truss design, patented in 1817, is not a true arch as it relies on the interaction of the arch segments with the truss members to carry the load. There were many of this type in the Pittsburgh area and they continue to be one of the most common type of covered bridges. Many later covered bridge truss types used an added arch based on the success of the Burr truss.

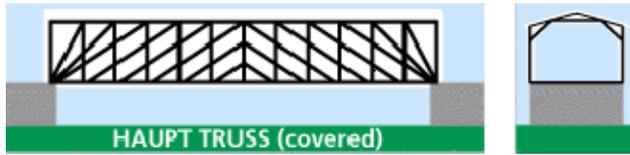


The **Town lattice truss** was patented in 1820 by Ithiel Town. The lattice is constructed of planks rather than the heavy timbers required in kingpost and queenpost designs. It was easy to construct, if tedious. Reportedly, Mr. Town licensed his design at one dollar per foot - or two dollars per foot for those found not under license. The second Ft. Wayne railroad bridge over the Allegheny River was an unusual instance of a Town lattice constructed in iron.

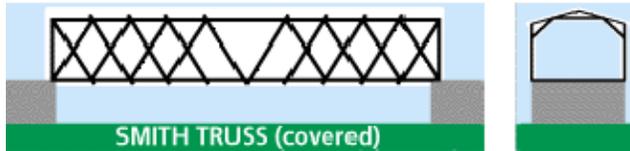


Herman Haupt designed and patented his truss configuration in 1839. He was in engineering management for several railroads including the Pennsylvania Railroad (1848) and drafted as superintendent of military railroads for the Union Army during the Civil

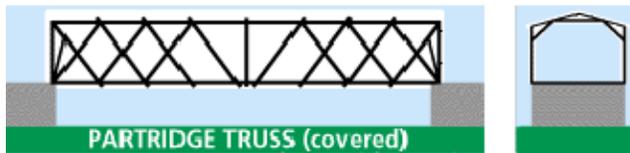
War. The **Haupt truss** concentrates much of its compressive forces through the end panels and onto the abutments.



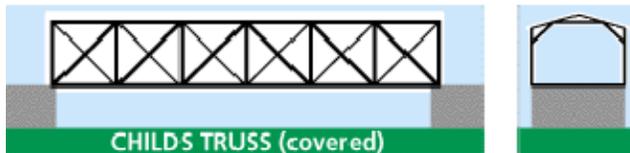
Other bridge designers were busy in the Midwest. An OhioDOT web page cites examples of designs used for some covered bridges in that state. Robert W. Smith of Tipp City, OH, received patents in 1867 and 1869 for his designs. Three variations of the **Smith truss** are still standing in Ohio covered bridges.



Reuben L. Partridge received a patent for his truss design which appears to be a modification of the Smith truss. Four of the five **Partridge truss** bridges near his home in Marysville, Union County, OH, are still in use.



Horace Childs' design of 1846 was a multiple king post with the addition of iron rods. The **Childs truss** was used exclusively by Ohio bridge builder Everett Sherman after 1883.

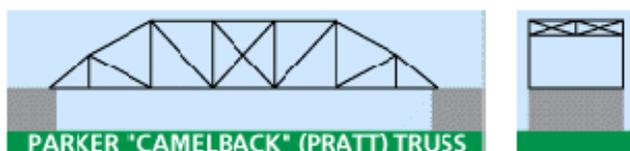
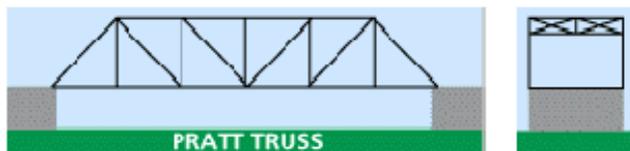


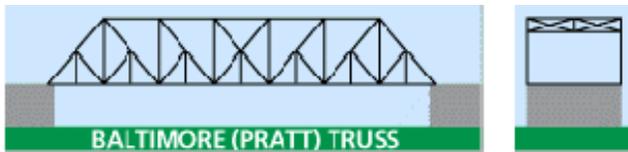
Truss - Pratt variations

The **Pratt truss** is a very common type, but has many variations. Originally designed by Thomas and Caleb Pratt in 1844, the Pratt truss successfully made the transition from wood designs to metal. The basic identifying features are the diagonal web members which form a V-shape. The center section commonly has crossing diagonal members. Additional counter braces may be used and can make identification more difficult, however the Pratt and its variations are the most common type of all trusses.

Charles H. Parker modified the Pratt truss to create a "camelback" truss having a top chord which does not stay parallel with the bottom chord. This creates a lighter structure without losing strength; there is less dead load at the ends and more strength concentrated in the center. It is somewhat more complicated to build since the web members vary in length from one panel to the next.

When additional smaller members are added to a Pratt truss, the various subdivided types have been given names from the railroad companies which most commonly used each type, although both were developed by engineers of the Pennsylvania Railroad in the 1870s.





BALTIMORE (PRATT) TRUSS

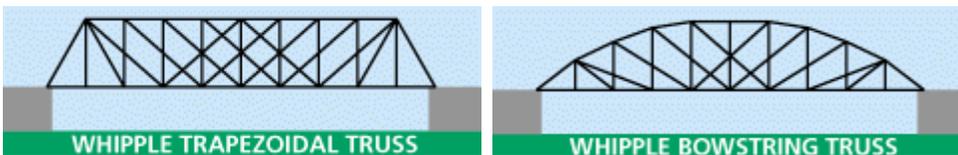


PENNSYLVANIA-PETIT (PRATT) TRUSS

The **Whipple truss** was developed by Squire Whipple as stronger version of the Pratt truss. Patented in 1847, it was also known as the "Double-intersection Pratt" because the diagonal tension members cross two panels, while those on the Pratt cross one. The Indiana Historical Bureau notes one bridge as being a "Triple Whipple" -- possibly the only one -- built with the thought that if two are better than one, three must be stronger yet.

The Whipple truss was most commonly used in the trapezoidal form -- straight top and bottom chords -- although bowstring Whipple trusses were also built. The Whipple truss gained immediate popularity with the railroads as it was stronger and more rigid than the Pratt. It was less common for highway use, but a few wrought iron examples survive. They were usually built where the span required was longer than was practical with a Pratt truss.

Further developments of the subdivided variations of the Pratt, including the Pennsylvania and Baltimore trusses, led to the decline of the Whipple truss.

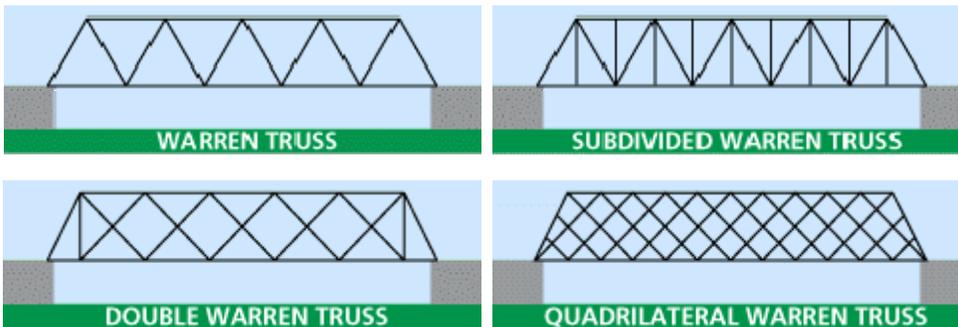


WHIPPLE TRAPEZOIDAL TRUSS

WHIPPLE BOWSTRING TRUSS

Truss - Warren variations

A **Warren truss**, patented by James Warren and Willoughby Monzoni of Great Britain in 1848, can be identified by the presence of many equilateral or isosceles triangles formed by the web members which connect the top and bottom chords. These triangles may also be further subdivided. Warren truss may also be found in covered bridge designs.



WARREN TRUSS

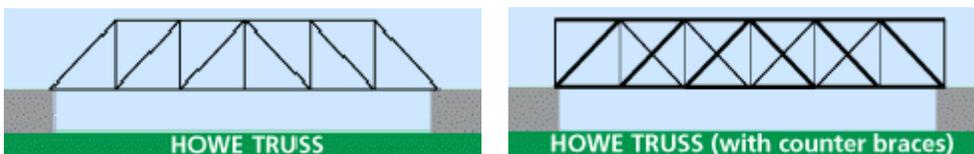
SUBDIVIDED WARREN TRUSS

DOUBLE WARREN TRUSS

QUADRILATERAL WARREN TRUSS

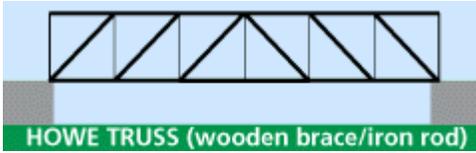
Truss - other types

The other truss types shown are less common on modern bridges. A **Howe truss** at first appears similar to a Pratt truss, but the Howe diagonal web members are inclined toward the center of the span to form A-shapes. The vertical members are in tension while the diagonal members are in compression, exactly opposite the structure of a Pratt truss. Patented in 1840 by William Howe, this design was common on early railroads. The three drawings show various levels of detail. The thicker lines represent wood braces; the thinner lines are iron tension rods. The Howe truss was patented as an improvement to the Long truss which is discussed with covered bridge types.

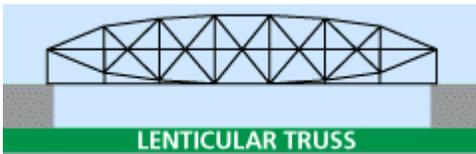


HOWE TRUSS

HOWE TRUSS (with counter braces)



Friedrich August von Pauli (1802-1883) published details of his truss design in 1865. Probably the most famous **Pauli truss**, better known as the **lenticular truss** -- named because of the lens shape, is Pittsburgh's Smithfield Street Bridge. Its opposing arches combine the benefits of a suspension bridge with those of an arch bridge. But like the willow tree, some of its strength is expressed in its flexibility which is often noticeable to bridge traffic.



Before the use of computers, the interaction of forces on spans which crossed multiple supports was difficult to calculate. One solution to the problem was developed by E. M. Wichert of Pittsburgh, PA, in 1930. By introducing a open, hinged quadrilateral over the intermediate piers, each span could be calculated independently. The first **Wichert truss** was the Homestead High Level Bridge over the Monongahela River in 1937.



The composite cast and wrought iron **Bollman truss** was common on the Baltimore and Ohio Railroad. Of the hundred or so following Wendell Bollman's design, the 1869 bridge at Savage, MD, is perhaps the only intact survivor. Some of the counter bracing inside the panels has been omitted from the drawing for clarity.



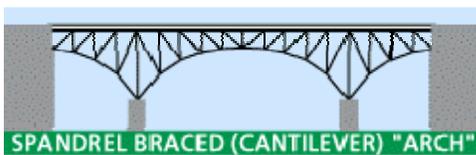
Also somewhat common on early railroads, particularly the B&O, was the **Fink truss** - - designed by Albert Fink of Germany in the 1860s.



Cantilever types - truss

A cantilever is a structural member which projects beyond its support and is supported at only one end. Cantilever bridges are constructed using trusses, beams, or girders. Employing the cantilever principles allows structures to achieve spans longer than simple spans of the same superstructure type. They may also include a suspended span which hangs between the ends of opposing cantilever arms.

Some bridges which appear to be arch type are, in fact, cantilever truss. These may be identified by the diagonal braces which are used in the open spandrel. A true arch bridge relies on vertical members to transfer the load to the arch. Pratt and Warren bracing are among the most commonly used truss types.



The classic cantilever design is the through truss which extends above the deck. Some have trusses which extend both above

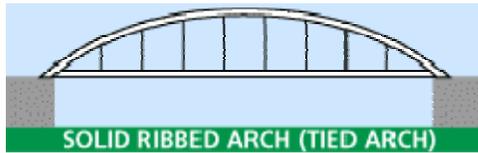
and below the deck. The truss configuration will vary.



Suspension types

The longest bridges in the world are suspension bridges or their cousins, the cable-stayed bridge. The deck is hung from suspenders of wire rope, eyebars or other materials. Materials for the other parts also vary: piers may be steel or masonry; the deck may be made of girders or trussed. A tied arch resists spreading (drift) at its bearings by using the deck as a tie piece.

Pittsburgh was the site of the earliest wire rope suspension bridge, the Allegheny Aqueduct carrying the Pennsylvania Mainline Canal. A similar structure still stands at Minnisink Ford, NY, crossing the Delaware River. John Roebling and his son Washington Roebling, later famous in building the Brooklyn Bridge, began their work in Saxonburg, PA, north of Pittsburgh.

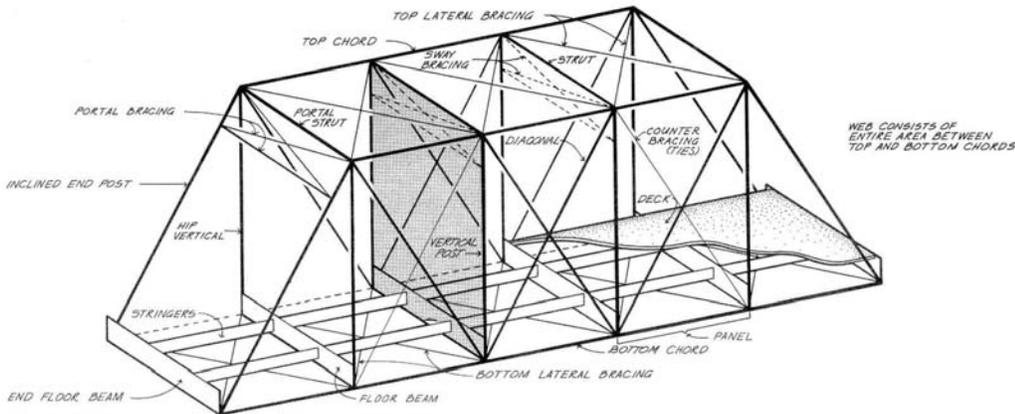


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Appendix C

Trusses, A Study of the Historic American Engineering Record

Provided by staff of the National Park Service/HAER for use in this document, June 2005



TRUSSES

A STUDY BY THE HISTORIC AMERICAN ENGINEERING RECORD

A TRUSS IS COMPOSED OF STRUCTURAL TRIANGLES JOINED TOGETHER WITH PINNED OR RIVETED CONNECTIONS. THE MAIN PIECES OR MEMBERS MAY BE EITHER STIFF HEAVY STRUTS, POSTS OR THIN FLEXIBLE BARS. IT IS THE ARRANGEMENT OF THESE MEMBERS THAT DETERMINES THE SPECIFIC TRUSS TYPE.

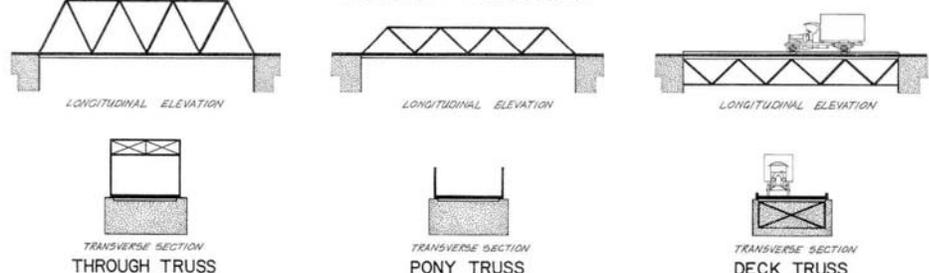
STRUCTURAL MEMBERS RESIST FORCES IN TWO PRIMARY WAYS — COMPRESSION AND TENSION. HEAVY RIGID MEMBERS MAY RESIST BOTH COMPRESSIVE AND TENSILE FORCES BUT THIN RODS CAN ONLY RESIST TENSION AND THESE CHARACTERISTICS ARE MAJOR CLUES IN TRUSS IDENTIFICATION. NOTE THAT THE MAIN STRUCTURAL MEMBERS OF A TRUSS PANEL MAY BE SUPPLEMENTED BY THIN DIAGONAL TIES. BECAUSE TRUSS TYPES ARE DETERMINED BY THEIR MAIN STRUCTURAL MEMBERS THESE COUNTER BRACES (INDICATED BY DOTTED LINES ON THE IDENTIFICATION SHEET) MAY BE IGNORED. AFTER MATCHING THE STRUCTURAL OUTLINE OF THE TRUSS IN QUESTION WITH THE DIAGRAM IT MOST RESEMBLES CHECK TO MAKE SURE THE ARRANGEMENT OF HEAVY COMPRESSION AND LIGHT TENSION MEMBERS IS COMPATIBLE WITH THE DIAGRAM. IF THERE IS AGREEMENT, THEN

THE BASIC TRUSS TYPE IS IDENTIFIED.

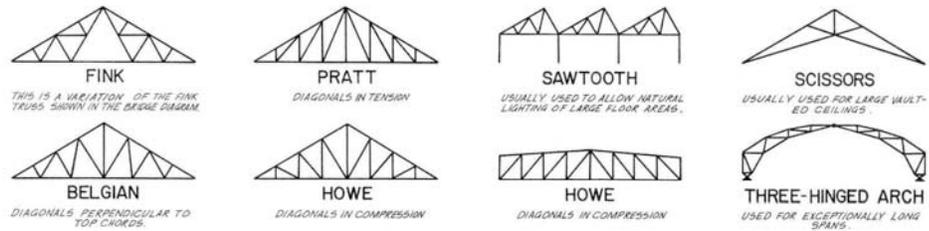
THE SHEET OF TRUSS DIAGRAMS PRESENTS ONLY THE STANDARD FORMS OF THE MOST COMMON TRUSSES. THERE ARE ALSO MANY VARIOUS TRUSSES THAT DO NOT FALL INTO EASILY-DEFINED CATEGORIES. IN SUCH CASES IDENTIFICATION SHOULD BE MADE AS CLOSELY AS POSSIBLE IN TERMS OF THE STANDARD DESIGNS. ADDITIONALLY, TRUSSES OFTEN ARE INVERTED, CREATING OUTLINES QUITE DIFFERENT FROM THE ORIGINAL — TENSION MEMBERS BECOMING COMPRESSION MEMBERS AND VICE VERSA BEING ASSUMING A TRUSS IS NOT REPRESENTED ON THE DIAGRAM, CHECK TO SEE IF IT IS AN INVERTED FORM.

MOST BRIDGE TRUSSES ARE OF THREE BASIC TYPES. IF THE DECK AND JOIST RAILS ARE LEVEL WITH THE BOTTOM CHORDS, IT IS A THROUGH TRUSS. A DECK TRUSS IS A THROUGH TRUSS WITH NO LATERAL BRACING BETWEEN TOP CHORDS. A DECK TRUSS CARRIES ITS TRAFFIC LOAD LEVEL WITH THE TOP CHORDS.

TRUSS BRIDGES



ROOF TRUSSES



STRUCTURAL CONNECTIONS



