CHAPTER 1

TIMBER AS A BRIDGE MATERIAL

1.1 INTRODUCTION

The age of wood spans human history. The stone, iron, and bronze ages were dramatic interims in human progress, but wood-a renewable resource-has always been at hand. As a building material, wood is abundant, versatile, and easily obtainable. Without it, civilization as we know it would have been impossible. One-third of the area of the United States is forest land. If scientifically managed and protected from natural disasters caused by fire, insects, and disease, forests will last forever. As older trees are harvested, they are replaced by young trees to replenish the wood supply for future generations. The cycle of regeneration, or sustained yield, can equal or surpass the volume being harvested.

Wood was probably the first material used by humans to construct a bridge. Although in the 20th century concrete and steel replaced wood as the major materials for bridge construction, wood is still widely used for short- and medium-span bridges. Of the bridges in the United States with spans longer than 20 feet, approximately 12 percent of them, or 71,200 bridges, are made of timber. In the USDA Forest Service alone, approximately 7,500 timber bridges are in use, and more are built each year. The railroads have more than 1,500 miles of timber bridges and trestles in service. In addition, timber bridges recently have attracted the attention of international organizations and foreign countries, including the United Nations, Canada, England, Japan, and Australia.

Timber's strength, light weight, and energy-absorbing properties furnish features desirable for bridge construction. Timber is capable of supporting short-term overloads without adverse effects. Contrary to popular belief, large wood members provide good fire resistance qualities that meet or exceed those of other materials in severe fire exposures. From an economic standpoint, wood is competitive with other materials on a first-cost basis and shows advantages when life cycle costs are compared. Timber bridges can be constructed in virtually any weather conditions, without detriment to the material. Wood is not damaged by continuous freezing and thawing and resists harmful effects of de-icing agents, which cause deterioration in other bridge materials. Timber bridges do not require special equipment for installation and can normally be constructed without highly skilled labor. They also present a natural and aesthetically pleasing appearance, particularly in natural surroundings.

The misconception that wood provides a short service life has plagued timber as a construction material. Although wood is susceptible to decay or insect attack under specific conditions, it is inherently a very durable material when protected from moisture. Many covered bridges built during the 19th century have lasted over 100 years because they were protected from direct exposure to the elements. In modern applications, it is seldom practical or economical to cover bridges; however, the use of wood preservatives has extended the life of wood used in exposed bridge applications. Using modem application techniques and preservative chemicals, wood can now be effectively protected from deterioration for periods of 50 years or longer. In addition, wood treated with preservatives requires little maintenance and no painting.

Another misconception about wood as a bridge material is that its use is limited to minor structures of no appreciable size. This belief is probably based on the fact that trees for commercial timber are limited in size and are normally harvested before they reach maximum size. Although tree diameter limits the size of sawn lumber, the advent of glued-laminated timber (glulam) some 40 years ago provided designers with several compensating alternatives. Glulam, which is the most widely used modem timber bridge material, is manufactured by bonding sawn lumber laminations together with waterproof structural adhesives. Thus, glulam members are virtually unlimited in depth, width, and length and can be manufactured in a wide range of shapes. Glulam provides higher design strengths than sawn lumber and provides better utilization of the available timber resource by permitting the manufacture of large wood structural elements from smaller lumber sizes. Technological advances in laminating over the past four decades have further increased the suitability and performance of wood for modem highway bridge applications.

1.2 HISTORICAL DEVELOPMENT OF TIMBER BRIDGES

The history and development of timber bridges can be divided into four periods: (1) prehistory through the Middle Ages (to 1000 A.D.), (2) the Middle Ages through the 18th century (1000-1800), (3) the 19th century (1800-1900), and (4) the 20th century (1900 to present). The definition of these periods is based on the sophistication of timber bridge design and construction, and the periods closely parallel human cultural and industrial evolution. From prehistoric times through the Middle Ages, our ancestors adapted available materials, such as logs and vines, to span crossings. From the end of the Middle Ages through the 18th century, scientific knowledge developed and influenced the design and construction of timber bridges. In the 19th century, the sophistication and use of timber bridges increased in response to the growing need for public works and transportation systems associated with the industrial revolution. With the

20th century came major technological advances in wood design, laminating, and preservative treatments.

PREHISTORY THROUGH THE MIDDLE AGES

In prehistorical times, bridges were built using adaptable materials within the environment. Where trees abounded, the first timber bridge was probably a tree that fell across a waterway. The first humanmade timber bridge is assumed to have been built by a Neolithic human who felled a tree across a chasm with a hand-fashioned stone axe circa 15,000 B.C.[10] Ideas for prototype suspension bridges probably came from hanging vines or stems. In subtropical parts of central Asia, palms with lengthy stems were used for constructing suspension bridges. In areas where plants with woody stems grew, native residents could build rope bridges constructed of twisted vines. Bridges of this type ranged in complexity from two or three stretched ropes to more sophisticated configurations employing several ropes to support a floor of tree limbs and branches (Figure 1-1).

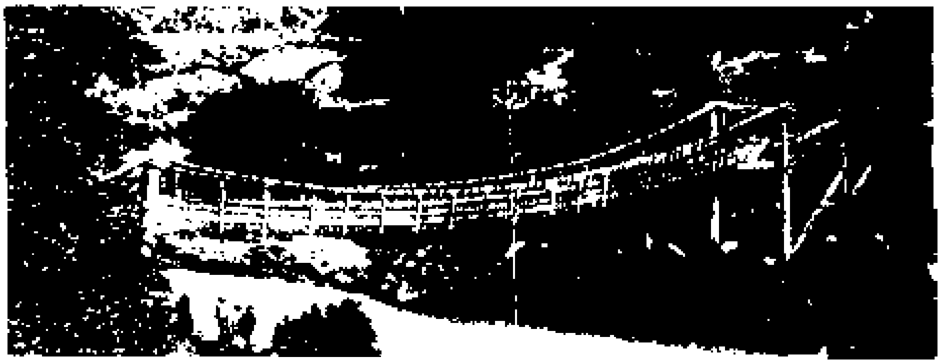

Figure 1-1.—Early highway type of rope bridge. This example is from the island of Java and has an apparent span of approximately 100 feet (photo courtesy of the American Society of Civil Engineers: © 1976. Used by permission).

Many timber bridges were probably built in the last 800 years B.C. by the Persians, Babylonians, Greeks, Romans, and Chinese, although there is little available literature describing specific designs. One of the oldest bridges on record was 35 feet wide and 600 feet long, built in 783 B.C. over the Euphrates River in Babylon.[10] It is theorized that most prehistoric timber bridges in remote areas remained virtually unchanged in design at least to the period of Julius Caesar (100-44 B.C.). One such prehistoric bridge, used by the Gauls in the hills of Savor in Italy, was viewed by Julius Caesar, who described it as follows.[12]

> It is a timber bridge or empilage, piled together rudely, not constructed by art. It needs no carpentry.... On each bank of the stream a rough foundation of water-worn boulders was laid, about fifteen feet square; upon this a criss-cross of the tree trunks was built so that the logs in the direction of travel, in the alternative

layers, were made to jut out farther and farther over the water, narrowing the gap to be bridged later by a few logs serving as beams.

A particular Roman bridge, known as Caesar's Bridge, was built about 2,000 years ago to carry the Roman army into Germany. This bridge was documented by the Venetian architect Palladio (1518-1580), who made an exhaustive study of the remains of the Roman empire. In his treatise *Architecture,* Palladio describes the bridge and renders a drawing of his interpretation of its configuration (Figure 1-2). The structure consisted of a series of beams and inclined struts that fit together in notches so that the bridge could be erected and removed quickly. The imposed weight of the structure and of passing loads served to make the joints tighter. It is rather doubtful, however, that the actual structure utilized timbers as square and smooth as Palladio's drawing indicates.

Approximately one century after Caesar's Bridge (104 A.D.), Roman history mentions one of the most noteworthy works ever undertaken by the Romans. Trajan's Bridge across the Danube River reportedly rested on 20 timber piers, 150 feet high and 170 feet apart. The bridge spans between the piers were circular timber arches. During the same period, evidence shows that builders were concerned with extending the life of wood in structures. A book by a Roman architect covered various means of preserving trees after they were cut, gave remedies to protect against disorders, and included recommendations that (1) fresh cut timber be covered with ox dung to protect it from rapid drying, (2) wood be anointed with Lees of Oil to preserve it from all manner of worms, and (3) pitch was the best defense against deterioration caused by water.[10]

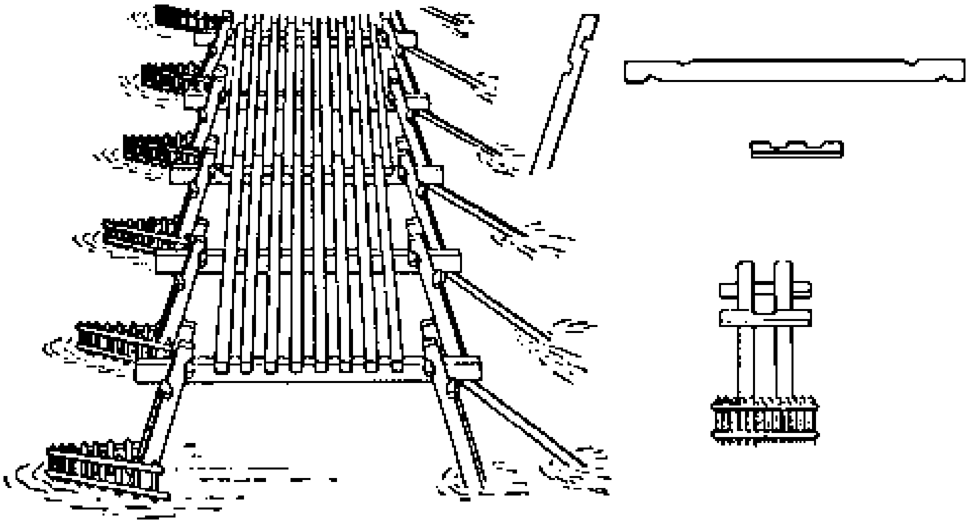

Figure 1-2.–Caesar's Bridge according to Palladio (photo courtesy of the American Society of Civil Engineers: © 1976. Used by permission.)

MIDDLE AGES THROUGH THE 18TH CENTURY

During the period from the Middle Ages to the end of the 15th century, literature documenting timber bridges is limited and incomplete. No significant developments are found until the 16th century, when Palladio composed *Architecture* around 1550. In his work, Palladio provides several timber bridge designs, or inventions as he called them, including a timber arch and the first illustration of a framed truss (Figure 1-3). The arches were apparently capable of spans of approximately 100 feet, while the framed truss was used for spans in the range of 50 to 60 feet. Although they were meaningful contributions to timber bridge evolution, Palladio's bridges attracted little attention, and there was no further development of timber bridges in Europe until the middle of the 18th century.

The 18th century was a period of rapid progress in which attention focused on the development of public works projects, including bridges. It was the period when civil engineering became recognized as a profession. In Europe, the French excelled in engineering developments and constructed numerous timber bridges in spans ranging from 65 to 150 feet. Most French designs were characterized by level floors and flat arches and were built from layers of planks that were clamped together. Covered or roofed bridges were not a common feature in European construction, although several such bridges were constructed by the Grubenmann brothers in Switzerland. The most notable of these bridges was the Schaffhausen Bridge constructed across the Rhine River in 1758 (Figure 1-4). This bridge was built in two spans (171 feet and 193 feet) and was top heavy with a needless amount of timber in the roof system.[12] It was destroyed by the French in 1799. Several other notable timber bridges were constructed in Europe during the 18th century, including a single-span crossing of 390 feet at Wittingen, Germany. However, the most significant timber bridge progress in the latter part of the century was made in the United States and Russia.[17]

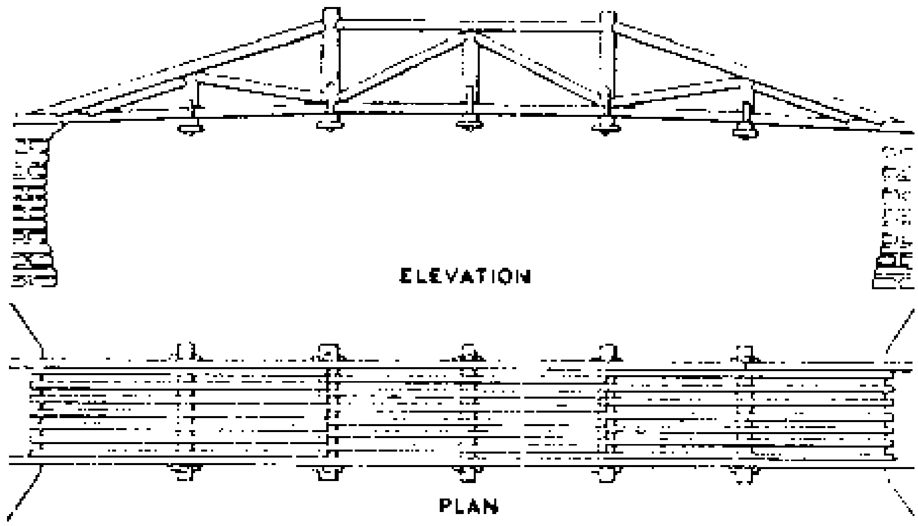

Figure 1-3.—Patiadio's design for a framed truss, dated about 1550 (photo courtesy of the American Society of Civil Engineers; © 1976. Used by permission).

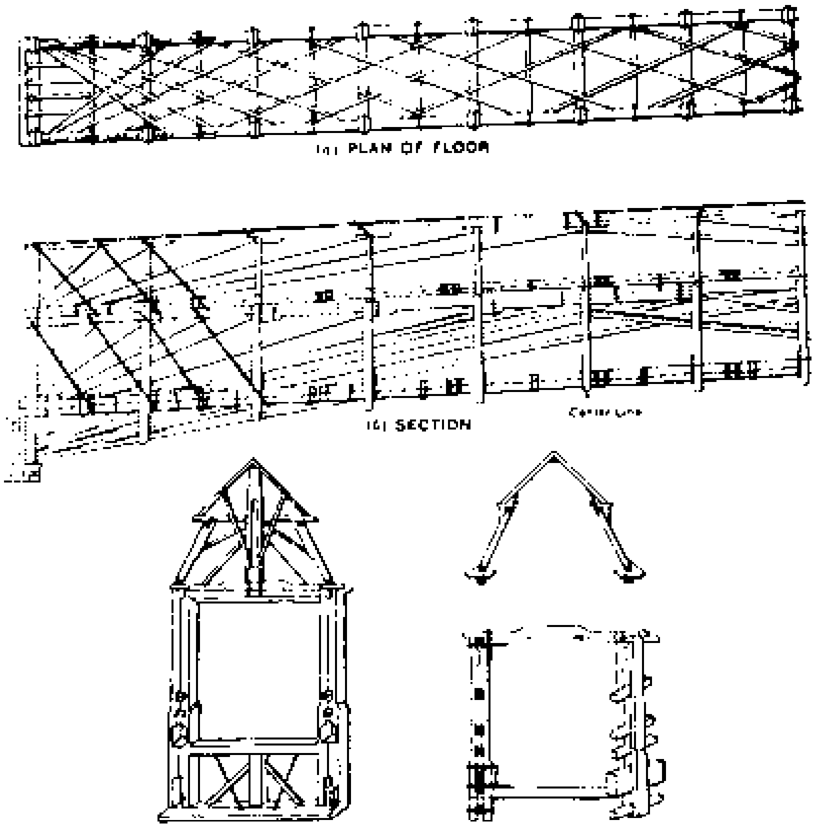

Figure 1-4.-The Schaffhausen Bridge constructed in 1758 over the Rhine River in Switzerland (photo courtesy of the American Society of Civil Engineers; © 1976. Used by permission).

In the United States, most timber bridges built before the 18th century were pioneer bridges with short spans. During the mid-18th century, longer spans were made with trestle bridges consisting of timber beams placed between closely spaced pile piers. The first may have been constructed in 1761 over the York River at York, Maine, by Samuel Sewall. This bridge was 270 feet long, 25 feet wide, and supported on four-pile bents spaced approximately 19 feet apart. It also included a draw span to allow boat passage under the structure. The timber bents, including the pile cap and bracing, were completely assembled and driven as a unit, which was quite an engineering achievement in itself.[1] Pile driving was accomplished by hoisting the butt ends of large logs (with their tips fastened to the previously driven bent) and letting them fall with considerable impact on the cap. This bridge is noteworthy because it is the first on record to be built from a design based on a survey of the site.

The earliest timber bridge to provide clear spans greater than could be negotiated with a single log or beam was completed by Colonel Enoch Hale in 1785, 2 years after the end of the Revolutionary War. It was constructed over the Connecticut River at Bellows Falls, Vermont, and was a 365-foot-long, two-span structure with center support provided by a natural rock pier (Figure 1-5). This was the first bridge over the Connecticut River at any point, and residents reportedly looked on it as a foolhardy experiment.[12] After it was constructed, the bridge was widely noted and considered a remarkable feat of construction. It stood until about 1840.[10]

One of the most ingenious and famous bridge builders of the late 18th century and early 19th century was Timothy Palmer (1751-1821), a distinguished civil engineer from Newburyport, Massachusetts, In 1794, Palmer built the Piscataqua Bridge, 7 miles north of Portsmouth, New Hampshire. The bridge was 2,362 feet long and 38 feet wide. Approach spans were pile trestles that led to three arched trusses, the largest of which had a span of 244 feet. This bridge was considered a wonder of its time and became known as the Great Arch. The arch ribs were made from crooked timbers so that the grain was nearly in the direction of the curves.[7] In 1794 Palmer built a similar bridge at Haverhill, Massachusetts. It consisted of three arches, each 180 feet long, and included a short 30-foot draw span on one end (Figure 1-6). Ten years later, from 1804 to 1806, Palmer built the first American covered bridge over the Schuylkill River in Philadelphia.[28] This was a continuous three-span arch truss consisting of two 150-foot spans and one 195-foot span. It is recorded that the city bridge committee insisted that the heavy timbers be covered with a roof and siding to preserve and protect the structure from weathering. The bridge thus became known as the Permanent Bridge.

19TH CENTURY

With the 19th century came a tremendous demand for bridges in the United States both for highway use and, beginning in about 1830, to meet

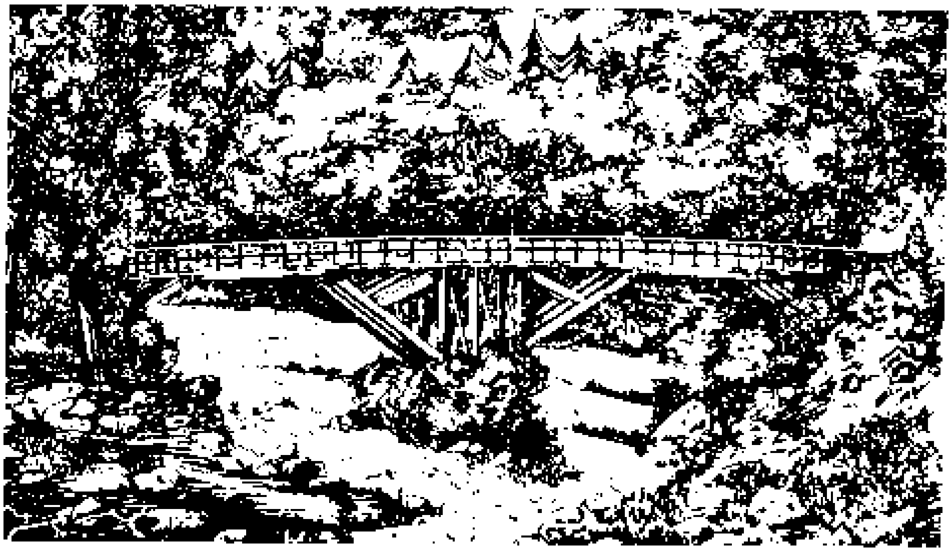

Figure 1-5. Hale's bridge at Bellows Falls, Vermont, built about 1785. This is a sketch from an oil painting of the locality, showing the original structure, or a successor to it. The date of the painting is unknown (photo courtesy of the American Society of Civil Engineers; © 1976. Used by permission).

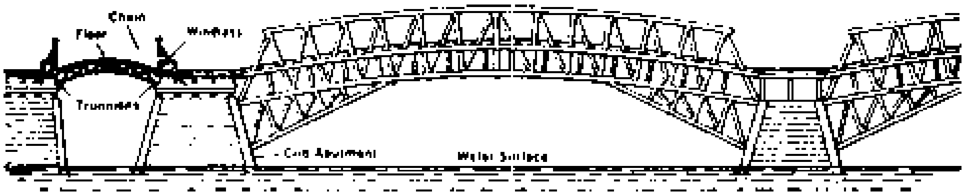

Figure 1-6.- Palmer's arch bridge built at Haverhill, Massachusetts, in 1794 (photo courtesy of the American Society of Civil Engineers; © 1976. Used by permission).

the demands of the railroad boom. During this period, truss and arch bridges became predominant in timber bridge design. Although both arches and trusses were adapted by Palmer in the late 18th century, large-scale application of these structures did not take place until the turn of the 19th century. In the early 1800's, bridge builders strived not only to fulfill design requirements, but also to make their designs bolder and superior to any before. The U.S. Patent Office issued 51 patents for timber bridges between 1797 and 1860.[28] Insistence on careful protection from weather for most of these bridges inaugurated the distinctly American covered bridge (Figure 1-7). An estimated 10,000 covered bridges were built in the United States between 1805 and 1885. Wernwag, Burr, Town, and Long were the four men who led the pioneering efforts during the first four decades of this period. A brief summary of some of the major American bridge accomplishments from 1785 to 1868 is shown in Table 1-1.

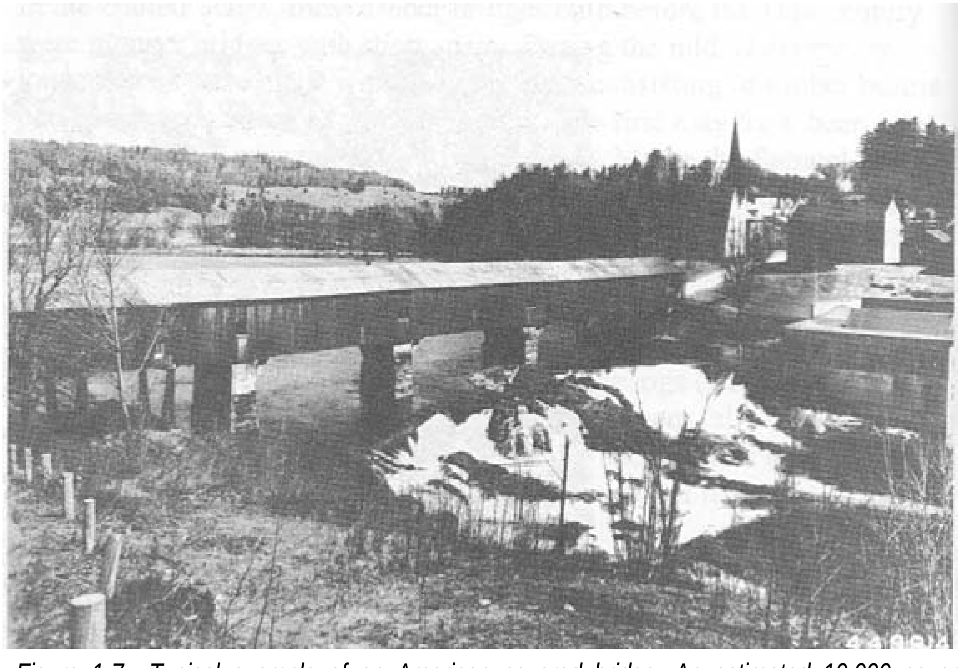

Figure 1-7.- Typical example of an American covered bridge. An estimated 10,000 covered bridges were built in the United States between 1805 and 1885.

Table 1-1.-Some major American timber bridges built between 1785 and 1868.

Enoch Hale's braced-stringer bridge, at Bellows Fails, VT	1785
Timothy Palmer's Essex Merrimac Bridge	1792
Timothy Palmer's Piscataqua and Haverhill Bridges	1794
Timothy Palmer's Georgetown, Washington, DC, Bridge	1796
Timothy Palmer's Permanent Bridge, at Philadelphia, PA	1804-06
Timothy Palmer's Easton, PA, Bridge	1805-06
Graves' (second) Connecticut River Bridge at Hanover, NH	1796
Windsor, VT, Bridge, contemporary with the Graves' Bridge	1796
Theodore Burr's Waterford, NY, Bridge	1804
Theodore Burr's Trenton, NJ, Bridge	1806
Theodore Burr's Mohawk River Bridge	1808
Theodore Burr's Harrisburg, PA, Bridge	1816
Lewis Wernwag's Colossus Bridge at Philadelphia, PA	1812
Lewis Wernwag's New Hope, PA, Bridge	1813-14
Lewis Wernwag's Economy Bridge	1810
Earliest lattice-truss bridge of which there is a record	1813
Ithiel Town's plank-lattice truss, patented	1820
Truss of Stephen H. Long, patented	1830
Ithiel Town's timber-lattice truss, patented	1839
Wernwag's Cheat River Bridge, WV	1834
Wernwag's Camp Nelson Bridge, near Lexington, KY (Standing in 1933 after 95 years. In both these bridges the arch is on the center line of the truss.)	1838
The Ramp Creek Bridge, IN, Burr trusses (Renovated and in service, 1933, after 96 years.)	1837
The Raccoon Creek Bridge, IN, Burr trusses (Still in use, 1933, after 95 years.)	1838
Brunel's experiments with preservatives in England	1835
Wooden lattice bridges on British railways after Ithiel Town's visit about 1840 (before 1846)	1846
William Howe's patent for the Howe truss	1840
William Howe's Connecticut River Bridge, at Springfield, MA	1840
The Tucker Bridge, at Bellows Falls, VT, plank lattice	1840
The trusses of Thomas W. and Caleb Pratt, patented	1844
Typical Burr truss railroad bridge (framed with white pine), at White River Junction, VT	1848
Howe truss bridge with double arches, at Bellows Falls, VT	1850
The unclassified truss of Nicholas Powers, North Blenheim, NY	1855
First bridge across the Mississippi River, five spans, Howe trusses with double arches, at Rock Island, IL	1853-56
Second historic bridge at Rock Island, IL, Howe trusses with curved upper chords and no arches, some time before	1868
The Ledyard Bridge, at Hanover, NH, timber lattice	1859
Howe truss bridge with double arches (12 spans) at Havre de Grace, MD	1862-66

Adapted from Fletcher and Snow.[12] © 1976. Used by permission.

In his bridge building career of 27 years, Lewis Wernwag (1770-1843) built a total of 29 timber bridges in the States of Pennsylvania, Maryland, Virginia, Kentucky, Ohio, and Delaware. His most noteworthy accomplishment was the Colossus Bridge built in 1812 over the Schuylkill River in Pennsylvania (Figure 1-8). This bridge was composed of five parallel arched trusses, each with a rise of 20 feet, that spanned a clear distance of 340 feet. The design, which was not patented until 1829, used iron tension rods, which also served as points of adjustment for joints in each panel. Other major bridges built by Wernwag include the Economy Bridge and the New Hope Bridge. The Economy Bridge was a timber cantilever structure built in 1810 across the Nashammony River in Pennsylvania. It incorporated provisions for tipping the center panel to allow passage of masted vessels and, according to Wernwag, could be used to advantage for spans up to 150 feet. The New Hope Bridge was built during 1813-14 over the Delaware River, at New Hope, Pennsylvania (Figure 1-9). It consisted of a parallel-chord truss arrangement with six arch spans of 175 feet. It was Wernwag's practice to saw all timbers through the heart in order to detect unsound wood and allow seasoning. He used no timbers greater than 6 inches thick and separated all arch timbers with cast iron washers to allow free air circulation.7

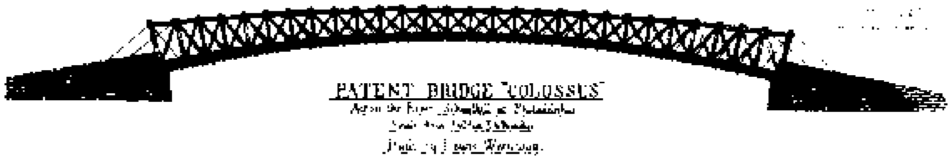

Figure 1-8.- Wernwag's Colossus bridge built over the Schuylkill River at Upper Darby, Pennsylvania, in 1812 (photo courtesy of the American Society of Civil Engineers; © 1976. Used by permission).

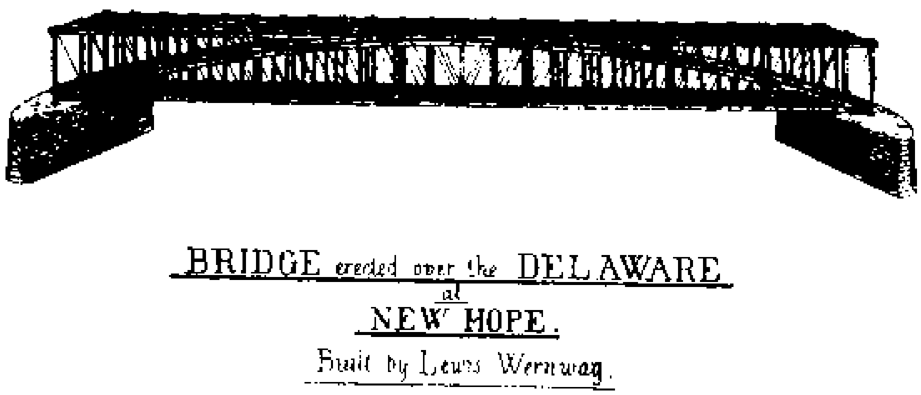

Figure 1-9.- Wernwag's New Hope bridge built over the Delaware River at New Hope, Pennsylvania, in 1814 (photo courtesy of the American Society of Civil Engineers; © 1976. Used by permission).

Theodore Burr is credited with building many famous timber bridges in the first two decades of the 19th century. His designs were based primarily on the combination of parallel-chord trusses with one or more reinforcing arches projecting from the supports, below the point of truss bearing. The first was a 176-foot span crossing the Hudson River between Waterford and Lansingburgh, New York, in 1804 (Figure 1-10). In 1817, Burr was granted a patent based on this Waterford design, which became widely used and known as the Burr truss. Another good example of a Burr bridge was built over the White River at White River Junction, Vermont, in 1848 (Figure 1-11). Constructed as a railroad bridge, it was as strong and serviceable after 54 years of service as when it was built.[12] Although it was capable of much longer service, it was removed in 1890 and replaced with an iron bridge. Hundreds of highway bridges, based to some degree on the Burr principle, were built in various parts of the East, Midwest, and New England States. Most were over 50 feet in span and were constructed as covered bridges of naturally durable white pine. Their longevity has been remarkable, with many providing service in excess of 100 years.

Ithiel Town (1784-1884) was a New Haven architect who recognized the need for a covered bridge truss that could be built at a low cost by good carpenters. In 1820, he was granted a patent on a plank-lattice bridge truss design that represented a first step toward modern truss form. Town's bridge included a web of light planks, 2 to 4 inches thick and 8 to 10 inches wide, that were criss-crossed at a 45 to 60-degree angle (Figure 1-12). The webs were fastened together at their intersections with wooden pins (trunnels). Town lattice trusses could be built for spans up to 220 feet, were lightweight and inexpensive, and could be assembled in a few days. They generally used sawn lumber with uniform sections throughout. Although this feature is often criticized as being wasteful of material, such waste was more than offset by the simplicity of framing and construction. A great number of covered Town lattice trusses were built for highway and railroad traffic in many parts of the United States where wood was abundant (Figure 1-13). Town was a promoter and salesman

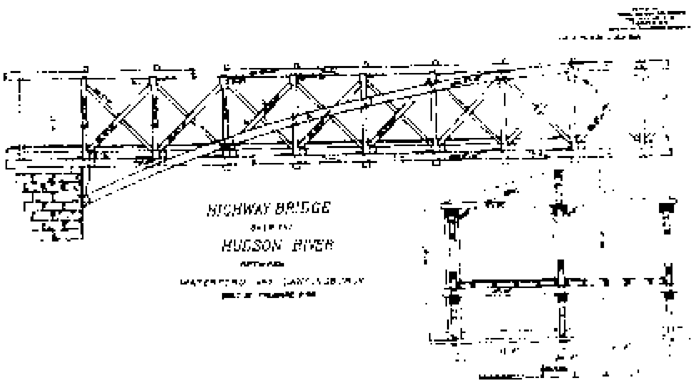

Figure 1-10.- Burr bridge built in 1804 over the Hudson River between Waterford and Lansingburgh, New York (photo courtesy of the American Society of Civil Engineers; © 1976. Used by permission).

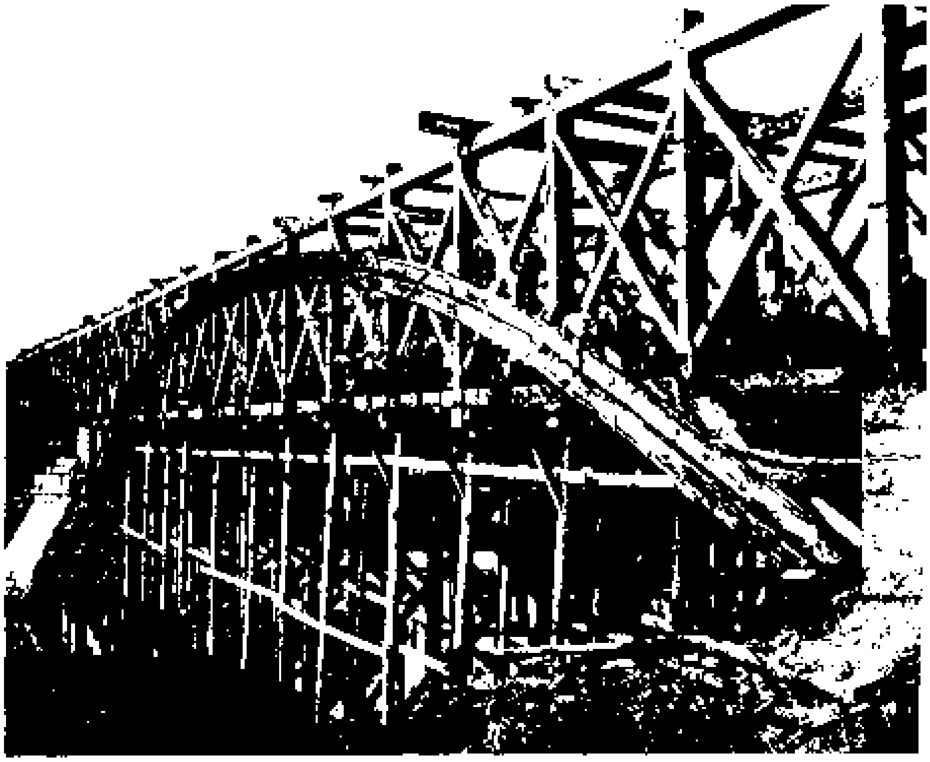

Figure 1-11.- Burr bridge built in 1848 over the White River at White River Junction, Vermont. This photo was taken as the bridge was being removed in 1890, to be replaced by an iron bridge (photo courtesy of the American Society of Civil Engineers; © 1976. Used by permission).

rather than a builder.[12] He sold rights to build his design and published advertising pamphlets.

Many bridges built during the 19th century were designed using a trial-and-fail method by local carpenters. In 1910, more than 100 bridges of this type were in existence on the Boston and Maine Railroad system. Although built without any knowledge of stresses and strains, many of these bridges provided satisfactory service for the trains using them. Notwithstanding several common defects resulting from a lack of scientific design, it is remarkable how well the trial-and-fail method served.

In 1830, Brevet-Lieutenant Colonel Stephen H. Long patented a parallel-chord truss bridge that was modified in 1836 and again in 1839. The truss was of the panel type with crossed timbers between wooden posts. His 1830 patent drawing also included braces extending to the first and second panel points for an assisted truss arrangement (Figure 1-14). Connections were made by framing parts together or by using wooden keys or treenails (treenails are wooden pins, pegs, or spikes driven in holes to fasten lumber together). Although Long's bridges did not become widely popular, many highway and railroad bridges that were hybrids of his design were built by local carpenters. Most of them were for clear spans well over 150 feet.

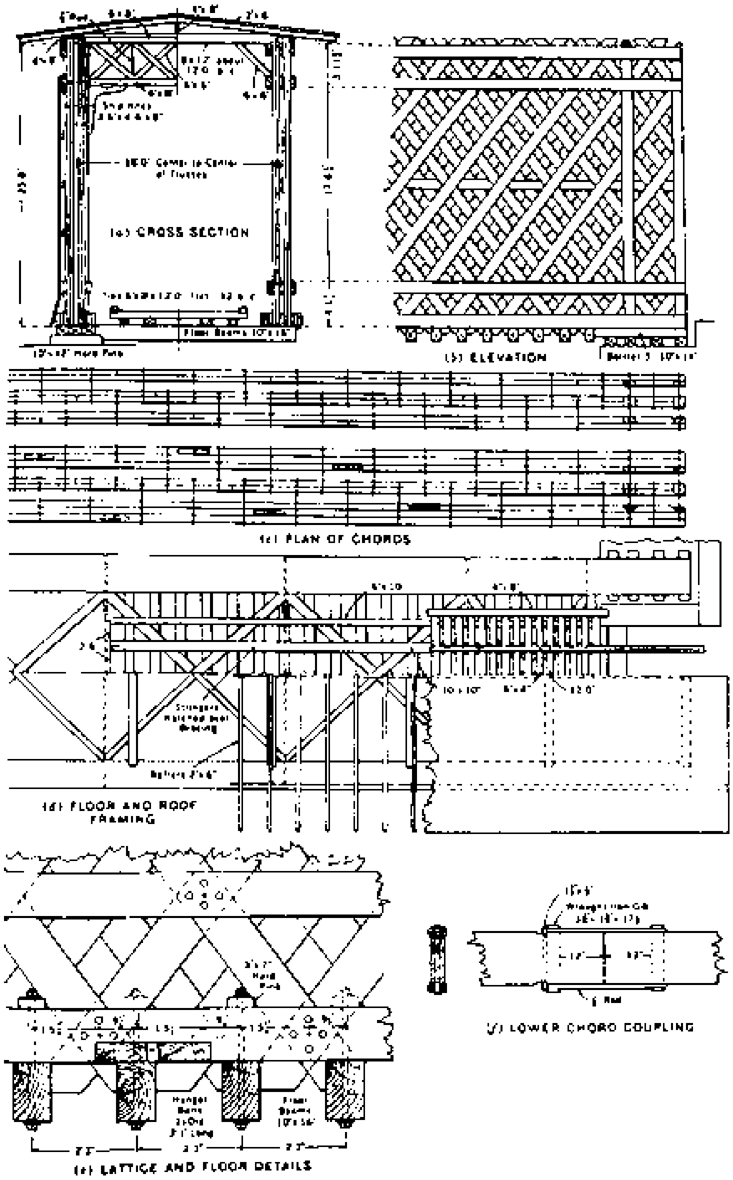

Figure 1-12.-Town's lattice truss patented in 1820 (photo courtesy of the American Society of Civil Engineers; © 1976. Used by permission).

The 1840's marked a turning point for timber bridge development. Until this time, most timber bridges, including those of Wernwag, Burr, Town, and Long, were built almost totally from wood. Iron components, when used, were limited to small fasteners or other hardware that could be forged by blacksmiths. From 1830, rapid railroad expansion provided great motivation for bridge development, and cast iron bridges were introduced. Although wood continued to be used as a primary bridge material, iron became a structural component for timber bridges, and the so-called combination bridges were born. It is obvious that until 1840, the development of timber bridges was empirical. The concepts of earlier designs were often used as a basis for developing newer bridge types.

Figure 1-13.-Typical Town lattice truss covered bridge.

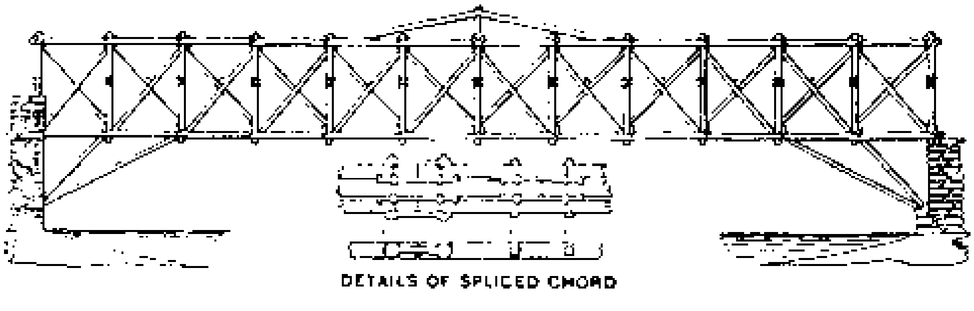

Figure 1-14.---Drawing of Long's truss bridge as patented in 1830 (photo courtesy of the American Society of Civil Engineers; © 1976. Used by permission).

Although many pioneer builders may have considered the use of mathematical rules when determining structural elements for their bridges, no substantiating records of this exist.

After the Long trusses, no significant timber bridge developments occurred until William Howe of Massachusetts patented his bridge in 1840. The Howe truss was a parallel-chord truss design that used two systems of web members (Figure 1-15). The chords and diagonal braces were made of timber and the vertical web-tension members were made of round cast-iron rods. This was the first design to use iron as an essential structural element of a timber truss system. Howe's patent was also the first to include a complete stress analysis of the design by mathematical practices then in use. In 1840, Howe, in company with Amasa Stone (who bought the Howe patent in 1841), built the great bridge over the Connecticut River at Springfield, Massachusetts. This bridge was constructed to carry the new Western Railroad and consisted of seven spans, each measuring 190 feet, measured from the center of one pier to the center of the other pier (Figure 1-16). After a number of years, several modifications were made to the original Howe design to more accurately reflect the actual stresses the members sustained. The design continued to be widely used for railroads and highways and became the most popular truss for the last half of the 19th century.

In 1844, shortly after the Howe truss became popular, Thomas W. Pratt and Caleb Pratt patented their truss design. The Pratt truss was a panel type parallel-chord truss that used vertical timber posts in compression and crossed iron diagonals in tension, just the reverse of the Howe design (Figure 1-17). The advantage of the Pratt truss was that it used timber web members in the simplest and most efficient manner, by confining them to the verticals. The disadvantages were that the truss required a large quantity of expensive material and needed awkward angle blocks for the diagonals. Although numerous timber Pratt trusses were built, the design

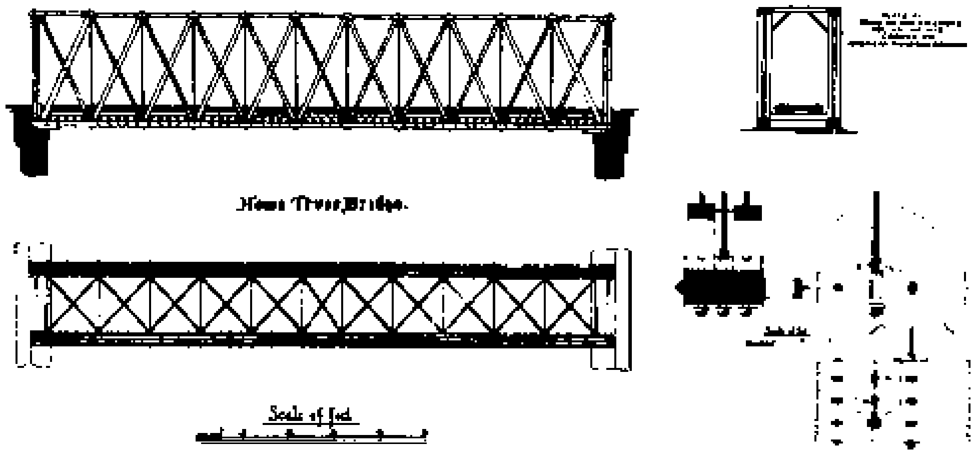

Figure 1-15.- Howe truss bridge patented in 1840 (photo courtesy of the American Society of Civil Engineers; © 1976. Used by permission).

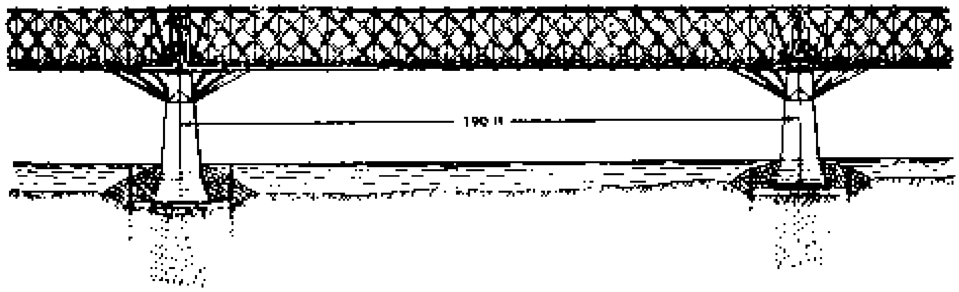

Figure 1-16.- Howe truss built over the Connecticut River at Springfield, Massachusetts, in 1840 (photo courtesy of the American Society of Civil Engineers; © 1976. Used by permission).

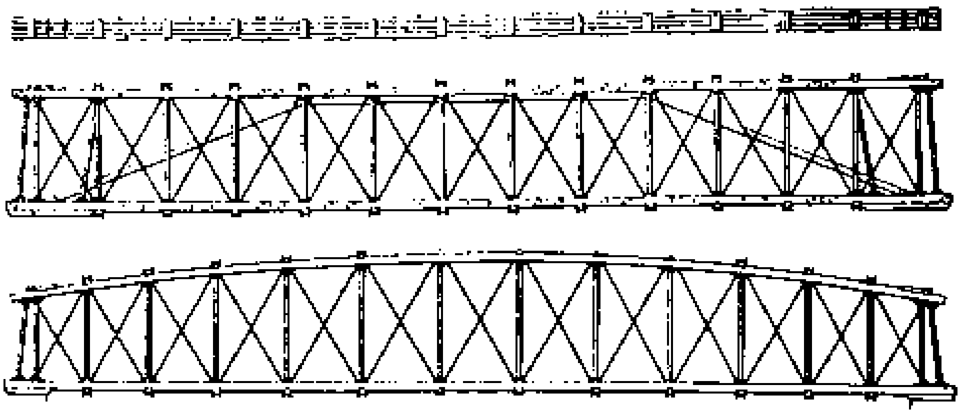

Figure 1-17.- Pratt truss as patented in 1844 (photo courtesy of the American Society of Civil Engineers; © 1976. Used by permission).

was not well suited for the joint use of wood and iron, and it never achieved the popularity of the Howe truss. However, it did become a favored form for constructing totally iron bridges, and thus was a major step in the development of American bridges.

For the remainder of the 19th century, there were other timber bridge builders and designs, but they were relatively minor in comparison to those previously discussed. For most of the century, bridges were constructed of untreated wood, and builders relied mainly on the use of naturally durable species and covers to provide long service lives. The first major development that improved timber bridge performance was the introduction of pressure preservative treatments. The fast pressure creosoting plant in the United States was built in Somerset, Massachusetts, in 1865. The number of plants increased steadily to 70 by 1910.[10] Thus, by the end of the 19th century timber bridges could be built with preservative-treated wood without the covers that had been traditionally used for protection.

In the latter half of the 1800's, iron bridges became increasingly popular and began to compete strongly with timber. In 1859, Howard Carroll built the first all-wrought-iron railroad bridge. In the last decade of the 19th century, steel took the place of iron as the most popular bridge material. Although timber continued to be used for bridges, its use began to decline as new materials were introduced.

20TH CENTURY

Technology in the steel industry developed rapidly in the early part of the 20th century, leading to a more expanded and economical use of steel as a bridge material. Until about 1890, timber lattice bridges could be built with spruce lumber (then costing about $18 per thousand board feet) for one-half the cost of iron bridges.[12] Twenty years later (1910), steel bridges could be built as economically as those of wood. By the mid-1930's, steel was less expensive than wood on a first-cost basis and took the lead as the primary bridge material. Also during the early 20th century, the popularity of reinforced concrete increased and became a primary material for bridge decks.

During this rapid technological development of other bridge materials, progress in timber bridge development slowed. Although there was substantial progress in the areas of wood fasteners and preservative treatments, it was not until the mid-1940's that the biggest single advancement in timber bridges occurred with the introduction of glulam as a bridge material. In the 1960's and 1970's, glulam continued to develop and became the primary material for timber bridge construction. In the 1980's, new glulam bridge designs have evolved, and the innovative concept of stress-laminated lumber has been introduced. As a result, there is a renewed interest in timber as a bridge material and a corresponding increase in the number of timber bridges constructed each year. A more complete description of the types of timber bridges currently in use in the United States is given in Chapter 2.

1.3 THE FUTURE OF TIMBER AS A BRIDGE MATERIAL

Deterioration of the Nation's infrastructure has been well publicized in recent years. Despite this recognition, bridge deterioration continues at an alarming rate. Over the next two decades, the role of timber in bridge applications has the potential to increase significantly, not only in the construction of new timber bridges, but also in the rehabilitation of existing structures constructed of timber, steel, and concrete. According to the 1987 Federal Highway Administration's national bridge inventory,[26] there are 575,607 bridges in the United States with spans of 20 feet or more. Among them, 304,307 are off the Federal aid system on city, county, and township roads. Of these bridges, 95,241 or 33.4 percent are classified as structurally deficient, and 71,542 or 27.4 percent are classified as functionally obsolete. A 1987 summary of substandard bridges by State is shown in Table 1-2.

Table 1-2.-- 1987 Summary of substandard bridges by State.

State	Total Interstate & State Bridges	Total Substandard	Total City/County/ Township Bridges	Total Substandard	Total All Bridges	Combined Total Substandard
Alabama	5,373	2,014(37.5%)	10,090	6,372(63.2%)	15,463	8,386(54.2%)
Alaska	704	75(10.6%)	80	25(31.2%)	784	100(12.7%)
Arizona	3,936	117(2.9%)	1,691	172(10.3%)	5,627	289(5.1%)
Arkansas	6,644	1,786(26.9%)	6,307	4,175(66.2%)	12,951	5,961(46.0%)
California	11,848	931(8.0%)	11,661	4,238(36.0%)	23,509	5,169(22.0%)
Colorado	3,577	470(13.1%)	4,040	2,194(54.3%)	7,617	2,664(35.0%)
Connecticut	2,565	548(21.0%)	1,208	422(35.0%)	3,773	970(26.0%)
Washington, D.C.	202	60(30.0%)	13	5(38.5%)	220	65(29.5%)
Delaware	716	180(25.1%)	7	2(28.6%)	723	182(25.2%)
Florida	5,618	669(11.9%)	4,462	1,477(33.1%)	10,080	2,146(21.3%)
Georgia	6,308	1,275(20.2%)	8,242	3,262(39.6%)	14,550	4,537(31.2%)
Hawaii	691	148(21.4%)	415	131(31.5%)	1,106	279(25.2%)
Idaho	1,347	308(22.9%)	2,459	1,044(42.5%)	3,806	1,352(35.5%)
Illinois	8,110	1,679(20.7%)	17,255	5,846(33.9%)	25,365	7,525(29.7%)
Indiana	5,279	2,819(53.4%)	12,408	7,392(59.6%)	17,687	10,211(57.7%)
Iowa	3,859	912(23.6%)	22,462	12,207(54.3%)	26,321	13,119(49.8%)
Kansas	5,096	1,356(26.6%)	20,781	12,187(58.6%)	25,877	13,543(52.3%)
Kentucky	8,273	4,250(51.4%)	4,464	3,773(84.6%)	12,737	8,028(63.0%)
Louisiana	7,720	2,323(30.1%)	6,972	4,487(64.3%)	14,692	6,810(46.3%)
Maine	1,900	400(21.1%)	488	373(76.4%)	2,388	773(32.4%)
Maryland	2,529	1,036(40.9%)	2,509	1,087(43.3%)	5,038	2,123(42.1%)
Massachusetts	3,320	560(16.9%)	1,685	675(40.0%)	5,005	1,235(24.7%)
Michigan	4,133	320(7.7%)	6,452	2,813(43.9%)	10,585	3,133(29.6%)
Minnesota	2,860	420(14.7%)	10,012	3,086(30.8%)	12,872	3,506(27.2%)
Mississippi	4,715	2,036(43.2%)	12,420	8,498(68.4%)	17,135	10,534(61.5%)
Missouri	9,351	3,731(39.9%)	14,308	12,269(85.7%)	23,659	16,000(67.6%)
Montana	2,660	1,232(46.3%)	2,063	1,349(65.3%)	4,723	2,581(54.6%)
Nebraska	3,085	743(24.1%)	12,918	8,838(68.4%)	16,003	9,581(59.9%)
Nevada	898	13(1.4%)	230	31(13.4%)	1,128	44(3.9%)
New Hampshire	1,453	372(25.6%)	1,062	821(77.3%)	2,515	1,193(47.4%)
New Jersey	2,291	492(21.5%)	3,725	1,260(33.8%)	6,016	1,752(29.1%)
New Mexico	3,046	413(13.6%)	479	220(45.9%)	3,525	633(17.9%)
New York	7,264	2,687(36.9%)	12,290	6,330(51.5%)	19,554	9,017(46.1%)
North Carolina	16,831	8,992(53.4%)	556	272(48.9%)	17,387	9,264(53.3%)
North Dakota	1,432	287(20.0%)	4,129	2,670(64.7%)	5,561	2,892(52.0%)
Ohio	11,364	1,918(16.9%)	18,780	4,462(23.8%)	30,144	6,380(21.2%)
Oklahoma	6,729	2,554(37.9%)	15,936	10,517(65.9%)	22,665	13,071(57.7%)
Oregon	2,550	240(9.4%)	4,030	782(19.4%)	6,580	1,022(15.5%)
Pennsylvania	15,812	5,315(33.6%)	6,618	2,903(43.9%)	22,430	8,218(36.6%)
Rhode Island	530	68(12.8%)	*195	*72(36.9%)	*725	*140(19.3%)
South Carolina	7,969	1,197(15.0%)	989	630(63.7%)	8,958	1,827(20.4%)
South Dakota	1,759	179(9.9%)	5,094	3,035(59.6%)	6,853	3,214(46.9%)
Tennessee	6,907	2,695(39.0%)	11,456	6,263(55.0%)	18,363	8,958(49.0%)
Texas	31,243	5,841(18.7%)	15,069	10,486(69.6%)	46,312	16,327(35.3%)
Utah	1,603	61(3.8%)	960	251(26.1%)	2,563	312(12.2%)
Vermont	1,336	391(29.2%)	1,401	858(61.2%)	2,737	1,249(45.6%)
Virginia	11,461	3,703(32.3%)	893	192(21.5%)	12,354	3,895(31.5%)
Washington	3,034	1,107(36.5%)	4,264	857(20.1%)	7,298	1,964(26.9%)
West Virginia	6,869	4,292(62.5%)	177	103(58.2%)	7,046	4,395(62.4%)
Wisconsin	4,431	1,862(42.0%)	8,477	4,213(49.7%)	12,908	6,075(47.1%)
Wyoming	1,894	102(5.4%)	933	574(61.5%)	2,827	676(23.9%)
Totals	271,125	77,179(28.4%)	315,555	166,201(52.7%)	586,680	243,380(41.5%)

* Includes local railroad bridges.

Numbers vary slightly from those published by the Federal Highway Administration[26] due to differences in survey techniques.

From an exclusive survey conducted by Better Roads Magazine[2]; © 1987. Used by permission.

Over the past four decades, properly designed and preservative-treated timber bridges have demonstrated good performance with long service lives, given proper maintenance. Over the same period, timber has continued to be economically competitive with other bridge materials, both on a first-cost basis and a life-cycle basis. Despite these beneficial attributes, there has been a marked hesitation on the part of bridge designers to use timber, although this has been changing since the 1970's. Perhaps the biggest obstacle to the acceptance and use of timber has been a persistent lack of understanding related to design and performance of the material. Although well educated about other materials, such as steel and concrete, most bridge designers lack the same level of knowledge about wood. The following perspective on why wood has not received the same recognition as other materials was presented by Ken Johnson.[27]

> The practice of engineering, as it evolved over the years, has been shaped by the persuasive efforts of the steel and cement industries. This persuasion has been beneficial, in some ways, in that it produced and distributed good technical information about the design and the use of their respective products. In fact, many engineering schools use industry produced textbooks in their curriculum. That advantage has led to an increase in the reliance, use, prestige and position of those materials and to a corresponding decline, in the same factors, for other construction materials from those industries that have not provided the same level of technical information.
>
> The timber industry is one of those industries that has not made a substantial unified effort to generate and distribute technical information. This has been interpreted by some engineers as a reflection on the suitability of the material itself, and not as an indictment of the industry for failing to provide the information. The reason the timber industry has not met the challenge is quite obvious once one looks at the respective industries.
>
> The methods by which basic materials are produced provide the answers as to why steel and cement provide technical information and why timber has not. The basic difference between steel/cement and timber is the ability of steel/cement to form single industry-wide institutions to do the necessary research and to publish the results. This is possible because of the relatively small number of companies actually producing the product. The production of only three steel companies account for about ninety percent of the steel produced in the United States. The number of companies producing cement is somewhat larger, but still relatively small when compared to the timber industry.
>
> The timber industry, by contrast, consists of a multiplicity of sawmills, both large and small, resource based companies and many other independent operations such as treating plants. The

production is then further diversified by different species. Each of these entities is fiercely independent. The task to organize all of these independent operations is something akin to trying to organize all the farmers. However, the fact that the farmers do not have a single voice does not make their choice beef and Durham wheat less acceptable as steak and bread.

Given the potential market and the economic and performance advantages of wood, the future success of timber in bridge applications depends primarily on (1) the education of engineers on the basic design and performance characteristics of timber, (2) continued coordinated research to develop new bridge systems and improve existing ones, and (3) development of an effective technology transfer system to disseminate current design, construction, and maintenance information to users. Over the past several years, the Forest Service, in cooperation with the timber industry and other public and private agencies, established an Industry-Federal Government Cooperative Program on timber bridge technology to meet needs in these three areas.[25] One of the efforts of this program is to prepare and distribute information that provides engineers and educators with state-of-the-art information on timber bridges. This manual is one step in providing such information.

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