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" (*1*, 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 (*1*, 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 30^{th} 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 voissoirs 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.

<u>Concrete</u>: 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 superceded 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).

<u>Steel</u>: 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, superceded 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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