CONTEXTUAL ESSAY ON WIRE BRIDGES
John A. Roebling's Sons Co.
Trenton
Mercer County
New Jersey

HAER No. NJ-132

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WRITTEN HISTORICAL AND DESCRIPTIVE DATA

HISTORIC AMERICAN ENGINEERING RECORD
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HAER No. NJ-132

Location:	United States, but particularly associated with John A. Roeblings' Sons, of Trenton and Kinkora, NJ.
Date of Construction: (extant buildings)	19^{th} and 20^{th} centuries
Fabricator:	various
Present Owner:	N/A
Present Use:	N/A
Significance:	The history of wire bridge evolution, at present, is badly garbled. New works and treatises are being published each year, some of which contain repetitions of factual errors corrected elsewhere, while others exhibit novel, or confusing explanations, sometimes inaccurate. This report is a summary attempt at reducing existing confusion about the suspension bridges built with ferrous metallic wire cables in the United States.
Historian:	Donald Sayenga, 1999. Mr. Sayenga is a management consultant based in Bethlehem, Pennsylvania, and serves as historian/archivist for the Wire Association International. He was formerly chief executive of Bethlehem Steel Wire Rope Division, and was responsible for Bethlehem acquiring the assets of the former John A. Roeblings' Sons Corp., Trenton, NJ.

General Introduction

Although the techniques of wire drawing and suspension bridge building are thousands of years old, proposals for bridges suspended by wire cables did not appear until the end of the eighteenth century. As soon as the concept of using wire cables had been introduced and tested successfully (c. 1815) wire bridge proposals proliferated very rapidly in selected areas. In other places, the idea was rejected as inappropriate. The history of wire bridge evolution, at present, is badly garbled. New works and treatises are being published each year, some of which contain repetitions of factual errors corrected elsewhere, while others exhibit novel, or confusing explanations, sometimes inaccurate. This report is a summary attempting to reduce existing confusion about the suspension bridges built with ferrous metallic wire cables in the United States.

Why build a bridge using metallic wire?

The first wire bridges were built in places where iron wire already was being made for other purposes. All of the first wire bridges were erected within a brief time period of less than a decade, at widely-separated locations in eastern Pennsylvania, southern Scotland, and southeastern France. The decade of the first wire bridges, 1815-1825, was also a decade in which rapid mechanization of various textile processes was underway at these same three places. One machine, for "carding" (or aligning) of textile fibers for the production of yarns, was being mechanized in a way requiring thousands of small iron teeth. The easiest was to make those teeth was to cut up wire. Each individual piece of card wire was short, but positioning the teeth in the most expedient manner warranted production of the longest possible length of iron wire as raw material.

Card wire was the largest single item, by volume, in the wire trade during the decade 1815-1825. Wire makers producing card wire were trying to make longer and longer lengths in response to the demands of carding machine makers. The men who built the first wire bridge in Pennsylvania were wire makers drawing and selling card wire to the local textile industry of Philadelphia. The men who built the first wire bridges of Scotland and France were not bridge builders by profession; they were in the textile business. They were practical men who merely applied an everyday item to the construction of short span bridges by imitating chain-cable suspension bridges.[1]

The Properties of Ferrous Wire

The metal used in wire cables in bridges is an alloy of naturally-occurring elemental iron. It has been manufactured into wire in one of two differing forms: wrought iron wire and steel wire. These two kinds of ferrous wire have several similar physical properties shared with other kinds of iron goods. Wrought iron wire, used for bridges prior to 1880, was displaced by the advent of steel wire with better physical properties. The metallurgical processes for making these two kinds of ferrous wire are different. To avoid confusion, the two processes have been separated in this report into two main sections. For better clarity, it is appropriate to begin with an elementary understanding of ironmaking, and the properties of ferrous wire that bridge builders found desirable.

Most of the technology for using metallic iron was devised in prehistoric times. There are two naturally-occurring recognizable forms of iron on the surface of the earth: almost pure iron meteorites, and rocky, oxidized, iron ore. Both have a tendency to be strongly magnetic. Early civilizations somehow

[1]The best general description of how the textile business stimulated the birth of a wire industry in the United States is given by Kenneth B. Lewis, *Steel Wire In America*, (Branford CT, The Wire Association International, 1952, reprinted 1974), 1-43. A very detailed history of how the Seguin family applied their textile wire to innovative bridge building was documented by Marc Seguin, *Des Ponts En Fil De Fer*, (Paris, Bachelier, 1824). The wrought iron wire business in the United States represents a relative minor segment of a much larger industrial expansion of numerous other ferrous products, described by James M. Swank, *History Of The Manufacture Of Iron In All Ages*, (Philadelphia, AISA, 2nd Ed.,1892).

discovered natural magnetism, and from this seem to have learned intuitively about four other significant physical qualities possessed by ironware. These four properties of fabricated iron are known generally as *malleability, weldability, ductility,* and *hardenability.* All four properties apparently had been discovered prior to recorded history.

Malleability, loosely defined as an ability to withstand, or be shaped by, impacts from forming hammer, allows iron to be physically manipulated again and again. Because it possesses this property, a rounded lump of properly prepared, heated, iron can be hammered into a squared loaf (called a *billet*) or flattened between rolls into a slab. Billets, or slabs, can then be stacked, stored, and later carried to other hammers or rolls, or to another location for further physical conversion into more useful forms. Iron that has been shaped in this way is known as *wrought* iron. Wrought iron billets can be hammered into longer, slimmer bars. Slabs can be beaten into flatter, thinner plates and sheets. Again, the bars and plates can be stacked, stored, and shipped to other hammers. This is a direct parallel to the commercial process of converting trees into logs into lumber, but with one extremely significant difference: there was very little waste in the wrought iron trade. If the iron has been properly prepared, even the smallest scraps remain *malleable.*

Accompanying malleability, the property *weldability* allows a portion of heated metallic iron to be joined together with other pieces, or connected to itself, when manipulated properly. This is achieved by heating iron almost to the melting point, then hammering it to achieve welding. A normal part of the procedure for making wrought iron products included the concept of *piling* (also called *fagoting*) whereby bars of iron rolled previously, were re-rolled and welded together again in packets. This process of welding together pieces of iron greatly enhanced its physical properties.

Ductility, the most significant property for the wire industry, is unlike the other qualities of iron because it involves cold working the metal. It does not require heat from exterior sources to take advantage of this property. Conversely, cold working (mechanical deformation) actually generates heat. Ductility is the ability of the metal to withstand reshaping by being pulled through a hole. It is this specific property that makes wire drawing possible. Wire that has been drawn through the hole of a wire-drawing die becomes harder and stronger as the outer diameter is reduced. Careful application of heating below the melting point of iron will soften it, erasing the effects of cold work. This softening, called *annealing,* can be done over and over again. After each anneal, the ductility is restored. Iron wire that is not annealed will become brittle as glass after a certain amount of cold work.

Hardenability is a unique property that is exploited most completely in steel wire. It is a metallurgical phenomenon caused by different forces than those seen in the wire drawing, work-hardening process. By means of careful application of thermal treatments it is possible to make steel wire harder and stronger by means of heat alone. Because of its almost alchemical nature, hardenability remained a mystery for years after other ironmaking techniques and methods were fully understood.[2]

The Bridge Builders of the United States of America

Among a large group of bold American suspension bridge innovators, two men, Charles Ellet, Jr. (1810-1862) and Washington A. Roebling (1835-1926), stand foremost among those who were daring enough to introduce new concepts and cling tenaciously to their beliefs in the face of often bitter opposition. These two men in particular caused important wire bridges to be built in new ways by wagering their own personal confidence, often disputing established and proven techniques. In both cases, they did this even at the risk of their own lives, acting with bravery seldom equaled in any field.

[2]Simplified metallurgical explanations have been extracted from *Ferrous Wire,* (Branford CT, The Wire Association International, 1989), vol 1, pp 1-44, and vol 2, 75-134; and *The Making Shaping And Treating Of Steel,* Pittsburgh PA, United States Steel Corporation, 1951, particularly the Sixth Edition, pp 1-59, 283-371. The volumes published by the Wire Association also contain brief historical summaries that are somewhat inaccurate.

Charles Ellet's career marks the beginning of a long period of extensive wire bridge building in North America using cables made of wrought iron wire. Although Ellet's attainments in other areas of civil and military engineering, combined with his radical theories of political economy, easily surpass his brief involvement with bridgebuilding, each of the three bridges upon which he worked represented a major breakthrough in technology at the time of its completion. Ellet's unique charisma provided the primary driving force needed to establish the concept of wire bridges in American culture. His writings stimulated the bridgebuilding efforts of several other men, notably John A. Roebling. His career was ended abruptly in action during the Civil War, while demonstrating the efficiency of a naval steam ram he had devised.[3]

Washington Roebling, who designed and built only one large (and very permanent) bridge, exerted highly significant influence among a small group of other American engineers and architects with whom he communicated. Like Ellet, he stimulated other men such as William Hildenbrand, while at the same time providing leadership for a family-owned company that became the world's primary manufacturer of wire cables. His bridge, the Brooklyn Bridge, was unequaled as the greatest bridge in the world at the time of its completion. His family company, John A. Roebling's Sons, endured for many decades after his death due to his presence and the skills of his younger brothers Ferdinand and Charles. By displaying direct personal involvement in all phases of his Brooklyn Bridge project, Washington Roebling set an example for bridge builders that few since have been able to emulate. His health was permanently damaged by his own deliberate personal exposure to deleterious conditions at the site that were affecting his workmen. He built no other bridges.[4]

In retrospect, it seems unlikely the technology for building wire cable suspension bridges would have evolved so rapidly and so effectively in the United States without the presence of such unusual men as Charles Ellet Jr. and Washington A. Roebling and without the stimulation they provided to followers. The United States boasts a greater number of wire cable suspension bridges than any other nation. Modern suspension bridges currently being built in other nations are derivations of American examples.

The Era Of Wrought Iron Suspension Bridge Cables 1816-1880

Americans built more than sixty suspension bridges with iron wire cables during a period lasting slightly longer than six decades. It began in 1816 when the two most innovative American wiremakers, Josiah White & Erskine Hazard,[5] used their own product for a hastily-erected footbridge over Falls of Schuylkill in Pennsylvania near Philadelphia. This small, temporary, bridge, 18" wide and 400' long, was likely the "world's longest span" for a wire cable bridge because it was probably the world's first wire cable suspension bridge. The era drew toward a close with two other "world's longest" suspension bridges. The first, over the Ohio River in Kentucky, adjacent to Cincinnati, had a central span exceeding 1000'.[6]

[3]Ellet's remarkable life is summarized by biographer Gene D. Lewis, *Charles Ellet Jr., The Engineer as Individualist*, (Urbana, University of Illinois Press, 1968).

[4]The best of several Washington A. Roebling biographies is: David McCullough, *The Great Bridge*, (New York NY, Simon & Schuster, 1972).

[5]The best of several treatises on the achievements of Josiah White is by Norris Hansell, *Josiah White, Quaker Entrepreneur*, (Easton PA, Canal History And Technology Press, 1992). It is very unfortunate that Erskine Hazard, who is equally important, has no published biography.

[6]The original world's record bridge over the Ohio River at Cincinnati was described in detail by John A. Roebling, *Report To The President And Board Of Directors Of The Covington And Cincinnati Bridge Company*, (Cincinnati, Murphy and Bechtel, 1867). Later, the bridge was rebuilt almost completely by William (Wilhelm) Hildenbrand, and the structure of the 1990's, except for the towers, bears little resemblance to the original. Despite this, it is now often called "The John A. Roebling Bridge." Hildenbrand's achievement is rarely mentioned in the extensive literature about this suspension bridge. His work is explained by Dr. Joseph Gastright, "Wilhelm Hildenbrand and

An even longer bridge across Niagara Gorge at Clifton opened in 1869, establishing a new record over 1200 feet, more than triple the White & Hazard original.[7] During the interval, there was rapid and prolific development of this kind of bridge in the United States and Canada.

Although the span attainable by catenary cable suspensions may have tripled during the era, there was very little change in the kind of iron wire used for these bridges. During the era of iron wire cables, the science of metallurgy was in infancy. There was little or no technological understanding of significant pyrochemical phenomena. Concepts such as the recrystalization of metallic iron at elevated temperatures, the time required for change in metallurgical values at elevated temperatures, or the notion of solid solutions of metals within metals, were then unknown. These fundamental phenomena continued to be mysterious for years after the end of the era of wrought iron wire cable suspension bridges.

Bridgebuilders, however, had little reason to be concerned with metallurgy at the time because they were experimenting with the substitution of wrought iron cables merely as minor structural elements, combined with traditional materials such as stone and wood. White & Hazard's 1816 footbridge was the sole American example comparable to several similar bridges erected in Europe shortly after it. All the early bridges used the readily available textile product *card wire* for their cables because of two related intrinsic attributes. First, it was stronger than the iron bars from which chain links were forged, due to cold-forming of the wiredrawing process, and therefore it could be substituted for bars to reduce the total suspended weight of the structure and the cost of the bridge. Second, it was safer to use: after having been pulled forcibly through a die, *card wire* had been pretested for unseen internal flaws not readily detectable in wrought iron bars.

A major disadvantage of iron chain cables with links forged from rolled iron bars was that the integrity of each link depended upon the weldability of the forged connection, and a single faulty link could cause failure of the entire structure. Wrought iron wire cables with higher tensile strength obviated this disadvantage, and also allowed the spans of bridges to be increased because the supported weight was reduced. The vast American landscape, interlaced with broad rivers, provided promoters with opportunities to experiment with longer spans of bridges. The primary merit of a longer span was elimination of costly piers. Longer spans also permitted crossings at locations such as wide gorges previously uncrossable. Bridgebuilders were not united in their opinions on this subject, however, and many rejected the reapplication of *card wire* as a suitable engineering metal, for a variety of reasons. The British engineers, in particular, preferred eye bar chains; the Menai Suspension Bridge by Thomas Telford was the most notable example, and was built with eyebars only after Telford had completed an experimental model using iron wire. [8]

Despite its advantages compared to iron chains, the quality of the wrought iron wire used by early engineers wasn't uniform. This is best demonstrated by the vague definition adopted as recently as 1930 by the American Society for Testing & Materials (ASTM), which described wrought iron as a ferrous material, aggregated from a solidifying mass of pasty particles of highly refined metallic iron, with which, without subsequent fusion, is incorporated a minute and uniformly distributed quantity of slag. As a result of its poor uniformity, all early accounts of the wrought iron trade include heavy emphasis upon the source of the original iron ore, as this was believed mistakenly to be the most significant determining factor for quality (e.g. *Dannemora* iron from Sweden, *Adirondack* iron from northern New

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the 1895 Reconstruction of the Roebling Suspension Bridge," *Proceedings - Fifth Historic Bridge Conference* (Cincinnati, OH, 1997).

[7]George A. Seibel, *Bridges Over The Niagara Gorge*, (Niagara Falls, Ontario, Niagara Falls Bridge Commission, 1991), 121-135.

[8]There is much in print about Telford's career, but the best explanation of this key decision is given by Roland A. Paxton, "The Early Development of the Long Span Suspension Bridge in Britain 1810-1940," *Proceedings of an International Conference on Historic Bridges* (Morgantown, WV: West Virginia University Press, 1999), 179-90.

York, and *Juniata* iron from Central Pennsylvania). When chemical analyses of ferrous materials became a common practice after c.1860, these and other names of the ore, or the furnace locations, often cited in historical accounts, ceased to be important, because metallurgists had recognized ways to make in-process chemical corrections. Initial chemical studies were soon supplanted by microscopic visual examinations, leading to more complete comprehension of the fundamental nature of metal alloys.

Of the many differing techniques for making *wrought iron*, the process known as *puddling* most closely approached a mass production technique. The advent of *puddling* as a common practice is usually credited to the aggressive activities of an Englishman, Henry Cort, in the 1790's.[9] Regardless of whether *puddling*, or the older technique usually known as *forging*, was implemented, and no matter what sort of *piling* or *rolling* of the intermediate bar and rod products was employed, the mid-point product at the conclusion of hot forming sequence became known as a *wire rod* which was the raw material supplied to the wiredrawer for conversion into wire.

In France, the first generation of iron wire cable bridges was not built by the existing corps of academically-trained military engineers, but instead by self-taught intuitive bridgebuilders such as the Seguin family of textile weavers from Annonay in the Rhone Valley. French military engineers, trained at the *Ecole des Ponts et Chaussees*, quickly adopted, and improved upon, Seguin bridges. Readaptation of *card wire* for bridge cables proceeded very rapidly in France, so that hundreds of wire suspension bridges were built prior to 1850. The French engineers were not silent about their discoveries. Publications by Seguin, and by French engineers such as Navier, Vicat, and others, were combined with a series of detailed analyses presented as lectures at the Ecole des Ponts et Chaussees in Paris, providing ample technical and practical background for anyone designing this kind of bridge. The numerous and varied French theories, reports, and structures were studied in many other countries.[10]

After White & Hazard, iron wire bridges in the United States were built by trained civil and military engineers seeking to refine designs and theories of the wire cable structures on a scientific basis, imitating French and British practice. A relatively large number of improved practical techniques were devised by these trained engineers, so that by the time of the transition to *crucible steel* wire 1870-80, Americans had become world leaders in suspension bridge construction, a position they held for almost a century. The American engineers did not, however, make many new contributions to basic suspension bridge theory during the earliest period. British metallurgists and wire-drawers, working in cooperation, elevated the state of the metalworking art to new plateaus at the same time the French civil engineers were perfecting suspension bridge designs. The Americans, who were not notable innovators in either realm, easily adopted the best technology from both nations.

Factory-made wire cables

The earliest iron wire bridges were erected by fabricating cables on site, either at a location nearby in line with the bridge, or else directly in place as part of the bridge itself, by bringing finished wire from the wire factory to the bridge. From a manufacturer's standpoint, it is much more expedient to make wire cables off-site, at a factory. The application of wire cables for other purposes soon created a thriving market for factory-made products in the United States. Factory-made cables, known as *wire ropes*, rapidly displaced wrought iron chains and vegetable-fiber cordage ropes used in numerous different ways.

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[9]The most complete assessment of Cort's innovations is by R.A. Mott, *Henry Cort, The Great Finer*, (London, The Metals Society, 1983), 27-37.

[10]The first European wire cable suspension bridges are portrayed in depth by Tom F. Peters, *Transitions In Engineering*, (Basel, Birkhauser Verlag, 1987), and by Rosemarie Wagner and Ralph Egermann, *Die Ersten Drahtkabelbrucken*, (Dusseldorf, Werner Verlag, 1987). Also see Michel Cotte, "The Tain-Tournon Suspension Bridge," and Ted Ruddock, "Blacksmith Bridges in Scotland and Ireland, 1816-1834," both in *Proceedings of an International Conference on Historic Bridges* (Morgantown, WV: West Virginia University Press, 1999).

In 1877, William (Wilhelm) Hildenbrand described the three fundamental cablemaking methods implemented for construction of all wire cable suspension bridges.[11] These methods have been called by a variety of names, but for here, the purpose of a generic study, they are called "A," "B," and "C." Hildenbrand listed the attributes of each method, emphasizing that physical characteristics of bridge sites would be the determining factor for choosing the best method for each individual location.

The parameters and attributes of the three Hildenbrand cable-making methods are as follows:

A. Hildenbrand Method A: Cables are made with machinery at a cable factory, cut to exact length, and shipped to jobsite more or less ready to install in their permanent position in the bridge. This method is the quickest and cheapest, but individual wires cannot easily be adjusted, and effective combination of wire strengths is reduced.

B. Hildenbrand Method B: Cables are made on land near the bridge site. Wire is brought to location and stored there for use during fabrication. This is a good method if *space* is available, but wire tensions must be adjusted after placement in the bridge.

C. Hildenbrand Method C: Cables are made in place by positioning individual wires, or groups of wires, directly into the bridge structure. In this method, wire tensions can be equalized and adjusted with relative ease and the cable has high effective strength. It is also the slowest and most costly method.

"Each method has advantages which in certain cases will recommend its application," noted Wilhem Hildenbrand.

> A wire rope is easily handled and a cable of ropes can be formed quickly and without the aid of machinery. In small or light bridges therefore, this kind of cable is found to be most advantageous. But the tensile strength of a straight wire is ten percent larger than of one twisted... Secondly, the bulk of the former would exceed the latter by forty percent...Finally, there is great difficulty in making good attachments of heavy wire ropes...The second method is only applicable if in the line of the bridge behind either anchorage there is disposable room of the length of the cable. But...there are other reasons which speak against strand-making on shore...difference in tension in the single wires may amount to a loss of twenty-five per cent in total strength...Furthermore, it is no easy matter to handle a strand of fifty tons weight...being pulled over towers and put in position...All points so far are decidedly in favor of the third plan. But one great disadvantage is connected with it, namely the loss of time involved, from the fact that the towers and anchorages must be finished before cable making can begin.[12]

Which of the three Hildenbrand cable-making methods used is a salient feature of every wire suspension bridge. Bridge publicists have turned the main focus of suspension bridge documentation toward themes attractive to the general public, such as the width of the waterway being crossed, or the length of the central span in the crossing, or the total length of the bridge including approaches. The public, which only rarely witness all aspects of construction, is greatly impressed by that sort of factual information. For the benefit of engineering students, more complete suspension bridge appraisals also should include evaluations of which Hildenbrand method was chosen to make the cables, who made the decision and why, and how cost-effective it was in the final analysis.

The manufacture of American factory-made wire ropes began in the mid-1800's *after* the concept of iron wire suspension bridges had been firmly established by the studies of French military engineers. The first three wire rope factories in the United States were launched during the wrought iron era, by Erskine

[11]William (Wilhelm) Hildenbrand, *Cable-Making For Suspension Bridges, with special reference to the Cables of the East River Bridge, Van Nostrand's Science Series Number 32,* (New York NY, D. Van Nostrand, 1877), 5-9. This document is the earliest detailed American treatise on the subject. Hildenbrand's contribution to the design of the Brooklyn Bridge, and his exceptional achievements when rebuilding both the Wheeling and Cincinnati bridges, have been largely overlooked by American historians.

[12]Hildenbrand, *Cable-Making*, 5-9.

Hazard and Edwin Douglas at Jim Thorpe (Mauch Chunk), PA (1848); by John Roebling and Charles Swan at Trenton, NJ (1849); and by Andrew Smith Hallidie at San Francisco, CA (1857). At first these three factories were very small, and wire suspension bridge cables formed a significant and identifiable part of their product mix. Roebling's factory became the largest and most successful wire rope company in the country, expanding to a second location at Roebling, NJ; it closed in 1973. Hallidie built a series of suspension bridges, but is most famous for his introduction of the San Francisco cable cars. His wire rope factory was relocated in 1941 to Pittsburg, CA, remaining in business as part of U.S. Steel Corporation until the 1980's. The Hazard & Douglas factory is still in business making cables under the name Bridon American Corporation. It is now located at Exeter PA.

After the Civil War, however, when new uses for factory-made wire ropes such as cable-cars and passenger elevators appeared, the bridge cable market segment became relatively smaller and less significant. To some degree that same market shift has inhibited historically correct identification of bridge cables and wire sources in the bridge records, particularly in the case of the "catalog bridges" discussed below.

Three Conceptual Aspects of Suspension Bridges in General

The notion of hanging a catenary tension member ("cable") across an open space to make a bridge is prehistoric. When iron chains began to be applied to cable-making for suspension bridges, there were three fundamental approaches taken, each with its own set of special engineering problems. The three chain cable formats were adopted without modification by the wire cable proponents.[13]

The first and simplest approach was to hang several cables side by side, then build a dipping but laterally-horizontal, bridge deck surface directly onto the catenary curve of the cables. That kind of format is easy to build, but highly unstable when traversed. A flexible catenary cable, when disturbed, can sway laterally like a pendulum, and also can oscillate longitudinally with sinusoidal wave action. The low point of such a bridge is at the center of the span where the side-to-side instability is greatest. Primitive men learned how to create this kind of bridge with vines, but they never learned any good ways to stabilize such bridges. Although seventeenth and eighteenth-century engineers realized it was possible to control some of the motion by adding guys and stays, they generally rejected simple iron catenary bridges because of their inherent instability. Very few ever were constructed using wire cables.

The second format is known as a stayed-cable bridge, which at first seems most obvious. The bridge is simply guyed into horizontal position with straight line support cables. Early studies by French engineers showed this to be the most difficult format to analyze. Although the center of the bridge can be raised to be at least at a level with the abutments, the calculations needed to determine correct length and tension of the guys and stays were beyond the capability of early estimators. The only recourse was to provide some kind of means for take-up or adjustment to bring the wire cables into uniform tension, an almost impossible task with a large mass of wires filled with loops and kinks, and are not straight when received from the wiremaker. Early bridgebuilders therefore avoided stayed-cable designs except in very small structures.

The third format, more elegant from an engineering standpoint, involved building towers opposite each other on either side of the chasm, then creating a generally level roadway across the open space between the towers, suspended from catenary cables draped from the tops of the towers. By making the roadway level, the problem of mid-span low point is solved. Most of the other problems remain, and some new problems are introduced. A major question arises as to where and how to anchor the cables relative to the towers. Catenary wire cables hung from towers, with the midpoint of the bridge in a generally level configuration compared to the approaches, became an accepted practice. This is the format identified by

[13]This section provides a simplistic overview of early suspension bridge designs. For a more detailed analysis of the criteria, refer to Dario Gasperini, "Stiffening Suspension Bridges," *Proceedings of an International Conference on Historic Bridges* (Morgantown, WV: West Virginia University Press, 1999).

most people when they think of a wire suspension bridge.

Early bridgebuilders confronted the unusual motions of wire suspension bridges, and the uneven loading resulting from these motions, with different theories and remedies, most of which were wrong or inadequate. Only two partial solutions were popularized in the era of wrought iron cables: lightweight roadways suspended from catenary cables but also guyed with stays, and heavier roadways made rigid with trussing and deadweight. Even after academy-trained engineers began designing more rigid suspension bridges in accord with classic structural analyses, aerodynamic instability eluded understanding well unto the 20th century. It was not until the advent of high-speed electronic computers that the second format, (stayed bridges) returned to favor. The wrought iron wire applied to cablemaking for the first suspension bridges was much the same no matter which format was favored by the bridge designer. The most important characteristic was consistent tensile strength.

The Central Role Of Charles Ellet Jr.

The introduction of engineered wire cable bridges in America is due to the efforts Charles Ellet Jr. (1810-1862). Ellet's involvement with wire suspension bridges and their builders was a minor episode in an amazingly productive life ended prematurely in the Civil War. Largely self-taught, he traveled to Europe in 1831-32, assimilated basic French engineering knowledge about wire suspension bridges, witnessed the construction of a wire bridge (one of a dozen of wire bridges being built there at the time), and returned to the United States where he introduced the new French ideas and methods almost single-handedly. He never pretended to have originated any of those ideas himself, and he visualized his role as that of an executive promoter and planner, not merely a bridge designer or contractor.

Ellet's usual method was to make direct contact with political leaders, preparing detailed economic plans and explanations justifying construction of iron wire suspension bridges in accord with the early French engineering methods he had observed in person. Because his broad interests were mainly centered around the future evolution of rapid transportation, he was able to focus his proposals as justifications for replacing ferries with bridges, stimulating commerce. His many publications and proposals were eagerly supported by other forward-minded individuals. Adherents were fiercely loyal toward him, but his main character weakness was an inability to tolerate opposition, particularly when it came from powerful individuals whose intelligence he challenged. In many cases his plans were stymied by opponents who resented and, therefore, obstructed him. After 1845, when he was named president of the Schuylkill Navigation Company, one of the largest companies in America, his interest in wire bridges waned.

In the 1830's, Ellet was not alone in his efforts to introduce wire bridges. He was an elegant writer who often boldly published his advanced ideas at his own expense. In 1841, at the time he became involved with building the new Callowhill Street wire bridge in Philadelphia, he was at the same time writing to promote wire bridges at a half dozen other locations. Some of his surviving presentations amply demonstrate his clarity of persuasion and his depth of analysis.[14] But above all, Ellet's efforts and discussions stimulated several other talented engineers, who continued not only to promote the French basic concepts, but also innovated new construction techniques that were, in some cases, quite superior to methods used in France. Foremost among his followers was John A. Roebling, who became the most prolific American suspension bridge builder in the era of iron cables, executing twelve bridges and

[14]Ellet's only biographer, Lewis, *Charles Ellet Jr.*, cites numerous anecdotes about his many confrontations with opponents. Ellet was totally fearless, but he could not tolerate any disagreement with his innovative proposals, always reacting sharply. The Library Of Congress collection includes more than two dozen publications by Ellet, only a few of which are related to suspension bridges. None of his three wire suspension bridges has survived intact. The stone towers and original cables of his Wheeling bridge remain in use but the bridge deck has been rebuilt several times.

aqueducts.[15]

New Products Stimulated Technology for Making Iron Wire[16]

At the beginning of the nineteenth century *card wire* was the largest selling wire item in the world, a result of unprecedented demand for machine-woven textile fabrics. The vast English textile industry stimulated large demands for high quality wire, and the English wiredrawers became the best in world, particularly because they had available extremely high quality iron billets imported from Sweden. The superiority of English iron wire soon became legendary in the United States.[17] Although it was possible to import the same "Swedish" quality billets for wire-drawing, more often English-made wire was imported. Another approach was to bring in English craftsman with the needed skills. In a parallel development, the English also became leaders in techniques for factory-made wire ropes.

Other uses for similar kinds of wire soon arose.[18] Of these newest reapplications, two markets grew rapidly, both requiring wire to be manufactured in long lengths. Pianoforte music, popularized at public concert performances given by Ludwig Van Beethoven and others, beginning in Vienna around 1800, created significant consumer demand for the instruments. Each pianoforte contained a considerable quantity of high quality wire. The best pianofortes were made using high-tensile steel wire, much stronger than wrought iron wire. The new wire, which became known as *music wire* or *piano wire*, could be subjected to varying tensions to emit exact musical tones when struck. Wiremakers found it difficult to make good quality piano wire. It was tested by bridgebuilders and cablemakers who found it to be somewhat costly, and too strong for their applications, often lacking in elasticity.

Almost simultaneously, Christian Oersted, a Danish college professor, accidentally discovered the fundamental physical relationship between electricity and magnetism. After his revelation in 1820, wire telegraphy was introduced as a means of rapid communication all over the world, creating a new, and very large market for long lengths of iron wire. The wire telegraph became extremely popular in the United States after it was introduced here in 1844. Early telegraphs used wrought iron wire, known as *telegraph wire,* to transmit signals. Soon, as wire telegraphy grew rapidly in popularity, iron wire was supplanted by copper wire with better conductivity.

Telegraph wire had to be manufactured in the longest possible lengths to accommodate cross-country, or transoceanic, stringing, minimizing the splices. The eighteenth century practice of making wire from slit-and-hammered rods could not cope with the new demand. As a direct outcome, many experiments in

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[15]None of John A. Roebling's bridges has survived intact although portions of an aqueduct over the Delaware River at Lackawaxen PA (1848) and the towers of a highway bridge over the Ohio River linking Covington KY with Cincinnati OH (1867) can be recognized as his designs, despite complete rebuilding of both structures. Most of his cables were made of wrought iron wire. He claimed to have "executed" twelve bridges and aqueducts, but the list of his structures is uncertain." He died in 1869 prior to the era of steel cables. Ironically, he is often credited with the design of the Brooklyn Bridge (1883) completed with steel cables fourteen years after his death by his son Washington A. Roebling.

[16]The descriptions of various kinds of wrought iron wire in commercial trade, provided in the following section, are intended to clarify reasons why minor applications such as suspension bridge cables are noted only rarely in the records of the wire making companies. Refer to Lewis, *Steel Wire In America*, 29-51 for a more complete study of the primary commercial wire markets.

[17]For example, John A. Roebling, who was manufacturing wire for his own wire ropes in his wire mill at Trenton NJ, preferred to purchase wire from Richard Johnson & Nephew, Manchester UK, for the main cables of both the Niagara bridge and the Ohio River bridge.

[18]The abbreviated descriptions of the new wire reapplications given here are explained more completely by Joseph P. Bedson, "Iron and Steel Wire and the Development of its Manufacture", *Journal of the Iron & Steel Institute,* XLIV, (1894).

the United States resulted in the creation of mills able to roll and manipulate longer and longer lengths of rods for wiremaking. Luckily, just as substitution of copper telegraph wire began to displace iron, three new high volume markets arose: first, *crinoline wire* for a female fashion item known as a "hoop skirt"; next, *fence wire* for the newly-contrived barbed wire fences; and lastly, *nail wire*, when wire nails displaced wrought iron hardened cut nails. Fence wire and nail wire quickly became the largest selling wire items. Neither application demanded extremely the high tensile strength needed for *piano wire.*

Although the advent of higher strength wire was significant in the history of suspension bridge cables, the importance of the size of billets, rod coils, and wire coils that were commercially available is not generally appreciated in the histories of early iron wire bridges. To place emphasis upon this point, consider the example of the gauge size "Number 10" wire, often mentioned in descriptions of the early suspension bridge cables. "Number 10" as measured on the most popular gauge ("Birmingham Gauge") is slightly thicker than one-eighth inch. If a rod coil weighing 10 pounds is drawn into a coil of "Number 10" gauge wire, it will be converted into a piece of wire approximately 200 feet long. A crossing with a span of about 200 feet is about the distance at which suspension bridge spans could begin to compete cost-wise with wooden truss spans.

At the beginning of the iron wire suspension bridge era, ten or fifteen pounds of wire rod, converted into the same weight of wire in a coil, was about as much as could be purchased in one unbroken length. Obviously, any bridge with a span greater than 200 feet, therefore, probably required at least one wire splice in every wire across the span; in most cases two or more splices were needed. To accommodate these short lengths of wire, expert methods of wire splicing were developed. One of the more interesting aspects of bridge cable design is that these splices, which worried engineers because of their weakness, actually were developed to the point they were often stronger than the wire itself.

There were several techniques for making splices. The most durable method was to flatten the ends of the two pieces of wire, roughen them with a file, overlap them with the roughened faces against each other, then bind the joint with a miniature wrapping of very fine wire. Sometimes a coating of solder was also applied. This was a costly and time-consuming technique, but was considered superior to simply knotting the ends together. French bridge building technicians immediately adopted the concept of making long lengths from short ones by splicing and coiling up the individual pieces of wire. Splicing practices were applied universally to making bridge cables, so that each cable, while in reality composed of short pieces of wire spliced together, took the form of one long length passed back and forth across the span of the bridge. In this application, a collection or parcel of spliced wires, passed back and forth in this manner, became called a *strand.* In early historical accounts, the words "wire" and "strand" were sometimes synonymous, but in all later references, "strand" always means more than one wire.

But the new uses of wire for applications such as the telegraph did create the need for longer lengths of rods. The unprecedented distances to be crossed by telegraph wires in the United States stimulated expansion of rod mill capacity and capability soon after European wire telegraph techniques were brought to the American continent in 1844. A well-known English wiremaker, Joseph Bedson, when writing a historical treatise about the industry during the era of these new uses, placed much emphasis upon the importance of the new rolling mills in the expanded production of iron rods: "...in the United States of America...while in wiredrawing nothing new has been introduced, wire-rod rolling has been developed and perfected to a far greater extent than in any other country in the world."[19]

Patented Wire

The most significant new technology applicable to wire bridges was the innovation known as "patenting." Appropriate wire for pianoforte instruments had to possess consistent quality and dimensions, combined with exceptional strength, to permit high tension stringing. It had to be able resist thousands of vibrations, and yet be tough enough to be twisted around its own diameter. Iron wire of the

[19]Joseph P. Bedson, "Iron and Steel Wire," 77.

kind used for telegraphs, fences, and hoop skirts was inferior for this use. Two Englishmen, Webster & Horsfall, experimented in secret, looking for ways to improve the quality of piano wire. Working with higher strength steel wire, they devised a unique quenching method that succeeded in attaining small diameter wire exhibiting enormous improvement in wire quality. As early as May 7, 1836, Mechanics Magazine of London touted Webster & Horsfall's piano wire as the world's best. Much later, James Horsfall applied for a patent on their secret process.

The quality of Webster & Horsfall's product was so superior that their new form of piano wire was adopted into the wire cable trade in the 1860's. Apparently, they decided they were not ready to share the secret. Although their patent was granted in 1854, in the form published it contains a misinstruction, apparently deliberate, that they evidently inserted to prevent anyone from duplicating their process. Ultimately, a man named Smith discovered what they were actually doing and duplicated their efforts. The method is still known as "patenting," and it is used all over the world.[20]

So long as the method of patenting remained secret, other wiredrawers struggled (most often in vain) to duplicate Webster & Horsfall's piano wire product.[21] The most detailed assessment of wire industry methods at the time of the transition from wrought iron wire to steel wire was written by J. Bucknall Smith, but he was unable to explain the mysterious quality of the secret process: "Patent or improved steel wire implies that which... may have its tensile efficiency increased two or threefold without much detriment to its ductility...The patenting or improving...is rightly held to be an occult process in the trade, for each manufacturer has his own, more or less, special method and devices for attaining the same object, and upon such experience, judgment, and skill the excellent quality of certain wire largely depends."[22]

Corrosion of Wrought Iron

Iron corrodes (oxidizes) when exposed to the ambient atmosphere. As it corrodes, it loses strength. The by-products (rust) of corrosion impart an obvious reddish appearance. At first, French bridge engineers were greatly concerned about the effects of atmospheric corrosion on the long-term viability of small diameter iron wire. They designed anchorages for their suspension bridge cables as open chambers large enough for a human inspector to enter.[23] Because the chemical process of corrosion was not completely understood, the ordinary remedy was to apply an atmospheric barrier coating of linseed oil paint (or even molten tin or zinc) onto iron wire.

In the United States, numerous examples of the atmospheric durability of wrought iron wire have been

[20]According to Joseph Bedson "it is to Mr. Horsfall of Birmingham, in 1854, that the credit of first attempting to harden and temper cast steel is due; but it is to the late Mr. William Smith of Warrington that the secret of this 'patenting'...is due...he worked for many years on these lines almost unapproached by any other makers in the land or even the world...However, the secret leaked out and is now possessed by various makers in this country, who are able to produce this very high class wire." Bedson, "Iron and Steel Wire...," 77.

[21]It is fortunate for posterity that a descendent of James Horsfall has revealed the whole story; see John Horsfall, *The Iron Masters Of Penns*, (Kineton, Roundwood Press, 1971), 120-123.

[22]A more complete explanation of the complex thermal treatment known as "patenting" would occupy too much space here. Refer to J. Bucknall Smith, *A Treatise Upon Wire, Its Manufacture And Uses*, (New York, Wiley, 1891), 60. A more modem, but highly technical, treatise is found in *Ferrous Wire,* v.1, (Branford CT, The Wire Association, 1989), 467-490.

[23]The first French engineering recognition of how wrought iron wire resisted corrosion seems to have been the notice given by P. LeBlanc in the *Annales* of the Ecole des Ponts et Chausees, (1835) 315-327. French engineering leadership in wire suspension bridges was halted rudely in April, 1850 when a twelve year old wire suspension bridge at Anger collapsed, killing 220 people. One of the suspected causes was wire corrosion. Although the evidence was not conclusive, the French ceased building wire bridges soon afterward.

documented. A set of structural cables removed from the interior of an old bank building, after 140 years, showed almost no sign of corrosion and were tested at levels near what must have been the original strength.[24] Edwin A. Douglas, who was to establish America's first wire rope factory in 1848, declared to Josiah White in 1846: "In regard to the wire rope, I have no knowledge of them. My opinion has been heretofore against them, believing that jacket the wire as they will, I believe that the water will go to the middle of the rope and soon rust the wire. Perhaps I may be mistaken."[25] In 1858 Douglas manufactured two large wrought iron wire rope cables for his Lehigh River Change Bridge that are still hanging in place unloaded, 140 years later. If these ropes are ever analyzed they would provide a good long-term study.

When John Roebling removed Charles Ellet's Niagara Gorge bridge after 6 years service, he reused the cable wire for his new bridge, stating: "I tested it, and found its strength and toughness scarcely impaired... I found the oil inside still in a soft condition, forming a tenacious varnish, and no trace of oxidation."[26] Gustav Lindenthal dismantled Roebling's Smithfield Street Bridge after 35 years service, and reported "the wires had suffered no impairment of their original strength. They were in very good condition, and nearly free from corrosion, although the painting of the cables had been neglected for many years."[27] These early examples of apparent resistance to corrosion also led directly to a certain amount of hubris in the bridgebuilding community. In 1855, John Roebling asserted that the cables of his Niagara Gorge bridge were: "well protected against oxidation, and will consequently last an indefinite length of time." After inspecting the cables five years later he went even further: "This durability I am unwilling to estimate at less than several hundred years," but his cables were scrapped in 1897.[28] A suspension bridge failure at Charleston WV in 1903 was directly attributed to corrosion of the iron wire cables inside the anchorage at a point where rainwater was allowed to accumulate.

The presence of the non-metallic "stringers" of slag trapped within iron wire helped the metal resist corrosion. The phenomenon has not been completely explained because wrought iron wire was displaced prior to the advent of sophisticated chemical analysis. In modern times a form of low tensile steel known as "iron" has been used by cablemakers, but this product should not be confused with true malleable wrought iron. When wrought iron wire has corroded to destruction, it begins to "split," a process that apparently involves separation of the elongated original bars that were fused together in the pile prior to rod rolling. The appearance of splitting, combined with the general good appearance of even the most heavily rusted metal, is an indication that wrought iron wire is present. Steel wire rusts more vigorously, and does not exhibit splitting. This is one key to identifying wrought iron wire in older bridges.

Metallic zinc coating ultimately became the technique of choice for corrosion protection. Its application to iron wire cables was mentioned by one anonymous correspondent as early as September 16, 1843 in *Mechanics Magazine*: "Observing that the tar or composition used for covering wire ropes is not a sufficient protection against rust, I beg to suggest that the wires be dipped in melted zink so as to be

[24]Donald Sayenga, "Discovery And Analysis Of The Remarkable G-G-G Iron Wire Cables," *Wire Journal International*, (April 1996), 302. Dr. Sara Wermeil of MIT has identified these unusual wire cables as part of a post-tensioned girder system designed by Benjamin Severson.

[25]Quoted with permission from *The Letterbook Of E. A. Douglas*, Collection of Eleutherian Mills Historical Library, Greenville DE. See also Donald Sayenga, "The Mauch Chunk Wire Rope Factory," *Canal History And Technology Proceedings*, XVII (Easton PA, Canal History And Technology Press, March 14,1998), 135-158.

[26]John A. Roebling, *Final Report*, (Rochester NY, Lee, Mann & Co, 1855), 29.

[27]Gustav Lindenthal, "Old And New Forms Of The Suspension Bridge,", *Engineering Magazine*, (New York NY, Volume XVI, October 1898 - May 1899), 363.

[28]Roebling, *Final Report*, p. 29; John A. Roebling, *Report On The Condition Of the Niagara Railway Suspension Bridge*, (Trenton NJ, Murphy & Bechtel, 1860), 20.

completely covered by that metal...or the zink may be applied by other means."[29] This method became known as *hot dip galvanizing*,[30] and is easier said than done. At present, any zinc coated wire is generally known as "galvanized" wire, no matter which of several methods is used to apply the zinc.

Unlike the simple atmospheric barrier provided by oil, tars, paints, tin, or synthetic compounds, the coating of zinc acts in a sacrificial manner. Because of the electrochemical relationship between iron and zinc, the iron will not begin to corrode until the zinc has itself corroded away. The corroded by-product of zinc has a whitish appearance. In 1860, George Bedson perfected and patented a process for continuous application of molten zinc to iron wire.[31] His basic technique became the accepted practice during the era of steel wire cables, even though it was difficult to learn. Washington Roebling observed many years later: "...a great amount of experimenting and poor galvanizing was done...there were at least fifty difficulties to be solved satisfactorily..."[32]

After 1880, the use of wrought iron wire for suspension bridges was discontinued just as rapidly as it had been adopted, as bridge builders embraced crucible steel wire possessing higher strength. Wrought iron wire disappeared quickly from bridge cables. Rehabilitation of older cable structures with the duplicates of original material has become impossible because at present, the dominant metal in the ferrous wire trade is mass-produced steel made by a different process. Originally, there were many different methods for making wrought iron, but none was ever codified into a single uniform practice. An attempt at revival in 1925, led by James Aston and the A.M. Byers Co. of Pittsburgh, had little or no effect within the wire industry. Because there was no longer any commercial demand, wiremakers did not bequeath any of their wrought iron wire manufacturing techniques to the industry of present times.[33]

Steel Wire Suspension Bridge Cables, 1880 - present

Prior to 1850, mention of steel wire is rare. The main uses of steel were at first related solely to its extreme degree of hardness compared to wrought iron. Very hard metals tend to be brittle. Steel wire made in short lengths could be used for some applications such as needles, while yet remaining unsuitable for long length applications such as ropes and cables. Kenneth Barraclough, who has written the best metallurgical treatise on the subject, has emphasized the vague, alchemical, understandings of steelmaking that prevailed everywhere prior to the middle of the Nineteenth Century. Before the Civil War, the name "steel" was applied to slightly differing iron alloys made by at least eleven different

[29]Anonymous letter, *The Mechanics' Magazine, museum, register, journal and gazette,* (London UK, Volume 39, Number 1049, September 16, 1843), 223. During the period 1829-1852 when it was published by M. Salmon, *The Mechanics' Magazine* was an excellent source for news about early wire technology. As for the term "galvanizing", J. L. Schueler asserts: "Just how the process of zinc coating came to be called galvanizing is not clear". Refer to his detailed treatise on the subject: "Historical Data Relating To Hot Galvanizing Practice For Wire", *Wire & Wire Products*, (August 1936), 383.

[30]J. L. Schueler asserts: "Just how the process of zinc coating came to be called galvanizing is not clear." Refer to his treatise "Historical Data Relating To Hot Galvanizing Practice For Wire," *Wire & Wire Products*, (August 1936), 383.

[31]U.S. Patent 37669, February 17, 1863.

[32]Washington A. Roebling, "An Inside View Of A Great Industry" in Hamilton Schuyler, *The Roeblings*, (Princeton NJ, Princeton University Press, 1931), 332-333.

[33]The Aston process is described by A. Green in *Metals Handbook*, (Cleveland OH, American Society for Metals, 1948), 503. As of 1999, the American Society for Testing & Materials, West Conshohocken PA is still publishing a standard (ASTM A111) describing zinc-coated "iron" telephone and telegraph line Wire. In the standard, the word *Iron* appears with quotation marks. The metal described actually is steel. Several passenger elevator companies still issue purchase orders for items known as "Iron Grade" elevator cables, actually made of steel. These two cases are the only surviving vestiges of the wrought iron wire industry in the United States.

processes. All of these metallic substances and processes were secretive. Each had a unique metallurgical structure that was highly inconsistent and slightly different from the others, but each had physical properties superior to conventional wrought iron. All eleven processes yielded extremely small quantities of steel at extremely high cost.[34]

The distinction between the slightly differing varieties of steel always is less than clear in early historical accounts. The high cost associated with all early steelmaking efforts explains why steel wire for ropes and cables continued to be regarded as a costly item even after the advent of much lower-cost forms of steel in the 1850s. Very little steel of any kind was made in the United States in the period prior to Ellet's Callowhill Street Bridge (1841). The earliest dissertations on the merits of steel wire for ropes and cables first appeared in the 1850s. Two of the processes attempted in the USA were known as "blister steel" and "crucible cast steel". These were steels applied primarily to edge tools, not wire products, and the American endeavors to make them were not exceptionally successful.

It was not until the general adoption of steel instead of iron by the railroads, for use as self-supported rails, that mass-production techniques for generic low-cost steelmaking were implemented, very rapidly, all over the world. The pneumatic steelmaking technique, discovered spontaneously in the 1850s, was astonishingly less costly by comparison with all previous methods for making iron or steel. Mass-produced steel was not the same as crucible cast steel, but its advent yielded a side-effect ultimately resulting in greater availability of crucible steel wire. Almost all modern steels contain an amount of the metal manganese combined with the iron. In the new mass-production techniques of the 1850s, manganese was alloyed with iron in bulk. This crucial step wasn't very well understood at first. Mass-produced steel perhaps ought to be called pneumatic steel, or, as some have suggested, might even be called "Mushet" steel after Robert Mushet, the Englishman who illuminated what became the accepted manganese alloying technique. It has become well-known instead as "Bessemer" steel after Sir Henry Bessemer, one of the early English patentees.

Immediately after the American Civil War, Commodore Melancthon Smith of the U.S. Navy ordered a series of tests to determine the suitability of copper wire, galvanized iron wire, or ungalvanized "bright" iron wire to be used in place of hemp ropes for ship riggings. The Navy's elaborate testing program of rigging began in 1866, and continued for two years. More than 500 rope specimens were studied. Although the primary outcome of the Navy study was general acceptance of iron wire rope rigging, Chief Engineer Shock noted in his conclusions, that, "(a)lthough not strictly within the purview of our orders, we tried some experiments on steel wire rope, sent from the Roebling establishment, and the result indicates that a still greater saving of weight may be obtained by the introduction of steel instead of iron wire rope." [35]

Shock's report contains the first reliable documented evidence of the Roebling company's switchover to a steel product. Because it was issued at the same time the first draft designs for the Brooklyn Bridge were undertaken, it supports companion evidence from the files of that bridge, showing that two original versions were projected, one with iron cables and one with steel cables. It is clear that John A. Roebling, as of 1867, wasn't entirely enthusiastic about making any sweeping change. In his report to the Covington & Cincinnati bridge company, he inserted a very strongly-worded caution: "Steel wire, it is true, possesses greater strength, but its manufacture is not yet sufficiently perfected to insure entire

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[34]Kenneth C. Barraclough's *Blister Steel - Birth of an Industry,* (London, UK: The Metals Society, 1984), gives the best introduction to this complex subject. His companion volume *Crucible Steel - Growth of Technology,* (London, UK: The Metals Society, 1984) illuminates how Benjamin Huntsman's method came to dominance. The two-volume work now is available from the Institute of Materials under the title *Steelmaking Before Bessemer.* Barraclough has continued his illumination of this history in *Steelmaking 1850-1890* (London UK; Institute of Materials, 1990) where he explains how and why the pneumatic, or mass-production, method came to be associated with the name of the prolific English inventor Sir Henry Bessemer.

[35]William H. Shock, *Experiments On Hemp Rope And Wire Rope* (Washington DC: Government Printing Office, 1871), 5

uniformity, such as can be had in iron wire...I have not been able yet, to obtain from any source, as much as one-half ton of such uniformity as I consider necessary and essential for the manufacture of good wire ropes and cables."[36]

At the Paris Exhibition of 1867, American visitors saw first hand the most recent European metalworking techniques. Although American ironmakers had achieved some breakthroughs with the introduction of anthracite iron smelting for cast iron, and although the rolling mill devices of the Washburn family and the Fritz family represented state-of-the-art, the reports of U.S. Commissioners Abram Hewitt and F. J. Slade were in awe of the European metallurgical exhibits at Paris. The visitors were openly welcomed at factories in several nations. They returned with notebooks filled with details about recent steelmaking innovations. By contrast, there was only a single American exhibit in the iron and steel sector.
Hewitt noted: "By common consent it seems to be agreed that the most striking feature of the industry of the present day is the marked advance in the manufacture of steel, and its progressive substitution for iron, in all cases where strength must be combined with lightness...For the best steel the crucible process still maintains the first rank...like all other businesses it has of late undergone an immense extension in the size of the works and of the products." [37]

The transition from iron wire to steel wire for almost every bridge cable application began early in the 1870s but can be considered to have been completed by 1880. The first report of steel wire cables being applied to suspension bridges appears to have been a new set of guy ropes attached to the Clifton Bridge in 1872. The *Niagara Falls Gazette*, credited the new steel guys that were "one third stronger" with holding the bridge in place under gale force winds of 84 mph. The last major American suspension bridge built with wrought iron wire cables was completed at Minneapolis in 1878 by Thomas Griffith.[38]

Washington A. Roebling and the Brooklyn Bridge Cables

Standing in the historical record astride the period of transition from iron wire to steel wire in the 1870s is Washington A. Roebling (1835-1926), oldest son of John A. Roebling. His personal career has suffered from a severe (almost terminal) case of mistaken identity. There is so much literature already in print confusing him with his father, the matter now is hopelessly beyond any correction. Although the Brooklyn Bridge was not the first bridge to implement cables made from steel wire, it was the first where an engineering decision to design and build with steel wire cables in place of iron wire cables was made and approved after a careful evaluation of both alternates. Much evidence seems to indicate the choice, and description, of the steel wire cables, originated with Washington Roebling. Certainly it was he who wrote out the galvanized wire specifications in 1876, plus there is surviving evidence showing that his father always was ambivalent about steel wire's tendency toward inconsistent quality.

From a distance, the stone towers of the Brooklyn Bridge adorned with its dual suspension system of catenary cables and fixed wire rope stays, look like John Roebling's hallmarks. Other than the towers, however, the designs actually used for its construction were by Washington Roebling. This was verified in 1967 when thousands of original bridge drawings were recovered from storage. Virtually all of them were made by Washington and his able assistant, William Hildenbrand.[39] At the time of his father's

[36]John A. Roebling, *Report To The President And Board Of Directors Of The Covington And Cincinnati Bridge Company*, (Cincinnati, OH: Murphy and Bechtel, 1867), 84

[37]Abram Hewitt, *The Production Of Iron And Steel In Its Economic And Social Relations*, (Washington DC; Government Printing Office, 1868), 29.

[38]*Niagara Falls Gazette*, April 17, 1872. I am indebted to Ralph Greenhill for this citation.

[39]A selection of the most dramatic drawings was displayed in an art exhibit at Whitney Museum in 1976; see *Civil Engineering*, (October 1976), 12-15.

death in 1869, the initial proposal already had been authenticated by a blue-ribbon panel of American bridgebuilders that had been assembled by his father. Washington Roebling was secretary of that panel. But only preliminary plans had been approved, together with rough cost estimates for fund-raising purposes. Washington Roebling possessed all the facts. He was named Chief Engineer of the bridge immediately, a wise move that sustained momentum for the project. Six years were needed to complete the incredible stone towers and anchorages. During those years he made a series of major changes to the design. Usually, he acted with very little fanfare because of the political climate and his own reclusive tendencies.[40]

Although Washington Roebling and his brothers were operating their own successful rod and wire factory, he deliberately specified the highest possible quality of wire for his Brooklyn Bridge cables with full knowledge that his own company probably could not supply it. He emphasized he was seeking a very special kind of steel wire, *not* the highest strength available. Instead, he was hoping instead to obtain wire with a combination of desirable physical characteristics, each length of wire to be verified individually by a set of tests he had devised. For the first time, a major bridge was to be built using wire that was not the same wrought iron product adapted from card wire. The new cables were to be made of crucible steel, coated with zinc, and straightened before delivery to the jobsite. Due to some sort of prejudice against steel made by the Bessemer process, a large new wire mill was created nearby in Brooklyn specifically to draw crucible cast steel wire for the huge bridge. This new wire mill also attempted to enter the wire rope business in direct competition against the Roebling brothers.[41]

The first batches of crucible steel used by the Brooklyn wire mill were supplied by Anderson & Passevant of Pittsburgh in the form of rod coils weighing only around 75 to 90 pounds.[42] Presuming conversion to wire without loss as "Number 8 Full Birmingham Gauge" specified by Washington Roebling, this weight of rod represents an individual wire length of only approximately 1200 feet vs. the anchorage-to-anchorage length of the main cables which is 3578 feet. Obviously, Washington Roebling expected to put at least three splices into each connected length of wire as it was passed back-and-forth across the river. A new form of wire splice, using a counter-threaded ferrule, was devised for the purpose. Building up the Brooklyn Bridge main cables by traversing the wires from anchorage to anchorage, using John Roebling's patented spinning wheel system, required more than two years of laborious effort. Each of the four main cables was comprised of more than 5000 parallel steel wires. When the main cables were completed in 1878, almost five additional years were needed to hang the suspenders, add the system of radiating stays, and then attach the flooring. The bridge finally opened for business in 1883.

During the lengthy process of making the main cables, an unknown amount of substandard product was furnished by the Brooklyn wire contractor. After his deception was uncovered, changes in the cable design were made during construction to compensate for inferior wire already supplied.[43] In 1901, safety of the cables was questioned, but the quality of construction was defended ably by Hildenbrand who

[40]Washington Roebling was a recluse for many years after the Brooklyn Bridge opened in 1883. Later, when he began to reappear in society during the 1890's, he attempted often to explain how he, not his father, had designed the Brooklyn Bridge. He even wrote a harshly critical biography of his father but it was never completed, apparently because of peer pressure within the family. All his efforts at correcting the record have failed. As of the 1990's, almost every published reference for the Brooklyn Bridge continues to credit his father for the design even though there is very little evidence to support this notion.

[41]The political implications and intrigues connected with drawing wire for the bridge and making wire rope in Brooklyn have been masterfully depicted by David McCullough in *The Great Bridge*, (New York NY, Simon & Schuster, 1972).

[42]*Iron Age*, (January 25, 1877).

[43]There is a detailed explanation of what happened; see Homer R. Seely, "Brooklyn Bridge - Historical features Of Construction And Operation", *Proceedings*, (New York, NY, American Society of Civil Engineers, 1946), 192-193.

asserted the actual tensile strength of the wire in the main cables exceeded 177,000 psi.[44] During a close examination of the main cables in 1943, the average remaining strength of the wires, estimated from test samples, was found to be 162,600 psi "with no apparent deterioration." Also, the exterior main cable layers were found to contain mostly wire that was larger than originally specified.[45]

Utilization of larger, stronger, wire in the original main cables, combined with subsequent removal of railroad tracks and elimination of truck traffic from the bridge deck, explains in part how the Brooklyn Bridge main cables are at present somewhat understressed and remain in such good condition in the 1990s. The original stay cables, however, deteriorated from corrosion. After two stays failed without warning in 1981, killing one pedestrian, all of the suspender ropes and stays were completely replaced, while the main cables were rehabilitated and rewrapped during the renovation process. The bridge conveys commuters on a daily basis while serving as a historical and cultural landmark of great significance.[46]

Continuing Improvements in Rod and Wire Technology 1880-1950

The Brooklyn Bridge was built in the same era that iron wire telegraphy completely dominated the telecommunications industry, stimulating permanent need for longer and longer lengths of wire. Because end-to-end welding was then unknown, passing larger and larger billets through the rod rolling process was the only known approach to this problem. Many of the new rod mills built made longer lengths of iron wire simply by being capable of reducing larger billets. The new longer lengths reduced the number of individual splices needed in wire suspension bridge cables.

For example, John Roebling's 1852 wire specification for the Covington-Cincinnati bridge demanded wire coils weighing approximately eighteen pounds. He bought the wire for the bridge from the Manchester UK wire mill of Richard Johnson because he believed it had superior quality. By the time Roebling's bridge was completed fifteen years later in 1867, Samuel Keefer was able to buy wire for his Clifton Bridge from the same source, made from rod coils weighing more than 130 pounds. The primary wiremaking advantage enjoyed by the Johnson company was access to rods from George Bedson's new continuous rod mill at the Bradford ironworks. Bedson's mill was able to reduce a large billet into a rod coil double the size of anything elsewhere in the world. An example of one such large rod coil, weighing 281 pounds, exhibited by Johnson at Paris in 1867, attracted the attention of ironmaker Abram Hewitt, who called it "most remarkable" when he noted: "In the use of wire for telegraphic purposes, for wire suspension bridges, and for cables and ropes, the superior value of long lengths is undeniable. Bedson's machine has therefore the double merit of producing a better article at a lower cost."[47]

The other new process devised by Bedson (1860) provided an effective way to anneal and galvanize wire in continuous lengths. In the United States, the Washburn family of Worcester MA adopted many of Bedson's methods. The Washburns, later known as Washburn & Moen when a son-in-law became a partner, expanded their factories rapidly to become the largest wire producer in the USA. Their growth was based upon massive demand for new wire products such as telegraph wire, barbed wire fence, and wire nails. Washington Roebling also had visited Johnson's works when he traveled to Europe to see the Paris Exposition. He was deeply impressed. He attempted to convey his positive impressions in a series of letters to his father. In the transition to the stronger crucible steel wire, one of the last deterrents to

[44]William (Wilhelm) Hildenbrand, "The Safety Of The Brooklyn Bridge", *Engineering News*, (January 16, 1902) Reprinted as an unpaginated pamphlet.

[45]Harold E. Wessman, "Tests On Metals Removed From Cables And Stiffening Trusses", *Transactions*, v. 112 (New York NY, American Society of Civil Engineers, 1943), 235.

[46]*New York Times*, (June 29, 1981), A2.

[47]Hewitt, *Production of Iron and Steel*, 5.

making large coils was the limited size of crucibles in which steel was melted. Visiting the Krupp works in Germany, Washington Roebling was astonished to see sophisticated systems for creating very large ingots and billets of steel by using exceptionally large crucibles for melting and refining.

By adopting European techniques, the Washburns, the Roeblings, and Hewitt's Trenton Iron Company became major wire producers. The Washburn family entered the wire rope business in competition with Roebling Sons. Trenton Iron also became a wire rope supplier, specializing in unique English wire ropes known as "locked coil" construction, but Hewitt and his partner Edward Cooper were much more active in the introduction of rolled iron I-beams for construction of fireproof buildings. The adoption of new European techniques by Washburn, Roebling, and Hewitt in the 1870s was coupled with a change in the U.S. tariff laws in 1883 that stimulated creation of many new wire rope factories.[48] The Roeblings began to face competition in all parts of the USA. In addition to the Brooklyn factory, the Washburns, and Trenton Iron in the East, and Hallidie in San Francisco, three new wire rope companies (Broderick & Bascom, Leschen, and Macwhyte, a spin-off from Leschen) arose in the Midwest. The Leschen brothers began to specialize in an English-innovation known as flattened strand wire ropes. Roebling's dominant market position in the wire rope market gradually slipped to less than half the total American production of wire ropes. In the early 1900s Trenton Iron, Washburn, and Hallidie of San Francisco all merged into a single large steelmaking conglomerate known as American Steel & Wire. The Roebling brothers responding to this challenge by creating their own integrated steel mill at Kinkora, New Jersey, a location that later became known as Roebling, New Jersey.[49]

Although the basic Roebling business continued to be wire ropes, new uses for their wire rope products were being devised every year. The most significant of these novelties were the passenger elevator and the intracity cable car, both of which created large new markets for wire ropes. The switchover to wire rope rigging in the U.S. Navy was a short-lived requirement, displaced by a change to steam-powered metal ships. Likewise, a major market for wire rope power transmission in factories never really materialized, although several installations were a success. From time to time, the Roebling brothers dabbled in other businesses (such as binding wire, wire cloth, and insulated copper wire for the electrical industries) with mixed success. Their involvement with bridge cables, always emphasized in company advertisements, was actually only a small segment of their wire and wire rope enterprise.

Two highly significant changes in the dies used for wiredrawing acted as stimulants to mass production of high quality wire. First, in the 1870s, came the gradual abandonment of handmade steel-faced drawplates in favor of cheap, multi-hole, cast iron dies. The Wire Association noted that this change was forced by the larger wire rod coils, exceeding 100 pounds, causing, "...the need for improved machinery and better dies or plates than had been known up until that time. Until the early part of the 20th century, steel wire had been drawn almost exclusively on single-hole bench blocks - a method which will be recognized at once as both cumbersome and inadequate for supplying the ever-increasing demand for wire."[50]

The second change in dies was the advent of the very hard synthetic material known as "Widia." Originally developed in Germany during WWI as a substitute for diamonds, these dies were made from particles of tungsten carbide and other carbides sintered into a cobalt matrix. Excellent dimensional stability of the new dies allowed scientific study of die cross-sections, resulting in much more uniform and consistent steel wire. The same technology was applied to diamond dies used for finer wire sizes. The use of the microscope to control internal profiles of wire-drawing dies permitted vast improvement

[48]The new factories are described in much greater depth by Donald Sayenga, "Birth And Evolution Of The American Wire Rope Industry", *Proceedings - First Annual Wire Rope Symposium*, (Pullman WA, Washington State, 1980). This paper was repeated during a symposium at Esslingen, Germany in 1984.

[49]Kinkora steel mill at Roebling NJ was documented by HAER in 1997.

[50]This quotation, part of a full discussion about improved dies, tungsten carbide inserts, and continuous wire drawing, can be found in *Ferrous Wire*, (Guilford CT, The Wire Association, 1989), 279-376.

in wire quality after 1920 and also stimulated rapid improvement of continuous multiple-hole drawing machinery. In turn, the new wiredrawing machines of the 1930's were capable of handling much larger wire rod coils, so that after 1950 the main focus of basic change in the wire industry was a trend toward larger coils weighing thousands of pounds. As of 1998, a 6000 pound rod coil has become common.

Catalog Bridges 1880-1950

Although Washington Roebling always insisted that the Brooklyn Bridge was unique, and never would be duplicated, he was only partly correct. The combination of catenary cable plus stays was abandoned when it was realized that a stiffened deck could be achieved by means of steel trusswork without adding great weight to the structure, but the basic form of the large main cables, made from galvanized steel wire, by the Hildenbrand "C" method, and continuously wrapped after being laid up with a spinning machine, became the established norm for American suspension bridges. In the early years of the twentieth century, several variations were attempted seeking to reduce the enormous cost of such expensive cables, but a majority of engineers continued to believe that techniques for main cables had been perfected on the basis of this solitary example.[51]

Widespread acceptance of Roebling-style main cables allowed the company at Trenton to specialize in suspension cables as a subcontractor for many bridge contracts, both large and small. In addition to the major bridges, the Roebling brothers became the primary supplier of factory-made steel wire ropes installed in minor suspension bridges by using Hildenbrand's "A" method. The Roebling brothers' business prospered for a variety of reasons. Although their involvement with well-publicized major suspension bridges had a tendency to grant them first rank in the public eye, this never was their primary line of business. Because wire rope markets were growing steadily, the Roebling family was able to sustain specialty bridge cables as a satellite endeavor with excellent public relations value.

John A. Roebling's personal forte was construction of entire bridges, serving in the combined role of prime contractor and superintendent. At the time of his death, he had also established himself as a manufacturer with intent to supply factory-made products, such as bridge cables, to others. In a posthumous treatise outlining his theories, he described the use of standardized factory-made wire ropes, urging bridge designers to implement them in their proposals. He published catalogs offered standardized wire ropes for sale. His three sons, Washington, Ferdinand, and Charles, nurtured this strategy into reality. A recent history of the company indicates they had attained nearly a million dollars in gross annual sales at the time they incorporated in 1876. By 1880, they were employing 500 men at Trenton.[52]

During the period 1880-1915, the company accepted orders for factory-made ropes listed in their catalogs from quite a few independent suspension bridge builders, such as John Gray, D. Griffith Smith, and J. T. Shipman, who bought Roebling's cut-length wire ropes to erect smaller scale suspension bridges at widely-separated locations. There is no detailed record of how many such bridges were built by the small contractors, many of whom assimilated the name "Roebling" with their work. As a result, some of the surviving bridges, such as the bridge at Waco, Texas are sometimes alleged to have been contracted by the Roebling Sons company when in reality they furnished only the wire ropes to a private contractor.

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[51]John Roebling himself proposed altemate methods for making main cables. His book *Long And Short Span Railway Bridges*, (New York, Van Nostrand, 1869), was edited and published by Washington A. Roebling shortly after his father's death. Although it represents only the first part of what was intended to be a much longer treatise, it introduces his concepts about Hildenbrand's "A" method for assembling main cables from factory-made ropes.

[52]The Roebling family's success with catalog bridges is overlooked by most historians. The best brief summary of the brothers' early achievements is "An Inside View Of A Great Industry" written in 1919 by Washington A. Roebling, afterward published by Hamilton Schuyler, *The Roeblings*, (Princeton NJ, Princeton University Press, 1931), 330-366. Financial data is given by Clifford W. Zink and Dorothy W. Hartman, *Spanning The Industrial Age*, (Trenton NJ, Trenton Roebling Community Development Corporation, 1992), 72-77.

The Roebling Sons company did, however, occasionally act as contractor for smaller wire rope "catalog" bridges. Toward this end they erected a model for demonstration in a Trenton park. On a later occasion, they built another model as an upper level connector between two of their factory buildings at Trenton! The most notable example of their work was a bridge built by Charles Roebling at Oil City, PA. There is a lot of confusion about which of these "catalog" bridges were actually erected by Roebling Sons. This is particularly true of those erected while the Brooklyn Bridge project was underway. In no small part this has been caused by Charles Roebling's silence. He never wrote anything if he could avoid it, and he left behind few papers in contrast to his father's voluminous files.[53]

Of course, all of the new American wire rope companies soon began to publish similar catalogs, since any easily could convert galvanized steel wire into ropes for bridges, but the Roebling brothers tried hard to maintain their leading position in this market. An example of the Roebling company's established reputation for bridge cables is contained in the rope specification for an unusual multi-span footbridge built at Easton PA by H.G. Tyrell of the Boston Bridge Works. Tyrell's requirement was to have the galvanized wire ropes for support of his bridge "be of equal tensile strength to those manufactured for suspension bridges by John A. Roeblings Sons & Co."[54] During this era, a catch-phrase "Roebling or equal" became well known in the wire cable trade of the United States.

In 1996, historian Mark Brown studied some "catalog" bridges for HAER, describing how a series of stayed bridges were built in north-central Texas about 1890.[55] Another series of bridges built in Ohio and West Virginia are under study in 1999 by David Simmons of the Ohio Historical Society. These numerous wire cable and wire rope bridges, erected in remote locations, represent typical cases of "catalog" bridges, most of which are poorly recorded. For example, J. T. Shipman, acting alone, or as an agent of the Penn Bridge Company, Beaver Falls, Pennsylvania, built at least six bridges in the northeastern United States, between 1870 and 1890. None of Shipman's bridges have been documented.[56]

The period of "catalog" bridges began with the commencement of cablemaking began on the Brooklyn Bridge and ended around the time of the Surface Transportation Act of 1957. In 1898, Brooklyn and New York were unified into a single city. The Brooklyn Bridge soon became toll-free, and thus city-maintained. For historians, the removal of tolls and private company ownership from the Brooklyn Bridge, coinciding with the advent of private motor vehicles all over America, initiated an unexpected side-effect. Whereas earlier suspension bridges had been built by separately-incorporated private

[53]There are two very large collections of Roebling family papers at Folsom Library, Rensselaer Polytechnic Institute, Troy NY and at Alexander Library, Rutgers University, New Brunswick NJ. Searching into these fascinating documents is simplified by reliance upon Elizabeth Stewart's excellent *Guide To The Roebling Collections*, (Troy NY, Friends Of the Folsom Library, 1983).

[54]H.G. Tyrell, "Footway Suspension Bridge with Three Towers at Easton PA", *Engineering News*, v.44, (November 22, 1900), 346.

[55]Mark M. Brown, "Nineteenth Century Cable-Stayed Texas bridges" *Proceedings - Fifth Historic Bridge Conference*, (Cincinnati OH, 1997) 90-96.

[56]Comprehensive listing, augmented by additional study of the "catalog bridges" is a justifiable goal for HABS-HAER. Many of the "catalog" bridges built prior to WWI are shown in postcard views of smaller American cities. Some details can be extracted from archival records found in extinct local newspapers. Although these numerous private suspension bridges have been replaced by more modern structures or else rebuilt on the same site with more modern materials, they would form a good topic for further study. In the period 1920-1950, large integrated steel companies such as Armco Steel, Bethlehem Steel, Colorado Fuel & Iron, Jones & Laughlin, and United States Steel, all operated their own wire rope factories as quasi-independent divisions. Their factories routinely offered to sell rope and fittings for simple suspension bridges used most often for pedestrian traffic and pipeline crossings. All of the integrated steel companies abandoned their wire business in the 1980's. Although some firms documented their short span, non-highway bridges with historical records, much of these data have become lost or obscure, adding to the number of unrecorded American suspension bridges.

companies in the nineteenth century, and the record of the private bridges was limited by the publishing whims of the owners, the rule for twentieth century highway bridges was public ownership supported by taxes. Public-owned bridges require very complete justification. All major wire suspension bridges since 1900 have stimulated thick files of documentation, and even some of the minor suspension bridges of the twentieth century were documented by highway department officials. The lesser-known "catalog" suspension bridges pose more of a research problem, which is why they remain largely unrecorded.

Other New York City Bridges And Their Metropolitan Cousins 1880-1930

Wide, deep, waterways warrant the application of Hildenbrand's "C" method for cablemaking. There was no shortage of wide, deep, waterways in the vicinity of Manhattan Island. After the Brooklyn Bridge had served for more than ten years, variant copies were launched in rapid succession. At present there are six across the East River alone. The first of these was the Williamsburg Bridge designed in 1899, deliberately planned from the start to be larger, stronger and more impressive than the Brooklyn Bridge in every category. Ironically, the Williamsburg main cables were actually slightly shorter, the first of numerous meaningless facts that have crept into the historical record of New York City suspension bridges.

Fortunately, the Roebling brothers were willing to be subcontractors for the Williamsburg cables. Unfortunately, the designer of the bridge was a prolific bridge engineer named Lefferts L. Buck, who seems to have some sort of personal motive to contend against the Roebling brothers. Buck had achieved major success building and repairing suspension bridges at Niagara Gorge, including a complete renovation of John Roebling's bridge, but he had developed a theory that protecting cable wire with zinc was unnecessary. Due to this, Buck's designs for the 1903-era cables of the Williamsburg Bridge were less successful than the Brooklyn Bridge, even though the average strength of the steel wire specified was much greater than was specified in 1876. The disagreement between Buck and the Roebling brothers escalated for several years, resulting in a lawsuit. Perhaps because of negative publicity surrounding the dispute, New York's third East River crossing, the 1910 Manhattan Bridge, reverted to using Roebling-style galvanized parallel-wire cables of higher strength steel.

Urban bridgebuilding was interrupted by American involvement in the 1914-18 European War, but resumed almost immediately thereafter. Some examples of the major 1000-feet plus, parallel-wire suspension bridge projects launched after WWI include: two bridges over the Hudson River north of New York City known as Bear Mountain (1924) and Mid-Hudson (1928), a Delaware River bridge between Philadelphia and Camden (1926); a bridge over the bay at Providence, Rhode Island (1929); and an international bridge over the Detroit River to connect Detroit with Windsor, Ontario (1930). Other bridges with main spans shorter than 1000 feet were constructed over rivers and estuaries all over the United States until construction was slowed or halted by conditions imposed by the Great Depression, followed by resource-draining industrial activities in WWII.(See Appendix)

Roebling Sons' competitors were active in devising new technologies. In 1896, George Morison made some tests of Trenton Iron's wire ropes for a proposed North River Bridge (this later became George Washington Bridge). Morison described a way to build up a main cable by combining 253 factory-made wire ropes in huge sockets on top of the towers as well as in the anchorages, utilizing four such main cables to support a giant bridge almost twice the size of the Brooklyn Bridge.[57] Two years later, Gustav Lindenthal proposed a different way to make cables for the George Washington Bridge by using factory-made "links" built up from loops of wire fabricated into exact lengths.[58] Both schemes were aimed at reducing what Hildenbrand had called the "great disadvantage" of method "C" - lost time waiting for creation of towers and anchorages. Likewise, the current enthusiasm for cable-stayed bridges is based in

[57]George Morison, *Transactions*, v. 36, (New York NY, American Society of Civil Engineers, December 1898), 359.

[58]Gustav Lindenthal, *Engineering Magazine*, v. 16 (New York NY, 1898), 368.

part upon time-saving advantages of the Hildenbrand "A" and "B" methods. The problem as of 1900 was that there was no easy means for assuring exact duplicate lengths, plus equal tension, of factory-made cables, and no high speed computing devices to accomplish thousands of calculations quickly. In fact, Hildenbrand himself immediately rejected Morison's proposal by asserting that the wire cables simply could not be made as he had proposed. The bridge was postponed. Tunneling was substituted.

The cablemaker for Philadelphia-Camden Bridge (Benjamin Franklin Bridge) was the American Cable Company, a company formed by three of Roebling's minor wire rope competitors from Pittsburgh and New Jersey that banded together in 1923. The American Cable Company did not operate a wire mill, but purchased wire from specialty suppliers. This practice was then the established norm for most of the American wire rope industry which had expanded to include more than a dozen manufacturers, most of them much smaller than Roebling. American Cable's primary source was the wire mill of J. Wallace Page, Monessen PA. It was allied with American Chain Company, the nation's leading producer of automobile tire chains. Page was the nation's leading producer of chain link fencing.[59]

The driving force behind the collaboration of American Cable Co. and American Chain Co. (in 1925, the latter acquired the former, to become known thereafter by the acronym ACCO) was an intent to exploit certain patents issued to Edward A. Conner. The Conner patents revolutionized the art of making wire rope all over the world by introducing the concept now known as "preforming". The patents covered techniques whereby a ropemaker could deform wire <u>prior</u> to making a wire rope, giving it, in advance, exactly the complex helical curvatures that would be assumed in the completed rope. Obviously, this concept is a readaptation of a similar process used for weaving chain link fence.

George Washington Bridge And Its Metropolitan Cousins, 1930-1969

Ultimately, a new era for suspension bridges was initiated by successful completion of Othmar Amman's George Washington Bridge across the Hudson River using Hildenbrand method "C" after all. That new era continues to the present as major spans now are being built in other countries as well as the United States. Cable-making for the Hudson River crossing was finished in 1930. The bridge was opened for traffic the following year. Wire for the cables was made from "open hearth steel" billets, rolled into rod coils weighing about 375 pounds by Roeblings Sons at Roebling NJ. The four main cables contain more than 100,000 miles of galvanized wire. Many time-saving and cost-saving techniques were innovated before and during construction. A complete analysis of every aspect was published by the American Society Of Civil Engineers and reprinted for wide circulation by the Port Of New York Authority.[60]

The great 3400-feet span of the bridge that connected Manhattan Island with nearby residential communities in northern New Jersey without blocking Hudson River navigation, demonstrated conclusively that even the widest and deepest rivers and bays were not barriers to suspension bridges. Also, because the bridge flooring is so heavy, a stiffened truss for aeolian resistance notably was omitted. The most significant aspect, however, was the devotion of this bridge, from inception, to private, rubber-tired, vehicular traffic rather than rail traffic. At the present time 14 lanes of traffic are being carried to and from New Jersey by the George Washington Bridge. According to historian David Brown, it "redefined the state-of-the-art of suspension bridge construction" because it had "double the previous maximum unsupported span" and it "reflected the automobile's eclipse of the railroad."

Similar vehicular strategy was applied to create bond issues in California for construction of the Golden Gate Bridge (1937) and the Oakland Bay Bridge (1936), both of which surpassed the George Washington Bridge as epic construction projects. Although the Golden Gate is more popular as a tourist attraction, the Bay Bridge, which is actually a *doubled* suspension bridge with mid-water anchorage, is far more

[59]There is a discussion of ACCO's entry into the bridgebuilding arena in the Introduction of the *Wire Rope Users Handbook*, (New York, NY, American Cable Company,1932).

[60]American Society of Civil Engineers, *Transactions*, v. 97 (New York NY, 1933).

interesting in terms of engineering design because it was created with an enormous artificial concrete island in the center of the bay, an unprecedented undertaking remarkable on its own merit. These great pre-WWII bridges were followed in the post war period by other colossal structures such as the Straits of Mackinac Bridge (1957), Verrazano Narrows Bridge (1964), Newport Bridge (1969) and dozens of others with shorter central spans.[61]

In connection with creating the wire and cables for George Washington Bridge, the Roebling company installed a novel "prestretching" track at Roebling, New Jersey. This device was used very effectively to remove mechanical stretchiness from long lengths of factory-made wire rope that were used first as footbridge ropes, later to serve a doubled purpose when cut up into suspender ropes. The installation provided a great stimulus for the company to study methods of tensioning wire cables. In the post WWII era, construction of the interstate highway system necessitated the rapid construction of hundreds of durable bridges. Prestressed concrete (concrete structures containing wire cable reinforcement installed in a state of tension) proved an economical way to undertake the new quickly-built structures. The Roebling Sons company's advanced knowledge of prestressing served them well in the early days of the new concrete bridges, and they became a leader in supplying wire tendons for prestressed concrete.

Unfortunately Roebling Sons faltered, along with all the other large integrated steel companies, in the extremely competitive marketplace of the 1970s. Prestressed concrete cable methods proved to be easier, using the Hildenbrand "A" method, to adapt to the construction of stayed bridges. Cable-stayed bridges, popularized anew in Europe during the 1950s, exhibit a different "look" from catenary cable bridges. Modern computer techniques have permitted the stay cables to be cut to length and tensioned with great accuracy, reducing cost additives associated with the Hildenbrand "C" method.

Endless Problems, Aerodynamical And Metallurgical

Williamsburg Bridge had followed the Brooklyn Bridge as the second large scale American bridge designed to be built with steel wire main cables. The corrosion problems of the ungalvanized main cable wires of the Williamsburg Bridge were discovered as early as 1910, according to expert Frank Stahl. As of 1988, amid considerable negative publicity, serious damage from corrosion was detected only in "a small portion of the wires."[62] Early perception of the Williamsburg Bridge cable problems, and the numerous efforts to protect them by other means, caused most suspension bridge engineers to design with galvanized steel wire, but, as Stahl has observed, the remedies applied have been successful, and, when studied a half-century later, the corrosion of the bridge cables wasn't as bad as predicted. Despite this, not every engineer agreed with the necessity of galvanizing the wire. In 1927, the U. S. Grant Bridge over the Ohio River at Portsmouth OH was built with ungalvanized wire, on the recommendation of an engineer who said he believed the Williamsburg cables at the time were "were in an excellent state of preservation," an almost incredible assertion in view of the continuing problems that were being doctored intermittently over the years.[63]

A solution for long-term, cost-effective, atmospheric corrosion protection of suspension bridge cables continues to be sought at the present day. Many modern cable-stayed bridges are being erected with epoxy-coated wire encased in grout-filled polyethylene tubing. Coverings of neoprene and Fiberglas are also found in some bridges. Critics are quick to condemn existing techniques, but no new technology has

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[61] Americans have exhibited an unfortunate tendency to ignore shorter span bridges. Some of those built prior to WWII are described by Frederick H. Frankland, *Suspension Bridges Of Short Span,* (New York NY, American Institute of Steel Construction, 1934).

[62] Stahl has studied a series of remedies applied over the decades to extend the longevity of the structure, starting with rewrapping the entire length of the cables 19-22. Frank Stahl, *Cable Corrosion In Bridges and Other Structures*, (New York NY, American Society of Civil Engineers, 1995), 119.

[63] David Steinman, *Practical Treatise On Suspension Bridges*, (New York NY, Wiley, 1929), 235.

so far emerged to provide a complete answer. The main source of difficulty is at the connections where each flexible wire meets its rigid anchor, creating a focal point for stress, corrosion, and fatigue combined.

Unfortunately, the same engineers that had been willing to accept the concept of the galvanized parallel-wire steel main cables, also believed that rigid truss flooring was an answer to well-known windstorm difficulties of wire cable suspension bridges. These were called "stiffened" bridges because they implemented a continuous, or nearly-continuous truss to add stiffness to the bridge floor. Rapid advances in aeronautical engineering achieved during the first thirty years of the twentieth century were not, in general, assimilated by American civil engineers as a part of their basic theoretical understandings of suspension bridge behavior under aeolian conditions. The Wheeling Bridge was severely damaged by a windstorm in 1854 and the Clifton Bridge was likewise damaged by a windstorm in 1889. Perusal of engineering tracts written between 1840 and 1890 contain almost no mention of suspension behavior in a windstorm except for widespread but vague knowledge that the wind "acting from below" was one source of major danger. Remedies such as guys and stays, increased dead weight, and rigid trussing were proffered as complete solutions to the windstorm problem, but it should not be a surprise that the Tacoma Narrows Bridge failed disastrously as a result of cyclic motions induced and sustained by a relatively weak but steady wind force in 1940.[64]

A motion picture film of the Tacoma Narrows failure, while underway, authenticated the verbal descriptions of what had happened at Wheeling, Niagara, and elsewhere. Major advances in theoretical analyses, including computer modeling, have been achieved since 1940, seeking to attain a complete understanding of the windstorm problem. A variety of clever aerodynamic devices have been built into, or added to, modern bridges, such as the Whitestone Bridge in New York City, but the aeolian oscillation problem is far from solved. It is important to emphasize there has been almost no loss of human life in bridge failures due to windstorms due to the early warning provided by the oscillations.[65]

In a similar way, the unusual tensile strength properties of *patented* crucible cast steel wire were misunderstood by early metallurgists 1880-1930. During those decades a rapid broadening of the new science of metallography recognized the crystalline nature of steel microstructures by careful examination of samples with a microscope. At first, the new discoveries had very little impact among wire-drawers, who had successfully adapted all of the older iron wire technology to the newer steel wire. Traditional techniques, learned by rote, survived for decades without any scientific knowledge as to their cause and effect. In the mid-Twentieth Century, metallurgist Ralph Hultgren observed: "While the science of metallurgy seems to be the most ancient of the arts, the development of a science of physical metallurgy is very young indeed...only since about 1930 with the application of X-ray diffraction and wave mechanics to metals and alloys could it be said that the science of metals had been born."[66] By World War II, the new metallurgical science had risen to a level where *patenting* was understood to be a method for creating a structure known as *pearlite,* an extremely fine-grained alloy of iron, manganese, and carbon so-called because of its iridescent sheen in ordinary light. Such steel wire was known to be "especially applicable...for suspension bridge cables."[67]

Tardiness in the assimilation of the new metal science was costly to suspension bridge builders. In the late 1920's the Mount Hope Bridge at Newport, Rhode Island, and the Ambassador Bridge at Detroit, Michigan were quietly but abruptly dismantled during construction when the cable wire began failing for

[64]Gasperini has observed "the collapse also showed that torsional stiffness of the deck was an important design parameter." Dario Gasperini, "Stiffening Suspension Bridges", 107.

[65]The 1850 Angers Bridge failure in France is a notable exception. Michel Cotte, "The Angers Bridge catastrophe", *La Revue,* n.5, (Paris, Musee des Arts et Metiers, December 1993), 4-15.

[66]Ralph Hultgren, *Fundamentals Of Physical Metallurgy*, (New York NY, Prentice Hall, 1952), 4.

[67]D. K. Bullens, *Steel And Its Heat Treatment*, (New York NY, Wiley, 1948), 245.

no apparent reason while the cables were being made in place. Because specifications for the two bridges were written to take full advantage of higher tensile strengths, resulting from more sophisticated wire heat-treating methods, bridge designers presumed wire tensile properties (which could be attained by any one of several different forms of heat treatment) alone were the determining factors. The nation's leading bridge designers were advisors on the Ambassador Bridge, which was destined to attain the lofty status of "world's longest span" when opened. Wiremakers could offer no scientific documentation to sustain an argument against the experts. The average tensile strength specified for the two bridges was "220,000 psi" - slightly greater than "210,000 psi" used on the Manhattan Bridge, but more than one third higher than the "160,000 psi" minimum specified for the Brooklyn Bridge 50 years earlier. The use of higher strength wire, and higher strength structural steel in the flooring greatly reduced the total weight of the bridge. Both bridges were being built by McClintic-Marshall of Pittsburgh, using identical steel wire.

During construction, the severe wire breakage was first encountered in Rhode Island. Only two broken wires were noted at Detroit. "Early in 1929" noted Ernest K. Thum, editor of *Metal Progress* magazine, in summarizing the dilemma, "news was suddenly broadcast that two very long suspension bridges then approaching completion, had become unsafe and would have to be dismantled... tests did not determine this condition because the loading in a testing machine is at an infinitely greater rate than the creeping load of bridge erection... why this should be so is a matter for detailed and scientific investigation."[68]

After review of all conceivable possibilities, Thum confessed that metallurgical science was unable to explain the phenomenon. At the time of the discovery, McClintic-Marshall was far ahead of schedule at Detroit. Replacement of all the wire did not delay the bridge. Publicity about the broken wire in Rhode Island was suppressed because no one had any valid explanation as to what was going wrong with the wire. Although no major wire problems had been detected at Detroit, and none at Philadelphia, the contractor elected to replace all 3000 tons of main cable wire for security. According to historian Philip Mason, the decision to do this cost the contractor one million dollars.[69]

Despite astounding advances in data processing techniques allowing design stresses to be calculated with incredible accuracy, simple problems such as atmospheric corrosion remain unsolved. In April 1988, Stewart Watson and David Stafford said they had inspected, over a 2-year period, more than half of "nearly 200" cable-stayed bridges built around the world. In their opinion, most of them were "in serious danger" because "corrosion is attacking their cables."[70] At that point many cable-stayed bridges were already being fitted with replacement cables. Ten years later, *Houston Chronicle* reported, a "worrisome" problem that "has only been identified in the past few years" according Professor Karl Frank of the University of Texas. The 2475-feet main span Fred Hartman cable-stayed bridge over Galveston Bay exhibits unusual aeolian oscillations of the stay cables under specific wind and rain conditions. Professor Frank, who was identified as an expert on the subject, said there are twenty-eight cable-stayed bridges in the USA, about half of them exhibit the same problem, and "...it could eventually mean that we'd have to replace the cables." The physical phenomenon of minute aeolian oscillations was rarely, if ever, discussed by engineers prior to the time the costly, much-delayed, Houston bridge was opened to traffic in 1995.[71]

The intent of this recitation is not to ridicule the impressive attainments of bridge engineers, but only to

[68]*Metal Progress,* June-September, 1932.

[69]Philip Mason, *The Ambassador Bridge*, (Detroit MI, Wayne State University, 1987), ch. 6 & 7.

[70]Stewart Watson and David Stafford, "Cables In Trouble", *Civil Engineering,* (April 1988), 38-41.

[71]Dan Feldstein, "Bridge problem is worrisome but of no immediate concern". *Houston Chronicle,* July 8, 1998. According to estimates of the Texas Highway Department, reported in *Engineering News Record*, January 30, 1986, the Hartman Bridge had been expected to cost between 70 and 100 million dollars. The final cost tally in 1995 was $117.5 million. A contract for over one-half million dollars was arranged in 1998 to attempt correction of the aeolian problem.

emphasize that some of the most significant long-term suspension bridge problems are far from solved. The recent erection of spectacular wire cable bridges in China, Denmark, Japan, Portugal, and Turkey, using the most modern construction techniques, has not altered the status.

From 1965 Into the Future

At the present time, the HABS-HAER database lists more than one thousand American bridges.[72] Careful examination of that list demonstrates that wooden bridges plus a wide variety of trussed bridges have been studied in great detail but wire suspension bridges of various types are notably absent. Only eight wire suspension bridges have attained National Historic Civil Engineering Landmark status. Only half of these are also National Historic Landmarks. These landmark programs are tourist-related to a degree, imparting secondary status to bridges that have been demolished which is the case with almost all early wire bridges. The Wire Association International, based in Guilford CT, does not even have a historic landmark program.[73]

The total number of American vehicular wire cable suspension bridges, not counting minor local footbridges, but including all variants (such as the remarkable floating bridges on Lake Washington at Seattle) is probably less than 500. By use of the Internet, it should be relatively easy to enlist local researchers. Many bridges already have their own historic website; often these are less concise than might be desired, but there are a few exceptionally good sites, of which Wheeling is the best examples. By implementing a good academic listing, such as Jakkula's list,[74] as a starting point, the task of completing a database of wire cable bridges is not only surmountable, but might even prove to be relatively easy.

Of two dozen wire rope companies in the United States at the end of World War II, only four[75] remain in business in 1999. None are pursuing suspension bridges with much enthusiasm, and none are underwriting engineering teams similar to those previously sponsored by the Roebling family. Therefore, it seems unlikely there would be much industrial support for such a project. Academic interest for obscure subjects such as this is often inconsistent. Much of the existing historical research for wire cable bridges has been performed by dedicated amateurs.

Meanwhile, existing American wire cable technology, as of completion of the Verrazano Narrows Bridge (1964) and the Newport Bridge (1969), now is considered to be the design and technique basis upon which future catenary-style bridges are being built. The Japanese in particular have drawn heavily upon this American expertise.[76] Given this worldwide recognition, it seems desirable and appropriate to

[72] According to Eric DeLony, *Landmark American Bridges,* ASCE Press, 1993.

[73] The author, who serves as Historian for the Wire Association, has proposed a landmark program on several occasions, but the cost of marking sites is a deterrent.

[74] Arne Arthur Jakkula, *A History Of Suspension Bridges In Bibliographical Form* , College Station TX, Engineering Experiment Station Engineering Report No. 57, Texas A & M College Bulletin, 4th Series, V.12 n.7, (1941). His list is not perfect, but it represents the most accurate effort to date.

[75] Of the four companies, the largest by far is privately-owned Wire Rope Corporation Of America, St. Joseph MO. Three smaller companies are: Paulsen Wire Rope at Sunbury PA; GlobalLift Technologies which operates the wire rope factory at Williamsport PA; and Bridon American Corporation which continues to operate the wire rope factory in Exeter PA that has descended from the original American wire rope factory at Mauch Chunk PA. In addition to these four companies, there are several minor companies making only small wire cords and strands.

[76] A series of technical reports issued in May 1976 by Nippon Steel emphasizes this point in particular, see Shigeaki Tsuyama, Tokuo Sugita, Takeshi Kihara, and Yoshifumi Tawaraya, "New Construction Methods For Suspension Bridge Cables", *Nippon Steel Technical Report Overseas Number 8*, (May 1976), 73-74.

achieve a complete listing of American wire cable suspension bridges.

The trend toward cable-stayed designs, and the completion of beautiful structures such as Hale Boggs Memorial Bridge at Luling, LA (1983), Sunshine Skyway, St. Petersburg, FL (1987), and Dames Point Bridge, Jacksonville, FL (1988) have again awakened interest of the American public in them.

Summary: Who Made the Wire for American Wire Suspension Bridge Cables?

As an important facet of an improved historic record, it should appropriate to identify, wherever possible, the source of the wire used in the main cables (and suspenders) of every suspension bridge. This should be relatively easy for bridges built after the Brooklyn Bridge was opened in 1883, because the company names of the wire maker and the cable maker often are the same, or closely connected. Owing to the rise of automobile transportation, followed by institution of highway departments in every state where maintenance histories are kept, the wire source is recorded and is in most cases easily determined. In the era prior to the Brooklyn Bridge, the opposite is true, and many of the early bridges have disappeared without a trace.

From the time of the American revolution until White & Hazard's 1816 wire bridge, there was not much ferrous wire production of any kind in America. Commercial applications for iron wire were few, and for steel wire almost nil. Both iron and steel wire were available in small quantities as commercial items, sold by commission agents, but the slit rods used for wire-drawing also were applied to make many different wire items for consumers, and the source of the rods used for making wire is never cited. Wire-making was primarily cottage industry. It is mentioned only rarely prior to the widespread development of textile machinery. Eli Whitney's "cotton gin" patent application of 1794, for example, states: "Take common iron wire, about No. 12, 13, or 14. Steel wire would perhaps be best if it were not too expensive" obviously implying that wire was something that was then readily available to any artisan, possibly imported as finished wire from Europe. [77]

During a period of chaotic supply and demand following the Jefferson embargoes and the War of 1812, there was a shortage of wire in the USA. The first American treatise on wire-drawing was written at that time, describing the process as "easy." [78] The author insisted "American iron will make good wire" and urged "a protecting duty in the importation of the article" to stimulate industrial growth in a largely agrarian American economy. Josiah White and his partner Erskine Hazard began drawing wire in 1812, stimulated by the shortages. Unquestionably, they built their first emergency wire bridge of 1816 using their own commercial product already being sold at Philadelphia for other uses. They did not, however, operate a rod mill and their iron wire rod source has not been documented.

Ordinary (or "common") iron wire available locally at or near the construction site was used for the cables of all the early wire bridges of the 1840's. Charles Stewart, who documented the commercial circumstances causing his family to enter the iron wire business, made a list of the most common applications during that period, including: "common tinsmith, spring wire for all purposes, square wire for umbrellas, square and triangular wire for coal screens...chain wire, screw wire, rivet wire, bonnet wire, and clock wire."[79] He also explained procedures instituted by his company for purchasing iron billets of the best possible quality for conversion into rods on a toll basis at a rolling mill. In 1841, the Stewart mill was Charles Ellet's primary source when building his Callowhill Street bridge. Acting as

[77]Text from the Whitney original patent in the case file, National Archives II, College Park MD.

[78]Article signed "OE" in *Philadelphia Aurora*, February 14, 1812. The author of it is understood to have been Oliver Evans. There is a complete discussion of Evans role in encouraging American wire drawing by G. & D. Bathe, *Oliver Evans*, (Philadelphia, The Historical Society, 1935), 7-9.

[79]Charles Stewart, "The Stewart Company", *Canal History and Technology Proceedings*, (Easton PA, Canal History and Technology Press, Vol. V, March 22, 1986), 14.

general contractor at Philadelphia, Ellet initiated a practice of testing wire samples from several local wiremakers. His procedure became the usual mode for about twenty years afterward. Similarly, Ellet erected his Wheeling bridge cables with iron from the wire mill of Richards & Bodley near the bridge site. Roebling used two different Pittsburgh wire mills for his first two bridges, dividing his purchases equally between Robert Townsend and Samuel Wickersham.

The advent of electric telegraphy in the early 1840's, coinciding with the inauguration of hot-blast iron smelting using anthracite fuel, provided the first enduring stimulus for an expansion of American wire manufacturing. These changes launched a slowly-growing transition toward reliance upon American-made wire by all consumers. In the period 1840-60, American wiremaking was augmented by new rod mills built at Worcester and Fall River in Massachusetts and by Trenton Iron in New Jersey. At each of these new mills, part of the planned production specifically was directed toward rolling rods for wire. For his aqueducts in the Delaware Valley, Roebling bought some wire from Stewart, but he also used wire purchased through a New York commission broker including an unknown quantity from a wire mill in England. He also began methodically testing and tabulating the comparative quality of ordinary commercial wire, building a technical database needed to begin his own wire-making.[80]

After completion of the great bridge at Wheeling, two local wire-making companies named Bodley, and Dewey, were employing a specialist, John Downing, who traveled to remote sites to fabricate suspension cables from their wire. The activities of Downing in the valleys of West Virginia have not been documented with much detail, and would form an interesting topic for further study. In California, Hallidie was able to buy cable wire for his bridges from H. T. Graves who had established a wire mill at San Francisco in 1852, afterward better known as California Wire Works. The sources of iron rods for the mill are not identified, but must have been either an eastern rod mill or one of the English mills. As of 1865, Hallidie was working from the same address as Graves, an indication of their very close relationship leading into a partnership two years afterward. Much later, Hallidie gained complete control of the company. Wire sources for several other early California bridges built in the Sierra foothills during the period when gold mining was rapidly expanding remain undocumented. These bridges, together with the bridges being built in West Virginia and Ohio at the same time, deserve much more study. In 1996, one of Hallidie's anchorages at Nevada City CA, containing considerable amounts of intact cable segments was discovered and excavated.[81]

After Roebling and Swan built their own wire mill at Trenton in 1849, they became disenchanted with rods rolled at Trenton Iron, so they added their own rod mill in 1856. They bought "Swedish" iron billets made in Scandinavia as raw material because their tests showed its superiority. Most of the catalog bridges built with Roebling wire ropes in the 1850's utilized wire made by them at Trenton that was drawn from these imported Scandinavian billets. Later, Washington Roebling referred to their mill as "antiquated" as of 1871 because it "had a limited output and was adapted for small Swedish bars...". He emphasized that the 1870's were chaotic for American wire mills because: "(t)he telegraphs of the country were assuming enormous proportions... a change in the tariff cut us off from importing foreign rods for telegraph. There was nothing to do but make our own blooms... This worked with Swedish workmen for four years when another change in the tariff caused its abandonment."[82]

Prior to the Civil War, almost all American iron rod-rolling mills were located in the eastern seaboard states. As of 1857, Lesley recorded thirty-two American rod mills of which only seven were paired

[80]Two of John Roebling's notebooks, 296 and 319, contain his detailed notes about wire. These are in the Roebling Collection, Folsom Library, Rensselaer Polytechnic Institute, Troy NY.

[81]There is no published complete biography of Halladie, a wonderfully mysterious character whose real name was Andrew H. Smith. The files of the California Historical Society contain a limited amount of information about him, including several autobiographical anecdotes. His wire suspension bridges deserve more study.

[82]Washington Roebling, "An illuminating account of the industry", excerpted by Hamilton Schuyler, published in *The Roeblings*, (Princeton NJ, Princeton University Press, 1931), 332-335.

directly with wire mills. American ironmaking, rod rolling, and wire drawing were considered separate trades. Linking all three into one integrated enterprise, as Cooper & Hewitt did at Trenton Iron, was an exception to the rule. American rod mill developments were slowed somewhat by a financial depression starting in 1857, then halted almost entirely when the Civil War began. After the war, interest in new rod mills was rekindled with vigor by the advent of wire fence and wire nails.[83] Fred Daniels summarized the beginning of this rapid change:

> The increased demand for wire rods rendered larger productions imperative and stimulated competition among the various mills...Until 1860 looping mills were unknown, the billet being passed through the rolls back and forth, and this no doubt accounts for the light weight of billet used up to that time. The reel was also turned by hand. The demand for telegraph, suspension bridge, and rope wires in long lengths caused the manufacturers of wire rods to give careful attention to the question of improved rod-rolling facilities. Mr Ichabod Washburn, during a visit to England, made the acquaintance of Mr. George Bedson...and an extensive correspondence and exchange of ideas regarding wire-making passed between them. Bedson was, without a doubt, the best informed and most skilled wire and rod expert in Europe... In the fall of 1869, one of Bedson's continuous wire-rod rolling mills was erected...at Washburn & Moen...but other wire makers, during 1870 to 1880, were at the front in the line of improved rod-rolling facilities, among them being Messrs. Cooper & Hewitt and John A. Roebling Sons."[84]

Stimulated by the demand for telegraph cables, wire mills in England were adopting and improving important new advances in technology, most significant of which were Bedson's application of the continuous rod-mill principle and James Horsfall's secret discovery of the patenting furnace. For his Niagara Gorge Bridge of 1848 (where there was no local wire mill near the site) Ellet used wire made by Richard Johnson & Nephew of Manchester, England, the firm where Bedson was active. When Roebling took over the Niagara contract in 1851, he was very much impressed with Johnson's wire, ordering 500 tons from the same source, even though he was by then operating his own mill. Also, when he removed the cables from Ellet's bridge, he reapplied Johnson's product in the fabrication of his own cables, proclaiming he had noted "remarkable uniformity in the iron, and great care in the manufacture of the wire". The strength of Johnson's wire was tested at 100,000 p.s.i. Roebling likewise bought Johnson's wire for his Ohio River bridge at Cincinnati, as did Keefer for his Clifton Bridge at Niagara Gorge.[85]

The numerous new rod mills built in the United States during a 40-year period of expansion after the Civil War, were spawned by the unprecedented demand for new steel wire products: woven fencing, barbed wire, and wire nails. These mills were exclusively either straight-line continuous, or looping, mills of various designs. The new mills greatly enlarged American capability for making long lengths of wire.[86] By 1889, the production of iron and steel wire rods in the United States had increased to 300,000 tons per year; by 1899, it had had risen over one million tons, and by 1909, over two million.[87] The

[83]James Lesley's *Iron Manufacturers' Guide* (New York NY, John Wiley, 1859) was intended to be the complete sourcebook for every kind of factual information about the iron industry of that era. Published in parts, it was, unfortunately, never completed.

[84]Fred Daniels, "Rod-Rolling Mills and their Development in America," *A.S.M.E. Transactions XIV,* (August 1893) 585-597 .

[85]John Roebling, *Final Report*, 29.

[86]The impressive story of these new rod mills is detailed in a three-part series "The Manufacture of Iron and Steel Wire Rods in the United States" *The Iron Age,* (September 3, 1885) 19, continued (September 10, 1885) 33 and (September 17, 1885) 35. Other excellent summaries include: William Garrett, "Development of American Rod Rolling" *The Iron Age,* (January 2, 1896) 15-20 and Robert Hunt, "Wire Rod Rolling", *Cassiers Magazine Engineering Illustrated,* Vol. VI, (May 1894-October 1894) 249-261.

[87]*The Iron Age*, (September 29, 1910) 688.

Roebling brothers made numerous improvements to their rolling mill and wire mill, more or less ignoring the huge demand for fencing wire, and keeping their focus on wire ropes for other purposes in addition to their catalog bridges. They emerged as the primary source in the United States for suspension bridge cables when the Williamsburg Bridge cables were being designed and created 1899-1903, making them an obvious choice to supply all the wire for the new bridge.

But the four decades after the Civil War also represented a period when many new and varied systems of fabricated iron and steel trussing for bridges were being contrived, obviating any need for further technical development of wire cable suspension bridges. At first, iron was the favored structural material for trusses. Eric DeLony has called this the era of the "American Standard" truss bridge.[88] Cheap steel made by the pneumatic process and open hearth process quickly replaced wrought iron, reducing the basic costs of truss bridges even more. Although a few widely-separated suspension bridges were built during the era, by the eve of World War I, Waddell observed something of a hiatus in suspension bridge technology: "To very few American Engineers does there ever come an opportunity to design a large or important suspension bridge; for that style of construction is but little used in this country, owing to the fact that, on account of its inherent lack of rigidity, it is not adapted for carrying railroad trains, and because in highway bridge construction it cannot compete in cost with simple-truss, cantilever, or arch structures for ordinary crossings..."[89]

By 1909, the year of the Manhattan Bridge using wire cables made by Roebling Sons, steel wire's domination of the wiredrawing trade was final. No American wrought iron rods at all were reported that year for the first time. Steady advancement of metallurgical techniques by then allowed the making of steel wire with strengths routinely about double that of Johnson's iron wire used at Niagara and Cincinnati. The Williamsburg and Manhattan Bridges inaugurated a new trend toward major wire suspension bridge popularity. The Roebling brothers had deftly positioned themselves as leaders in the trend, augmenting their rod and wire complex at Trenton with their own steel mill at Kinkora (later known as Roebling) NJ.

The Washburn family of Worcester MA, who had become the largest wire producers in the world, entered the wire rope business in the 1880's to compete with the Roebling brothers. They may have been the source for some of the undocumented cables on smaller steel wire suspension bridges but in general bridge cables were never a major item for them. Other competitors entering the wire rope trade, such as St Louis companies Broderick & Bascom, and the Leschen brothers, continued to buy wire from specialty sources, including imported English-made wire, to remain competitive with the Roebling's established reputation for high quality products. The supply of English wire to American cablemakers was halted abruptly by submarine warfare during World War I; it never resumed afterward with the same vigor.

The Roebling Sons' monopoly on bridge cable wire was profitable but short-lived. In the late 1890's, John W. Gates (1855-1911) began his attempt to form a single nationwide wire trust, ultimately achieved in 1899 under the name American Steel & Wire of New Jersey.[90] He and his associates merged many large wire mills, including those of the Washburn family and Hallidie, but the merger trend was resisted by the Roeblings and by Cooper & Hewitt's Trenton Iron Company. Within a matter of months, American Steel & Wire was, in turn, caught up into the much larger effort to form a steel trust. From 1901 onward, the name applied to the steel trust was United States Steel. The new "USS" also included

[88]Eric DeLony, *Landmark American Bridges,* (Boston, A.S.C.E., 1990) 68-89.

[89]J.A.L. Waddell, *Bridge Engineering,* (New York, Wiley, 1916) 647.

[90]Gates was the dominant figure in the American barbed wire fencing business. He'd suggested formation of the monopoly as early as 1887. Joseph McFadden, "Monopoly in Barbed Wire; The Formation of The American Steel and Wire Company", *Business History Review,* (Winter 1978). The synopsis of the corporate developments sketched here are treated in greater depth by several authors. One of the best accounts is Robert Hessen, *Steel Titan,* (New York, NY: Oxford University Press, 1975).

another combined trust-like entity named American Bridge Company, specializing in bridge-building.[91]

In 1904, Trenton Iron capitulated to the merger trend. After that it became better known as one of the largest of numerous American Steel & Wire ("AS&W") wire mills. "USS" published a compilation of all its steel mills in *Iron Age*, listing more than a dozen wire mills; six located in Pennsylvania (Allentown, Braddock, Donora, Rankin, and Sharon); three in Illinois (DeKalb, Joliet, and Waukegan); two in Ohio (Cleveland and Newburg); plus others at Anderson IN, San Francisco CA, and Worcester MA.[92] The following year the National Wire factory in New Haven CT was added to the group. Of these many wire mills, only Trenton NJ readily became a focal point for the manufacture and sale of AS&W bridge cables. At the beginning, most of the wire for bridge cables was made at Trenton, which continued to operate under the name Trneton Iron until 1912, but many years later a newer, more modern wire mill was built across the river at Fairless, PA. Other wire facilities of AS&W that were built after USS was formed included: Cuyahoga, Ohio (1907), Fairfield, Alabama (1910), and Donora, Pennsylvania (1915).

Although Cooper & Hewitt occasionally had captured an iron wire contract for a suspension bridge, such as the 1850 Lewiston-Queenston bridge, the new AS&W, combining its sales monopoly with American Bridge, adopted a very aggressive strategy of competing directly with the Roebling Sons for suspension bridge ropes and cables. In 1913, they published a catalog similar to Roeblings. The new Roebling Sons steel mill, built at Kinkora NJ in 1904, was devised partly in response to this threat. Because USS functioned as a fully-integrated steel producer, controlling the entire production sequence from ore mines all the way to finished wire cables, the combination of AS&W with American Bridge mounted a formidable presence in all contract negotiations for any suspension bridge project, large or small. Roebling Sons resisted this presence by forming its highly specialized Bridge Division, with emphasis on engineering skills.

In addition to its many wire mills, AS&W also possessed the advantage of being linked to U.S. Steel's elaborate research facilities where scientific study was applied toward improving the quality and the tensile strength of galvanized steel wire for bridges. USS researchers provided leadership in a significant transition to the open hearth process, displacing both the crucible casting process and the Bessemer process, as the method for making the highest quality steel wire. Their research staff, mainly J. M. Camp and C. B. Francis, wrote a treatise in 1919 that eventually became a "bible" of the steel industry, under the title *The Making, Shaping, and Treating of Steel*. The book passed through many new editions and reprints.[93] This sort of effort enhanced the company's prestige as a builder of any kind of steel structure. By the decade of the 1930's, AS&W was fully competitive, supplying wire cables for the Bay Bridge in San Francisco at the same time that Roebling Sons were manufacturing wire at Kinkora for the cables of the Golden Gate Bridge on the other side of the city.

Strengthening their role as the premier bridge cable supplier, the Bridge Division of Roebling Sons survived devastating factory fires in 1908 and 1915, providing wire and cables for a series of significant bridges including: Parkersburg WV (1916), Roundout NY (1922), Bear Mountain NY (1924), and a half-dozen bridges in 1931 including St. Johns Bridge in Portland OR on the opposite shore of the American continent. They also supplied numerous smaller bridges built with factory-made wire ropes.[94] But new

[91]The best source for information about the mergers and acquisitions involved in the creation of USS is the AS&W Collection in Baker Library, Harvard Business School, Cambridge MA. All of the details about USS in this section are derived from study of these papers.

[92]*Iron Age*, August 16, 1906.

[93]Up until the 5th Edition in 1940, Camp and Francis continued to be credited as authors but the 6th Edition, published by USS at Pittsburgh in 1951, for the first time was identified as a joint, cooperative, effort of numerous authors, reviewers and researchers employed by the company.

[94]As of 1998, a group in Trenton NJ known as Invention Factory is attempting to compile a complete and accurate listing of every bridge built with Roebling Sons wire and techniques.

wire-making competitors entered the scene after WWI, intensifying the battle for major suspension bridge contracts. The two most significant new entrants were American Cable Company of Wilkes-Barre PA and Bethlehem Steel Company of Bethlehem PA.

American Cable ("ACCO"), described earlier in the discussion of metallurgical problems, was a smaller version of AS&W. Yet, in September 1923 they captured the wire contract for the largest bridge ever conceived, Benjamin Franklin Bridge at Philadelphia, Pennsylvania (known previously as the Phildelphia-Camden Bridge or the Delaware River Bridge). Supplying both the 6800 tons of .195" main cable wires and also the 2-1/4-inch wire rope suspenders, ACCO made the galvanized wire from open hearth steel at the Page wire mill in Monessen, Pennsylvania. The two 30-inch main cables were the largest ever made, requiring a special compacting machine, and the 1750-feet main span of the crossing exceeded the Manhattan Bridge by several hundred feet.[95] ACCO immediately obtained contracts for the even larger Ambassador Bridge in Detroit and the Mount Hope Bridge in Rhode Island. In 1932, they began to advertise that they would receive the Golden Gate contract in San Francisco. But the metallurgical problems at the Mount Hope Bridge, spreading to Detroit, combined with the severe business depression in 1930, halted their plans to expand this segment of business. They ceased to be a factor in bridge cables soon thereafter. Roebling Sons, after a fierce bidding struggle, got the Golden Gate contract on November 4, 1932.

Bethlehem Steel Company had first entered the wire business by acquiring Cambria Steel of Johnstown PA where a small wire mill was established in 1912. In the 1920's they elected to augment their production capability by building a large new state-of-the-art rod, wire, and wire products complex at Sparrows Point MD. By the 1930's Bethlehem was already a major supplier of galvanized wire, but this was always a sidebar to their primary business of flat-rolled and structural steel items, and shipbuilding. Having risen to prominence in 1909, under the bold leadership of Charles Schwab, Bethlehem's expansionist methods were an attempt to compete directly against USS in every marketplace where the latter was dominant. Schwab's protégé, Eugene Grace, carried onward with expansion. In 1930, he bought both McClintic-Marshall and Pacific Coast Steel, placing his company solidly in contention with AS&W and American Bridge. In 1935, during the construction of the Golden Gate bridge, Grace reorganized his corporation, eliminating the names of wholly-owned subsidiaries. He completed this phase of his expansion in 1939 by acquiring Williamsport Wire Rope, one of Roebling's smaller eastern rope-making competitors.[96]

In the post World War II-era, Bethlehem Steel launched a major campaign to establish its presence in the suspension bridge field by building the Chesapeake Bay bridge in 1950, a composite crossing involving both truss and suspension spans, combining galvanized wire from Sparrows Point MD, wire ropes from Williamsport PA, and structural steel fabricated at Pottstown PA, the former McClintic-Marshall factory.[97]

In hope of enlarging its reputation against the well-known Roebling and AS&W products, Bethlehem Steel put funding into research programs. The most significant outcome of their studies was a new Hildenbrand "A" system devised for making hexagonal bundles of parallel wires, measured to exact length at a factory. The bundles could then be shipped to a bridge site, hauled into place, and combined into a large diameter cables of the kind normally made in place by the Hildenbrand "C" method, creating great savings of time and effort. Glass-reinforced plastic tape was used to assemble the bundles. The method was first devised in the early 1960's and was implemented in the 1969 Newport RI bridge. The

[95]The construction of this bridge also marked the end of the "crucible cast steel" era in wire cables, the open hearth process having become perfected as the dominant production method. Charles Carswell, *The Building of the Delaware River Bridge*, (Burlington NJ, Enterprise Publishing, 1926), 1-43.

[96]The careers of Schwab and Grace are explained by Hessen, in *Steel Titan*.

[97]C.D. Meals, "Bridge Cables Tested for Effects of Cross-Pressure", *Civil Engineering*, v.20 n. 10, (October 1950) 36.

results were less than perfect, mainly owing to aging and fragility of the plastic tape.[98] Although Bethlehem Steel also built many smaller bridges with conventional wire rope cables in the same era, their efforts faded after Newport. They abandoned the fabricated steel business in 1975 and terminated rod and wire manufacturing in the early 1980's at Sparrows Point. Last of all, they closed Williamsport in 1989.

The post-war period began auspiciously for the Roebling Sons Bridge Division when they received a $3 million contract for the cables of the Tacoma Narrows replacement bridge in 1948. Meanwhile, the Roebling family, sensing intensified competition for the future, seized a post-war opportunity during a period of wage/price controls to liquidate their assets, selling the entire company to CFI Steel for cash on January 1, 1953.

CFI continued to operate the Trenton and Roebling factories using the "Roebling" name for another 20 years, hoping to sustain Roebling Sons' good image and established presence in the wire cable market. One of the first large contracts gained after the sale was for cables made in 1955 to refurbish the Manhattan Bridge. But when the contract for the record-breaking Verrazano Narrows Bridge was awarded, American Bridge was the successful bidder, so it was AS&W that made the massive bridge cables on a contract worth almost $57 million.[99] During this period, CFI set new focus on the emerging popularity for bridges made using prestressed concrete ("PC") construction techniques. Roebling's highly-skilled engineering staff played the leadership role in the American advancement of PC technology. After Federal legislation in the mid-1950s created the new interstate highway system, PC bridges proliferated all over the nation.

PC bridges are made of concrete placed into a state of compression with internal steel wire cables. They provide an easily-engineered, low-cost, maintenance-free solution to the need for numerous overpass crossings of the interstates. Other wiremakers rushed to enter the PC wire and strand business, including Bethlehem Steel, and Armco Steel at Kansas City MO, but CFI Roebling was in the forefront from the start. Unfortunately, an international economic megatrend countered all their investments. The federal government, seeking to transform the Japanese economy into a powerful trans-Pacific trading partner, ended the military occupation of Japan, granting Japanese currency a guaranteed 360/1 yen-to-dollar exchange. The rate remained fixed for about twenty years, providing Japanese industry with unprecedented leverage to enter the PC cable market.

PC cables, with high tensile strengths of 250,000 to 270,000 p.s.i. were imported into the U.S.A. from Japan at prices below the cost to make the same item in American factories. CFI Steel came under new management in 1969. Citing low profits and inefficiency, CFI closed the Trenton factory in 1973 and the Roebling NJ factory the following year. Bethlehem Steel purchased some inventories and the trade name "Roebling" but elected to phase it out at the first opportunity. For awhile, USS leased some of the Trenton equipment, but they too abandoned the business in 1984, closing down and selling off their rod, wire, and wire cable facilities all over the nation.[100]

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[98]These remarks are based on an unpublished thesis by Frank Neeld delivered before the American Society of Senior Wire Rope Engineers, September 3, 1988, augmented by some recollections of the author. There is no published history of Bethlehem Steel's suspension bridge cable ventures.

[99]Details of the Verrazano Narrows contract are provided by Edward M. Young, *The Great Bridge,* (New York, Ariel F.S. & G., 1965) 99-103.

[100]Clifford Zink, op.cit., 171-176. During the USS divestiture phase, American Bridge passed into private ownership in 1987, continuing their long-standing suspension bridge traditions but lacking an integrated wiremaking associate. As a result, they began to purchase wire on a global basis. For example, in 1998 when American Bridge used Hildenbrand "C" method to spin new cables for the Tagus River bridge in Portugal, the obtained wire from a source in Spain. In 1999, they plan to buy suspender ropes made in India for retrofit of the Lion's Gate bridge in Vancouver.

The demise of large integrated steel companies in the wire and wire rope business after 1980 permitted a few smaller, low-cost, firms to expand. Those that were successful based at least part of their prowess on the availability of low-cost, high-quality wire rods from Japan. The most notable example of the smaller companies, Florida Wire & Cable Company (FWC) of Jacksonville FL, became the leader in PC cable production. When PC tensioning methods were adapted directly into designs for the new cable-stayed bridges of the 1980s, companies like FWC prospered.[101]

The above recitation of the most important sources of wire used in the erection of American wire cable suspension bridges is intended as a guide toward a complete analysis and documentation of this significant aspect of the historic record of wire cable suspension bridge construction. The total number of suspension bridge wire sources is relatively small, so that the exact documentation and recording for recent bridges should not be a difficult task.

[101]The cable-stayed bridges being built in tbe United States since 1980 utilize a wide variety of steel tension members, not always comprised of steel wires. Examples of Florida Wire & Cable's product are the Quincy, Illinois and Alton, Illinois bridges over the Mississippi River where the cables are formed from epoxy-coated 7-wire PC strands. In contrast, the Dames Point Bridge, located (ironically) in Jacksonville FL, is tensioned with threaded-end steel bars.

APPENDIX

PRELIMINARY COMPREHENSIVE LISTING
WROUGHT IRON WIRE SUSPENSION BRIDGES - 1816-1878

Bridges built leading up to time of completion of the steel wire main cables of the Brooklyn Bridge over the East River, New York City, NY, October 5, 1878

There is a lot of confusion on the record about early iron wire suspension bridges built in the United States. The following draft appendix, containing some reasonably reliable information from all sources, is intended as a starting point and an aid to further research into the known wrought iron wire suspension bridges of the United States. Hopefully, this preliminary compilation will launch a major step toward satisfying the long-felt need for a catalog of the early American iron wire bridges, to be followed by a similar listing of steel wire bridges. Beginning around 1970, several gifted, professional experts (such as Knut Gabriel, Emory Kemp, Tom Peters, Robert Vogel, and others), plus dedicated pontists (such as Rick Allen and David Simmons), began working diligently to unearth and document missing details, yielding a more nearly accurate and complete historical record. Those men deserve greater recognition for their efforts.

Notes and Caveats:

1. Several "temporary" suspension bridges erected by Federal armies during the Civil War are known but haven't been listed because they were not made to be permanent.

2. The lists of early bridges in California, Kentucky, Ohio, and West Virginia, are known to be incomplete. Sufficient information is missing for several bridges reported at remote locations; some of these have been omitted from the lists pending additional details.

3. Descriptions of U.S. iron wire bridges usually are provided with dimensions in feet. The iron wire sizes, ordinarily provided as Gauge Numbers, have been changed to decimals of an inch whenever possible in this appendix by using the Conversion Tables found in Appendix C of the Ferrous Wire Handbook - Volume 1, Guilford CT, Wire Association, 1989. Where a number but not a gauge system was named in the original description, the Birmingham gauge number has been assumed.

4. The "total" number of wires in a parallel-wire cable, when given, refers to cross-section count of wire diameters. In most parallel wire cables, there is actually only "one" wire spliced end to end and doubled back repeatedly.

5. The transition from wrought iron wire to steel wire in the decade 1870-1880 creates uncertainty about what kind of ferrous wire actually was used during that decade. Some bridges have been included in the list that were probably built with steel wire rather than wrought iron wire; contemporary accounts vary and may not be accurate.

1. (1816) Josiah White & Erskine Hazard's Footbridge

Private footbridge across Schuylkill near Philadelphia PA. Anchored to their wire factory building on one side of the river; to a tree on the other. Built by the owners in the winter of 1816 as temporary replacement for the nearby Falls Of Schuylkill chain suspension bridge used by their workmen. Apparently dismantled (later in the same year) when the owners decided to abandon their wire making business. A single contemporary sketch of the bridge has survived.

Span = Approximately 400 feet; width 18 inches

Site marking: Unmarked. No traces. The location, known as The Falls, in what is now Fairmount Park, is submerged beneath the Schuylkill River behind Philadelphia's Fairmount Dam downstream.

Cables: Six individual wires each approximately 0.375-inch diameter.

Wire Source: White & Hazard wire mill at site.

Reference for description: Charles E. Peterson, "The Spider Bridge, A Curious Work at the Falls Of Schuylkill, 1816", (Easton, PA. *Canal History & Technology Proceedings*, Vol. V, 1986).

2. (1841/42) Callowhill St. Bridge, also known as Fairmount Bridge

America's first public suspension bridge. Built as a toll-free structure under a new (1839) Pennsylvania law known as the *Free Bridge Act.* Connecting Callowhill Street on the east bank of the Schuylkill with Bridge Street on the west bank, at the site of Wernwag's earlier wooden arch-truss bridge, "Colossus," in Philadelphia, Pennsylvania. Designed by Charles Ellet Jr. Built by local contractors in 1841 under supervision of Ellet. Grand opening January 1,1842. Several lithograph views, plus a single photograph survive. Removed in the early 1870's due to age. Replaced by a metal truss bridge on same site in conjunction with the 1876 Centennial at Fairmount Park. The truss bridge, completed prior to May 1877, later was replaced by a modern interstate highway bridge on same site.

Span = 342 feet

Site marking: Unmarked. No apparent traces.

Cables: Ten parallel-wire catenary cables, wrapped at intervals, containing total 2816 wires, each 0.134-inch diameter, draped garland-style, five cables each side of roadway. Flooring suspended by smaller vertical parallel wire cords.

Wire Source: Rodenbaugh & Stewart wire mill, South Easton, Pennsyvania

Reference for description:

4. Charles Ellet Jr., *A Popular Notice Of Suspension Bridges With A Brief Description Of the Wire Bridge Across The Schuylkill At Fairmount* (Philadelphia, J.C. Clark, August 16,1843) - includes text of Ellet's original promotional pamphlet published at Richmond Virginia, by Bernard, April 1839.
5. Ellet files - Transportation Library, University of Michigan, Ann Arbor, Michigan.

3. (1845) Pittsburgh Aqueduct

Retrofit of existing state-owned wooden aqueduct originally suspended by iron rods from wooden arches. Reconstruction funded by City of Pittsburgh when the Pennsylvania Canal Commission refused to repair it. Designed by John A. Roebling; built by Roebling and Jonathan Rhule. Seven spans, using existing mid-river piers from earlier structure. Numerous original architectural drawings have survived. Widely publicized at the time of the canal opening in Spring 1845. Abandoned soon afterward, when new railroad service made the canal aqueduct crossing obsolete. Removed by Rhule in 1861. Unmarked center city location at Pittsburgh, Pennsylvania.

Span = Seven contiguous spans, each 162 feet.

Site marking: Unmarked. No apparent traces.

Cables: Two parallel-wire cables; each cable 7-inch diameter containing 1652 wires 0.148-inch diameter, completely wrapped end-to-end Roebling-style, with multiple anchor chains. The cables were continuous across all seven spans.

Wire Sources: (a) Robert Townsend's Juniata Wire Works, Pittsburgh, Pennsylvania & Fallston, Pennsylvania. (b) Samuel Wickersham's Pittsburgh Wire Works, Pittsburgh, Pennsylvania

Reference for description:

1. John A. Roebling, *Specification Of The Wire Suspension Aquaduct*, MS, Pennsylvania State Archives, Harrisburg Pennsylvania (two versions in state files);
2. Roebling files - Folsom Library, Rensselaer Polytechnic Institute, Troy, New York;
3. Donald Sayenga, " 'Pittsburg Aqueduct' - Reconstruction of the Pittsburgh Aqueduct by John A. Roebling", *Canal History & Technology Proceedings*, (Easton, Pennsylvania, Vol. XIV, 1995);
4. Robert M. Vogel, *Roebling's Delaware & Hudson Canal Aqueducts,* (Washington DC, Smithsonian, 1971), 4-5.

4. (1846) Smithfield St. Bridge, also known as Monongahela Bridge

Retrofit of fire-damaged wooden covered bridge across the Monongahela River between City of Pittsburgh and former borough of Sligo. Designed and built by John A. Roebling. Opened in February 1846. This was Roebling's only attempt to implement a complex array of non-continuous wire cables. The 1500-foot bridge was built in eight spans, using existing mid-river piers from the previous structure. Each span had a set of two cables connected to an elaborate system of pendulums in hollow cast iron towers. The cables were made on shore in pieces, then floated to the bridge for mounting, beginning in the middle of the river. Removed in 1882. Replaced by metal truss. No traces.

Span = Eight spans, approximately 188 feet each span.

Site marking: Plaque at site where Lindenthal's replacement bridge is in use.

Cables: Sixteen individual parallel-wire cables, 4-1/2 -inch diameter, two cables per span, independently attached to each span. Cables assisted by solid rod stays. Continuous anchor chains attached to first tower on each end.

Wire Sources: Robert Townsend's Juniata Wire Works, Fallston PA and Samuel Wickersham's Pittsburgh Wire Works, Pittsburgh PA

References for description:

E. John A. Roebling, "Wire Suspension Bridge over the Monongahela at Pittsburg", *American RR Journal*, (June 13, 1846) 376-377

F. Gustav Lindenthal, "Rebuilding of the Monongahela Bridge", *A.S.C.E. Transactions,* Vol. XII, (September 1883), 373-392

5. (1849) Niagara River Gorge Highway Bridge - Version 1

Preliminary highway bridge with wooden towers, intended to be enlarged and strengthened at a later time for a railroad crossing over the Niagara River Gorge between Canada and USA. Financed by two separate companies, one in each country. (Perhaps the first suspension bridge across a border between two nations?) Designed by Charles Ellet Jr. Built by Theodore Hulett and Jonathan Baldwin under the direction of Ellet. Opened in 1849. Construction was halted by a violent dispute between Ellet and the Canadian-based part-owner. Modified and completed by W.O. Buchanan. Subsequently used as work-platform by John Roebling when building his 1855 highway + railroad bridge, obliterating the original site; see Version 2. Possible traces of original cables, and/or original buried anchorage, at the site.

Span = 759 feet

Site marking: 1948 marker plaque at span center of present railroad bridge.

Cables: Eight (?) banded parallel-wire cables, different sizes, arranged garland-style, four on each side of roadway. One source states 7 cables.

Wire Source: Much, if not all, of the original wire in the cables was made in Manchester, United Kingdom by Richard Johnson & Nephew, and delivered to the Canada side. The original wire was extensively reused by Roebling when making his own cables; refer to: Niagara River Gorge - Version 2.

References for description:

A. George A. Seibel, *Bridges Over Niagara Gorge*, Niagara Falls, Ontario, N.F. Bridge Commission, 1991;

B. "Niagara Suspension Bridge", *Mechanics Magazine*, Volume LIV, Number 1433, London UK, (January 25, 1851), 73;

C. Ralph Greenhill, *Spanning Niagara,* Smithsonian Exhibition catalog, 1985.

6. (1849) D & H Aqueduct - Delaware River Crossing

Smaller version of Allegheny River Aqueduct. Intended to expedite anthracite coal shipments over the

Delaware River on the Delaware & Hudson Canal. Designed by Russel Lord and John A. Roebling; built by John A. Roebling and David Rhule. First used April 26, 1849. Extensively rebuilt. Original cables and stonework remain at the site, owned, reconstructed and maintained by the National Park Service. Four spans.

Span = 535 feet total length; three spans 131 feet, one span 141 feet

Site marking: In use as bridge. National Historic Civil Engineering Landmark.

Cables: Two Roebling-style wrapped parallel-wire 8-1/2 inch diameter cables, each containing 2150 wires, with multiple anchor chains.

Wire Source: Roebling's notes mention several sources; one is "English" and another is Rodenbaugh & Stewart, South Easton PA.

References for description:

1. Robert M. Vogel, *Roebling's Delaware & Hudson Canal Aqueducts*, (Washington DC, Smithsonian, 1971);
2. HAER Reports & Drawings in Library of Congress Collection;
3. Peter Osbourne III, "The Delaware & Hudson Canal Company's Enlargement And The Roebling Connection", Easton PA, *Canal History & Technology Proceedings*, Vol. III (1984);
4. Harlan D. Unrau and Sandra Hauptman, "Roebling's Delaware Aqueduct During The 20th Century", Easton Pennsylvania, *Canal History & Technology Proceedings*, Vol. III (1984)
5. Edwin D. LeRoy, *The D & H Canal*, (Honesdale Pennsylvania, Wayne County Historical Society, 1950), 50.

7. (1849) D & H Aqueduct - Lackawaxen River Crossing

Companion to the Delaware River crossing of the Delaware & Hudson Canal. Designed by Russel Lord and John A. Roebling. Built by John Roebling and David Rhule. First used April 26, 1849. Abandoned 1898. Traces remain.

Span = 440 feet total length; two spans 120 feet.

Site Marking: Plaque at site.

Cables: Two Roebling-style wrapped parallel-wire 7-inch diameter cables, each containing 1624 wires, with multiple anchor chains.

Wire Source: Several sources; see Delaware River Aqueduct above.

References for description:

1. Robert M. Vogel, *Roebling's Delaware & Hudson Canal Aqueducts,* Washington DC, Smithsonian Press, 1971;
2. Peter Osbourne III, "The Delaware & Hudson Canal Company's Enlargement And The Roebling Connection", Easton Pennsylvania, *Canal History & Technology Proc.*, Vol. III (1984);
3. Edwin D. LeRoy, *The D & H Canal*, Honesdale Pennsylvania, Wayne County Historical Soc., 1950, 50.

8. (1849) Wheeling - Version 1

The first world-record-class highway bridge in America. At the time of its construction it was located entirely within the Commonwealth of Virginia (now WV), spanning the main channel of the Ohio River between City of Wheeling and Zane's Island (now Wheeling Island). This bridge provided a westbound route for the National Road. Federal lawsuit by Pennsylvania vs. Virginia demanded its removal as a menace to river navigation, was decided by U.S. Supreme Court in favor of Pennsylvania; decision was overturned by actions of Executive and Legislative government. Designed by Charles Ellet Jr. Built by the local Wheeling & Belmont Bridge Company, and its contractors, under Ellet's direction. Opened

November 11, 1849. The roadway and cables were severely damaged by a windstorm in May 1854. Rebuilt by Ellet and William McComas. Reopened July 1854. Many photographs survive of the earliest version of the bridge. Subsequent modifications and extensive retrofitting projects (notably by McComas in 1859 and by William Hildenbrand in 1886) have completely altered the cables and the roadway. The towers and a portion of the cables and anchorages remain from the original bridge; everything else has been renovated, most recently in 1989. Still in daily use as a highway bridge;

Span = 1008 feet.

Site Marking: National Historic Civil Engineering Landmark; National Historic Landmark. West Virginia State Historic marker plaque

Cables: Originally twelve cables, draped garland style, six on each side of roadway, containing approximately 6600 wires total.

Wire Source: Original wire: Richards & Bodley, Wheeling VA (now WV)

Reference for description: HAER Reports & Drawings in Library of Congress Collection

9. (1849?) - McMahon's Creek Footbridge

Minor footbridge in Belmont County, OH built at or near the same time as the Wheeling Bridge. No other details or traces are known. Exact location of this footbridge is now under study by David Simmons, but not yet established.

Span = Unknown
Site marking: Unmarked
Cables: Unknown
Wire Source: Unknown

Reference for description: Files of Ohio Historical Society, Columbus Ohio.

10. (1849) Fort Plain Footbridge

Minor footbridge over the Erie Canal at Fort Plain NY, built in 1849 by Theodore Hulett. No other details.

Span = Unknown.
Site marking: Unmarked
Cables: Unknown
Wire Source: Unknown
Reference for description: Letter from Hulett to Ellet, Ellet Collection, Engineering & Transportation Library, University of Michigan, Ann Arbor, Michigan.

11. (1850) Nashville - Version 1

Replacement for a wooden bridge at Woodland Street in the central area of the city of Nashville, Tennessee. The old bridge was being removed because it was blocking access to a new wharf on the Cumberland River. Bridge was conceived and built by Matthew D. Field of Haddam, CT, assisted by Nashville architect Adolphus G. Heiman. Field and Heiman disagreed during construction, particularly regarding stability of the north abutment. Heiman then consulted with William Strickland who supported his position. (Heiman resigned; afterward he was killed in action during the Civil War.) Completed May 1850. Flooring collapsed in 1855; immediately rebuilt. Bridge was totally destroyed by retreating Confederate armies on February 18, 1862. Original site obliterated by a newer suspension bridge at same location; see Nashville Version 2. Elevated approximately 110 feet above the Cumberland River, between masonry towers, with the abutment on the south (city) side in the limestone cliff at higher elevation than the opposing masonry abutment. Extremely long approach was built up on low ground on the north side.

Span = 656 feet.
Site marking: Unmarked.
Cables: Sixteen cables, each containing 200 wires, "Number 10" diameter.
Wire Source: Bodley & Co. of Wheeling made the cables, then shipped them in finished condition to Nashville.

References for description:

4. A. G. Heiman, *1849 Report on the Construction of a Suspension Bridge Across the Cumberland River*, handwritten copy by Heiman, (dated 1857) Tennessee State Archives, Nashville, Tennessee;
5. *Scientific American*, Volume 5 Number 28 (March 30, 1850) 218;
6. *The Daily Wheeling Gazette,* (November 21, 1849), 3;
7. *Engineering News,* (November 28, 1907).

12. and 13. (1850?/1851) Frankfort - Version 1 and Version 2

Obscure three-span railroad suspension bridge over the Kentucky River at Frankfort, KY. Built by Louisville & Lexington RR in 1850? Apparently the first railroad suspension bridge in America (possibly in the world) using wire cables. Reported by *Scientific American* as still being under construction as of 1851; completed that year? Designed and built by Matthew D. Field of Haddam CT. In 1852, Julius Adams of New York City, (Founder of the ASCE, Pres. ASCE 1874) studied the bridge when he was Chief Engineer of the Louisville & Danville RR. He changed Version 1 into Version 2, and noted he had achieved this change without interrupting travel on the railroad. He may have used new cables to achieve his change. No other details are available.

Span = Adams reported the original bridge had three spans: 90 feet, 240 feet, and 185 feet. Adams stated he redesigned and rebuilt the bridge by adding two new piers and removing the old piers, converting it into a different configuration with two spans 150 feet and one span 110 feet.
Site Marking: Unmarked.
Cables: Unknown
Wire Source: Unknown

Reference for description: Julius W. Adams, "New Bridge Over the Kentucky River...", *Engineer,* London UK, Volume 3 (June 5, 1857).

14. (1851) Lewiston-Queenston - Version 1

Designed and built in 1850 close to the mouth of the Niagara River, just below the whirlpool, by Edward W. Serrell of New York City, assisted by Thomas Griffith. Opened for traffic in March 1851. The cables were put together nearby the site and hauled over the river by capstan. Iron rod suspenders. Built with an elaborate system of guys and stays. Owing to a threat of damage by ice floes, some underfloor stays were disconnected, allowing the central portion of the flooring to be destroyed by a windstorm in February 1854. The old cables were still hanging in place in 1898 when a decision was made to build a new bridge. The site of the original bridge was partly obliterated by the new arch bridge located ¾ mile upstream. Numerous photos of original cables have survived.

Span = 849 feet. Width 20 feet.
Site Marking: Plaque erected by Niagara Falls Bridge Commission in center span of present arch bridge. Plaque incorrectly refers to cables of Roebling's bridge.
Cables: Originally ten parallel-wire cables, arranged side-by-side, five on each side of roadway, connected by hanger bars, each containing cable 150 wires
Wire Source: Ten cables were made from "New Jersey" wire, 150 wires per cable, "Number 9".

Apparently the source was Cooper & Hewitt's Trenton Iron Company, Trenton NJ. "Number 9" on the Trenton "old" Gauge = 0.155"-inch; "Number 9" on the Trenton "new" Gauge = 0.145-inch

Reference for description:
1. *Scientific American*, Volume 5, Number 31, (April 20, 1850) 242;
2. George A. Seibel, *Bridges Over Niagara Gorge,* Niagara Falls, Ontario, Niagara Falls Bridge Commission, 1991, 83-88.

15. (1851?) Powhatan Footbridge

Description discovered by David Simmons indicates this was one of five? similar footbridges erected in eastern Ohio near the Ohio River in 1850-51?.

Span = 250 feet. No other details.
Site marking: Unknown and unmarked
Cables: Unknown
Wire Source: Unknown

Reference for description: Notes provided by David Simmons, 1999.

16. (1851) Muscatine

Description discovered by R. S. Allen indicates this was a cable stayed wooden bridge built in 1851 over the Cedar River near Muscatine, Iowa with an incredible single span of 600 feet. (First cable-stayed bridge in America?) Damaged by wind while still under construction. Destroyed by a windstorm four months later. Designed and built by two men from Kentucky; one was either N. L. Milburn or Andrew Campbell. No trace of it was found during a search of the site by Allen in 1995.

Span = 600 feet
Site Marking: Unknown and unmarked.
Cables: Unknown
Wire Source: Unknown

Reference for description: File gathered from numerous source materials by Richard Sanders Allen, 1993.

17. (1851) D & H Aqueduct - Rondout Creek Crossing at High Falls

Delaware & Hudson Canal aqueduct, High Falls, New York. Designed by John A. Roebling. Built in 1851 by David Rhule and Roebling; stonework by D & H employees. The aqueduct carried the canal over the creek, replacing an adjacent stone and wood aqueduct that was afterward removed. Canal was realigned to permit continuous operation during construction. Abandoned in 1898 when the canal ceased operations. Traces at site.

Span = 145 feet
Site Marking: Uncertain
Cables: Two 8-1/2 inch Roebling-style wrapped parallel-wire main cables, each containing 2300 wires. Iron rod suspenders. Roebling-type anchorage with multiple anchor chains.
Wire Source: Roebling's notes mention several wire sources including Rodenbaugh & Stewart, South Easton Pennsylvania

Reference for description: Robert M. Vogel, *Roebling's Delaware & Hudson Canal Aqueducts,* (Washington DC, Smithsonian, 1971).

18. 1851 - D & H Aqueduct - Neversink River Crossing

Delaware & Hudson Canal aqueduct near Cuddebackville, New York
replacing adjacent stone & wood aqueduct afterward removed. Designed by John A. Roebling. Built by David Rhule and John A. Roebling in 1851; stonework by D & H employees. Abandoned in 1898 when canal ceased operations. Traces at site.

Span = 170 feet

Site Marking: Plaque and museum at site.

Cables: Two 9-1/2 inch Roebling-style fully wrapped parallel-wire main cables, each containing 2880 wires. Iron rod suspenders. Roebling-type anchorage with multiple anchor chains.

Wire Source: Roebling's notes mention several wire sources including Rodenbaugh & Stewart, South Easton Pennsylvania.

References for description:

1. Robert M. Vogel, *Roebling's Delaware & Hudson Canal Aqueducts*, (Washington DC, Smithsonian, 1971);
2. Malcolm A. Booth, "Roebling's Sixth Bridge", New Brunswick NJ, *Journal of the Rutgers University Library*, XXX, 1, (December 1966)

19. (1852) Fort Hunter

Small span bridge over the Mohawk River in New York, linking Fort Hunter and Tribes Hill, two communities on opposite banks of the river. The bridge connected the Tribes Hill - Johnstown Road with the Fort Hunter - Albany plank road. Original Cost = $17,500. Designed and built in 1852 by John W. Murphy? Date also given as 1854? The towers were "heavy oak timbers". According to Edward J. Sheehan, Montgomery County historian, the bridge was removed in 1936 when it "was replaced by the Barge Canal Lock Bridge".

Span = Uncertain

Site Marking: Unmarked.

Cables: Six (?) 3 inch diameter cables made from parallel wires, "bound together". The cables were constructed in place, said to have been "made by Roebling in 1852" (?). Postcard photo shows only two cables.

Wire Source: Roebling's wire mill at Trenton NJ ?

References for description:

1. R. C. Huberman, HAER-NY 6, "Schoharie Creek Aqueduct" mentioned in: *A Report Of The Mohawk-Hudson Area Survey*, (Washington,1973), 178;
2. Beers, *History of Mongomery & Fulton Counties,* no date.

20. (1852) Fairmont

Built in 1852 over the Monongahela River at Fairmont VA (now WV) by the Fairmont & Palatine Bridge Company. Designed by James L. Randolph. Built by Randolph and John Downing.

Span = 560 feet

Site Marking: Unmarked. No traces at site.

Cables: Twelve cables, six on each side of roadway. No other details.

Wire Source: Dewey & Co., Wheeling VA (now WV)

Reference for description:

1. *Scientific American,* Volume 7, Number 23 (February 21, 1852) 184;
2. Files of Ohio Historical Society, Columbus OH cited by David Simmons;
3. Emory L. Kemp, *West Virginia's Historic Bridges*, Morgantown WV, West Virginia Department of Highways, 1984;

4. *Scientific American* , v.7, n. 23, Page 184, (February 21, 1852).

21. (1852) Charleston

Built in 1851-52 over the Elk River at Charleston VA (now WV) by local citizens, under supervision of W.O. Buchanan, William Kuhn, and Abraham Wright. Plans were made by W.O. Buchanan. Cables were made on site by John Downing. Twice damaged and afterward repaired during the Civil War. During repairs in 1862 and again in 1865, new cable wires were spliced into the catenary. Apparently the bridge was well maintained during its career as a toll bridge, which came to an end in 1886. Anchorage on one side failed December 15, 1904 under a load of winter ice & snow, plus three heavy wagons filled with damp sand; two children were killed. Failure attributed to poor maintenance practice after 1886. The bridge was known to have bern in very poor condition at time of failure, but its daily use was not being restricted by any of the local authorities.

Span = 478 feet

Site Marking: Uncertain

Cables: 4 parallel wire cables, banded with wire at intervals, 3 inch diameter, each containing 300 wires.

Wire Source: original wire = Dewey & Co., Wheeling VA (now WV)

Reference for description:

1. Addison M. Scott, "The Suspension Bridge Failure At Charleston" *Engineering News* V.53 n. 5 (February 2, 1905), 114-115;
2. H.G. Tyrell, "The Charleston Bridge Failure" *Engineering News,* V. 53 n.5 (January 5, 1905) 10-11;
3. Emory L. Kemp, *West Virginia's Historic Bridges,* (Morgantown WV, West Virginia Department of Highways, 1984);
4. *Scientific American* , Volume 7, Number 23, (February 21, 1852) 184;
5. Files of Ohio Historical Society, Columbus OH.

22. (1852) Dresden

Built in 1852 over the Muskingum River at Dresden, OH by the Dresden Bridge Company. Financed by George Willison Adams. Designer and builder believed to have been Adams' nephew George Copland.

Span = 450 feet

Site Marking: Unmarked.

Cables: Eight 3-inch garland-style parallel wire cables, 215 wires in each cable, bound together at intervals

Wire Source: Unknown. Possibly Spaulding Iron Works in Dresden OH.

Reference for description:

1. Newspaper Article by Glenn Longaberger dated October 15, 1970.
2. Files of Ohio Historical Society, Columbus, Ohio

23. (1852) Cosumnes

Designed and built in 1852 over the Cosumnes River in Sacramento County CA by W.D. Wilson. Believed to have been the first suspension bridge built in California, based upon references uncovered by California Highway Department during a study in 1950. No other details.

Span = 135 feet.

Site Marking: Unmarked.

Cables: Unknown

Wire Source: Unknown

References for description: Cited by the California Highway Dept., quoting *Alta California* July 27, 1852, requoting mention in *Sacramento Union.*

24. (1852) O'Bryne's Bridge

Said to have been built in 1852 over the Stanislaus River by Peter O'Bryne at O'Bryne's Ferry between Calaveras and Tuolumne counties in California. Replaced in 1862 by a wooden bridge.

Site Marking: Unmarked.
Cables: Unknown
Wire Source: Unknown

References for description: Notes from file provided by Richard S. Allen.

25. (1853) Falmouth

Built in 1853 by D. Griffith Smith over the Licking River at or near Falmouth, Pendleton County, Kentucky. No other details.

Span = 323 feet
Site Marking: Unmarked
Cables: 8 wire cables?
Wire Source: Unknown

Reference for description:
(1) *American Railroad Journal,* April 23, 1853, 267
(2) Files of Ohio Historical Society, Columbus OH

26. (1853) Tiffin

Built in 1853 over the Sandusky River by John Gray. Located in the center of the city of Tiffin OH. No other details.

Span = 210 feet
Site Marking: Unmarked
Cables: Four 4-inch diameter cables, each containing 200 wires,
Wire Source: Unknown mill in Pittsburgh Pennsylvania?

Reference for description: Files of Ohio Historical Society, Columbus OH

27. (1853) Newport

Built in 1853 over the Licking River at Newport KY by John Gray and George Tarvin for the Newport & Covington Bridge Company. Designed by Gray. Collapsed in January 1854 when a drove of cattle were passing. Rebuilt with stronger ironwork and anchorage. Reopened May 1854.

Span = 550 feet
Site Marking: Unknown and unmarked
Cables: Eight cables; two containing 308 wires; six containing 250 wires.
Wire source: Unknown

Reference for description: Files of Ohio Historical Society, Columbus OH

28. (1854?) Sutton

Built in 1854? over the Elk River on the Weston & Gauley Turnpike at Sutton VA, now WV, according to the plans of J.S. Camden. Built by Benjamin Bryne? and Ira Hart. Stone towers. Cables made by John Downing.

Span = 460 feet; Width 12 feet.
Site Marking: Unmarked
Cables: Four cables, each containing 250 wires, 0.134-inch diameter
Wire Source: Wire furnished by Bodley & Co of Wheeling, VA (now WV)
Reference for description: Files of Ohio Historical Society, Columbus OH

29. (1854?) Albright

Built in 1854? over the Cheat River at Albright VA (now WV). The bridge connected the National Road with the Northwestern Turnpike. No other details.

Span = Uncertain
Site Marking: Unknown and unmarked
Cables: Unknown
Wire Source: Unknown

Reference for description: Verbal report provided by Emory Kemp

30. (1855) Morgantown

Built in 1855 over the Monongahela River at Morgantown VA (now WV). No other details.

Span = Approximately 555 feet
Site Marking: Uncertain
Cables: Six parallel wire main cables, assisted by diagonal (factory-made?) wire rope stays.
Wire Source: Unknown

Reference for description:

1. Emory L. Kemp, *West Virginia's Historic Bridges*, Morgantown WV, West Virginia Department of Highways, 1984;
2. W.H. Boughton, *Engineering News*, v 53, n 10 (March 9, 1905) 249.

31. (1855) Horseshoe Bar Bridge and Mining Flume

Andrew S. Hallidie's first effort at bridgebuilding. In his autobiography Hallidie stated that he had: "*In 1855, ...constructed a suspension bridge and aqueduct*" over the Middle Fork of the American River at Horseshoe Bar CA. He added he "*fell 25 feet off a suspension bridge*" around the same time, which seems to be an indication of the elevation above the river. He stated the structure was built to carry an "*open flume...for conveying water to the mines*".

Span = Approximately 180 feet
Site Marking: Unmarked.
Cables: Unknown
Wire Source: Eckfield & Graves, San Francisco CA?

Reference for description: Autobiography of A.S. Hallidie, Collection of the California Historical Society, San Francisco, California.

32. (1855) Minneapolis - Version 1

Built in over the Mississippi River, above the falls, near Minneapolis, by Thomas Griffith. Opened for traffic January 23, 1855. Removed and completely replaced in 1875-77. apparently by the same builder.
Span = 620 feet
Site Marking: Father Hennepin Bridge at same site?
Cables: 4 parallel-wire cables, each containing 500 wires "Number 10"
Wire Source: Cooper & Hewitt's Trenton Iron Company, Trenton NJ.

Reference for description: Thomas Griffiths, *Van Nostrands Engineering Magazine*, New York, (March 1878).

33. (1855) Niagara River Gorge Bridge - Version 2

Double-deck bridge across Niagara Gorge replacing Ellet's earlier bridge. The original bridge (see Version 1 above) was used as work platform. Guyed with stays to the towers and also to the cliffs below bridge. Designed and built by John A. Roebling. This bridge allowed the passage of railroad trains at a speed of 5 mph on the upper deck while foot and wagon traffic crossed on the lower level at the same time. Achieved considerable international fame and is often mistakenly called the "first" railroad suspension bridge in many accounts. Completed March 8, 1855. Anchorages rebuilt 1877. The entire bridge, except for the towers and the cables, was replaced on site as a metal structure in 1880. The towers were replaced with metal structures in 1886. Totally removed and replaced by an arch bridge in 1899.
Span = 821 feet
Site Marking: Plaque at center span of present structure dated 1948. Stonework of anchorage remains in place at U.S. approach. No other traces.
Cables: 4 cables, each 10-inch diameter, fully wrapped Roebling-style, each cable comprised of 3640 wires, 0.148-inch diameter, with multiple chain anchorage.
Wire Source: Richard Johnson & Nephew, Manchester UK

Reference for description:
1. John A. Roebling, *Final Report To the Presidents and Directors of the Niagara Falls Suspension and Niagara Falls International Bridge Companies*, Rochester NY, Lee, Mann & Co, 1855;
2. George A. Seibel, *Bridges Over Niagara Gorge*, Niagara Falls; Ontario, Niagara Falls Bridge Commission, 1991;
3. Ralph Greenhill, *Spanning Niagara*, exhibition catalog, 1985.

34. (1856) Strong also known as Sandy River

Built by local contractors over the Sandy River at Strong, Maine in 1856. Removed and replaced by truss bridge in 1922.
Span = 230 feet
Site Marking: Unmarked.
Cables: 300 feet between anchorages, 3-inch diameter, parallel-wire, banded at intervals, each containing approximately 200 wires.
Wire Source: Unknown

Reference for description: Llewellyn N. Edwards, *The Evolution Of Early American Bridges*, (Transactions of the Newcomen Society, Vol Xiii, 1934)

35. (1856) Bidwell Bar

According to the records of the California Highway Department, this enigmatic bridge in Butte County over the Middle Fork of the Feather River near Oroville CA was opened to traffic in 1856. Reported built by "Jones & Murray". A man named Evans was in charge of construction? It remained in service until threatened by rising waters of the Oroville Reservoir in the mid-1960's when it was taken apart and moved elsewhere to be reassembled for display purposes. Cast iron columns marked "Starbuck" imply an origin in Troy NY. Original site is now submerged.

Span = Approximately 225 feet

Site Marking: National Civil Engineering Landmark plaque.

Cables: Four parallel wire cables each containing 300 wires. The cables were said to have been made by the column foundry in Troy NY and shipped intact to the site (which seems unlikely).

Wire Source: Unknown

Reference for description:

1. HAER Photos in Library of Congress Collection;
2. "D.J.P," "Bidwell Bar Bridge", in *Rensselaer Review*, Volume 1 Number 4, Troy NY (1964)

36. (1856) Westmoreland's Bridge

According to the records of the California Highway Department, this enigmatic bridge over the Mokelumne River near Ione, CA was opened to traffic in 1856. Located at the former mining community of Lancha Plana. Collapsed at a later time. Ruins were still visible at site as of 1950. No other information.

Span = Approximately 270 feet

Site Marking: Unmarked?

Cables: Unknown

Wire Source: Unknown

Reference for description: California Highway Department Study, 1950.

37. (1857) Lehigh River Change Bridge

Built across the Lehigh River by the Lehigh Coal & Navigation Co. under the direction of their chief engineer Edwin A. Douglas, replacing a mule ferry at the same location. The purpose of the bridge was to allow mules pulling canal boats to cross a slackwater pool in the river above Dam No. 8, near Glendon Pennsylvania, where the Lehigh Canal shifted from the north bank to the south bank. The flooring of this structure was suspended from short iron hanger rods connected directly from the catenary of cables. Douglas proposed the bridge in a report dated January 1, 1855. The bridge was built in 1857. Two spans with mid-river pier. Severely damaged by a flood in 1862, it was repaired and remained in daily service until the canal was abandoned in the 1940's. Flooring destroyed by vandals in the 1960's. The cables and anchorages remain in place.

Span = Two unequal spans; unmeasured

Site Marking: Unmarked.

Cables: Two wire rope cables, 7 by 7 by 7 construction. Probably Hazard's.

Wire Source: Probably Hazard's wire works at Mauch Chunk Pennsylvania

Reference for description: Cables still in place. Otherwise unrecorded.

38. (1857) Black River

Built in 1857 over the Black River on Mill Street at Watertown, Jefferson County, NY. Also known as "Bradford's" Suspension Bridge after designer-builder Gilbert Bradford. Unusual riveted towers fabricated from iron boiler plate. Removed in the 1890's.

Span = 160 feet
Site Marking: Unknown
Cables: 5/8 -inch diameter wire cables?
Wire Source: Unknown

Reference for description: Notations from a folder in Smithsonian Institution files (cited by Richard Sanders Allen).

39. (1858) Guyandot

Built in 1858 by George Mason over the Guyandot River near Huntington VA (now West Virginia) by the Guyandotte Bridge Company. No other details.

Span = "About 450 feet" Width 18 feet
Site marking: Unknown and Unmarked
Cables: Four 3-inch diameter parallel-wire cables
Wire Source: Unknown

Reference for description: *Engineering Record*, Vol. 44, (July 13, 1901), 31.

40. (1858) Susquehanna Lumber Bridge

Built by John Dubois over the North Branch of the Susquehanna River at Williamsport Pennsylvania in 1858 for the lumber mill of Lowe & Dubois. The purpose of this unique bridge was to convey finished planed lumber 1200 feet across the river to a shipping point. The bridge carried a narrow 27-inch wide lumber-way mounted with a sequence of wooden rollers. Power-driven rollers at one end caused the boards to push each other across the river. Also used as a footbridge. No other details.

Span = 880 feet total; four spans 220 feet each. Width 10 feet.
Site Marking: Unknown and unmarked
Cables: Two Roebling factory-made ropes, 1-inch and 1-1/2 inch diameter
Wire Source: Roebling's wire mill, Trenton NJ

Reference for description: *Scientific American*, v 14 n 23 (Feb. 12, 1859) 188.

41. (1859) Sixth St. Bridge, also known as Pittsburgh & Allegheny

Four-span span bridge built by John A. Roebling and David Rhule in 1859 across the Allegheny River between Pittsburgh Pennsylvania and the city of Allegheny (since unified with Pittsburgh) replacing wooden bridge at the location. Site formerly called St. Clair Street, now known as Sixth Street. Roebling's son, Washington A. Roebling, a recent college graduate, assisted his father with the final stages of this work. Supported by three mid-river stone piers (one from earlier bridge) with two wrought iron towers on each pier. Replaced by a metal truss bridge in 1892.

Span = Two central spans, each 344 feet, plus two side spans each 171 feet
Site Marking: Plaque at site of present the bridge?
Cables: Four Roebling-style, fully wrapped parallel-wire cables. Two 7-inch diameter cables plus two 4-inch diameter cables, augmented with wire rope suspenders and stays. Wire in main cables 0.148-inch diameter. Anchored with Roebling-style multiple continuous chains.
Wire Source: Roebling's wire mill at Trenton, New Jersey

Reference for description: *Construction of Parallel Wire cables for Suspension Bridges*, (Trenton, New Jersey, John A. Roebling Sons Corp.), 1925, 5.

42. (1859) Volcano Bar

Built by Patrick Gordon in 1859 over the Middle Fork of the American River in El Dorado County CA. Mentioned in an 1883 county history of the county, cited in 1950 in a study by the California Highway Department. No other details.

Span = Unknown
Site Marking: Unmarked and uncertain
Cables: Unknown
Wire Source: Unknown

Reference for description: *History Of El Dorado County* (1883) unverified

43. (1859) Carlyle

Built by D. Griffith Smith in 1859 over the Kaskasia River at Carlyle IL. Original cost = $40,000. Rebuilt in 1958. Now used as footbridge crossing in park, Since rebuilding it has been known as "General Dean Bridge".No other details.

Span = uncertain
Site Marking: Exhibit at site of rebuilt bridge, foot of Fairfax Avenue, Carlyle
Cables: Uncertain; segment of original cable exhibited at the site.
Wire Source: Unknown

Reference for description: Files of Carlyle Historical Society; Case-Halstead Library, Carlyle, Illinois

44. (1860) Askew's Bar

California bridge built over the Bear River, five miles above Kearney, in 1860. Built by J.R. Rush of Grass Valley. No other details.

Span = Unknown
Site Marking: Unknown site
Cables: Unknown
Wire Source: Unknown

Reference for description: From a file collected by Richard S. Allen, 1995

45. (1862) Auburn-Coloma (formerly Murderer's Bar?)

Reportedly the cables of this 1862 bridge were part of an earlier bridge built at Murderer's Bar on the Middle Fork of the American River supposedly dated 1849. It is reported the cables were relocated, with a new floor added, to provide crossing of the North Fork of the American River between Auburn and Coloma at Middle Fork confluence. Photos exist. Supposedly collapsed in the 1920's? Built by John Mollett? No other details.

Span = Unknown
Site Marking: Unmarked?
Cables: Parallel-wire? Approximately 3-inch diameter. Coated with tar?
Wire Source: Unknown

Reference for description: H.D. Miller "California Suspension Bridge in Service Since 1862," *Engineering News Record*, v.95 (December 3, 1925), 908.

46. (1863) Portsmouth

Built 1858-1863? over the Scioto River at Portsmouth OH by E.B. Gray for the Portsmouth Bridge Company. Easternmost anchorage was undermined by extreme high water in November 1859 and the bridge fell. Redesigned by Max Becker and rebuilt with a different tower + anchorage combination. Collapsed May 21, 1884.

Span = 424 feet; width 16 feet
Site marking: Unknown
Cables: 3-1/2 inch diameter made from 0.134-inch diameter parallel wire

Reference for description:
1. Files of Ohio Historical Society, Columbus OH;
2. "Fall Of A Suspension Bridge" *The Iron Age*, v.33 n.22, (May 29, 1884).

47. (1862?) Weitchpec

Built by Andrew S. Hallidie over the Klamath River in Northern California. Construction was begun in 1861 but was interrupted by a local Indian uprising. Completion date unknown. This is the first of seven bridges Hallidie stated he began building in 1861. He added that floods in 1862-63 hindered completion, implying possible completion date as late as 1864. Location today is remote; somewhere within the boundaries of the Yurok Indian Reservation. No other details.

Span = Unknown.
Site marking: Exact site is "below the Trinity" - unknown and unmarked
Span = Uncertain
Cables: Uncertain
Wire Source: probably Eckfield & Graves, San Francisco, California

Reference for description: Autobiography of A.S. Hallidie, Collection of the California Historical Society, San Francisco, California.

48. (1862) Nevada City

Built by A.S. Hallidie to carry the southern extension of Pine Street across Deer Creek at Nevada City CA. completed in 1862. This is the second of seven bridge contracts obtained by Hallidie in 1861. Construction began in October 1861 but was interrupted by heavy rains. Wet earth disturbed the anchorages during construction. Bridge opened in June,1862; Collapsed July 10, 1862 when two wagons loaded with hay were passing across. Failure attributed to breakage of a "cast iron yoke" in one of the south anchorages. Two men and twelve oxen were killed. Rebuilt immediately by Hallidie. Served until 1903 when replaced by a steel arch bridge on same site. Portions of the north anchorages have survived and were excavated in 1996 for possible future display.

Span = 320 feet. Width 14 feet 9 inches.
Site Marking: Location obliterated by two subsequent arch bridges built in 1903 and 1996. Plaque at site: "Hallidie's Crossing" on city side of present bridge.
Cables: Two parallel-wire cables, 4-inch diameter, 1050 wires each
Wire Source: probably Eckfield & Graves, San Francisco, California

References for description:
1. Article in *Nevada City Transcript*, June 22, 1862, cited by Alan H. Peters;
2. Autobiography of A.S. Hallidie, Collection of the California Historical Society, San

Francisco, California;
3. Files of City Engineer, Nevada City, California.

49. (1862) Folsom

Built by A.S. Hallidie over the American River. Construction was begun in 1861 and completed in 1862. This is the third of seven bridges Hallidie stated he began in 1861. Apparently it was completed prior to June 22, 1862 when the Nevada City bridge was opened. No other details.

Span = 330 feet; width 12 feet
Site Marking: Unmarked
Cables: Uncertain
Wire Source: probably Eckfield & Graves, San Francisco, California

Reference for description:
1. Autobiography of A.S. Hallidie, Collection of the California Historical Society, San Francisco, California;
2. Mentioned in *Nevada City Transcript* newspaper June 22, 1862.

50. (1862/63 ?) McCourtney's Crossing or Bear River

A.S. Hallidie referred to this as his Bear River Bridge. Construction was begun in 1861 and completed in 1862 or 1863. This is the fourth of seven bridges Hallidie stated he began in 1861. No other details.

Span = 205 feet?
Site Marking: Unmarked, unknown location
Cables: Uncertain
Wire Source: probably Eckfield & Graves, San Francisco, California

Reference for description: Autobiography of A.S. Hallidie, Collection of the California Historical Society, San Francisco, California.

51. (1862/63 ?) Trinity

Built across the Trinity River in California by A.S. Hallidie. Construction was begun in 1861 and completed in 1862 or 1863. This is the fifth of seven bridges Hallidie stated he began in 1861 and finished after the flooding of 1862. Exact location unknown. No other details.

Span = Unknown
Site marking: Unknown and unmarked
Cables: Uncertain
Wire Source: probably Eckfield & Graves, San Francisco, California

Reference for description:
Autobiography of A.S. Hallidie, Collection of the California Historical Society, San Francisco, California

52. (1862/63 ?) Stanislaus

Built over the Stanislaus River in California by A.S. Hallidie. This is the sixth of seven bridges bridges Hallidie states he began in 1861 and finished in 1862 or 1863 after the flooding of 1862. Exact location unknown but presumed to be the same site as Stanislaus - Version 1. No other details.

Span = Unknown
Site marking: Unknown and unmarked
Cables: Uncertain

Wire Source: probably Eckfield & Graves, San Francisco, California

Reference for description: Autobiography of A.S. Hallidie, Collection of the California Historical Society, San Francisco, California

53. (1862/63 ?) Tuolumne

Built over the Tuolumne River in California by A. S. Hallidie. Construction was begun in 1861. This is the last of seven bridges that Hallidie stated he began in 1861 and completed after the flooding of 1862. No other details.

Span = Unknown
Site Marking: Unknown and unmarked.
Cables: Uncertain
Wire Source: probably Eckfield & Graves, San Francisco, California

Reference for description: Autobiography of A.S. Hallidie, Collection of the California Historical Society, San Francisco, California

54. (1866) Nashville - Version 2

In 1866, following the Civil War, a second Woodland Street suspension bridge over the Cumberland River was built to replace the one destroyed during the war. Original masonry towers were strengthened and re-used. The design consultant was Colonel Albert Fisk. City Engineer Major W.F. Foster supervised construction in 1867. Removed and replaced in 1886. The site is obliterated by more modern bridges at same location. Several photographs survive.

Span = Uncertain
Site marking: Unmarked. Present Woodland Street bridge obliterates site.
Cables: Uncertain. Surviving photographs show eight cables near anchorages but a written description in library files gives a different number of cables.
Wire Source: Unknown

References for description:

1. "The Nashville Suspension Bridge" *Engineering*, London, v. 5, p. 167, March 6, 1868 and v.11, p 133-134, February 24, 1871;
2. Arthur Weir Couch and Harry Dixon Claybrook, *Our Ancestors Were Engineers*, (Nashville TN, Nashville Section A.S.C.E., n.d.);
3. Files - Nashville Public Library, Nashville Room, Nashville, Tennessee;
4. Files - Tennessee State Museum, Nashville, Tennessee.

55. (1866) Williamsport

Five-span "Murphy Military Bridge" built across the Susquehanna River at the foot of Market Street, Williamsport, Lycoming County, Pennsylvania in 1866. Wire rope main cables stiffened with diagonal iron rods as stays. Boiler plate towers riveted into tubular form, mounted on piers.

Each of five spans = 185 feet.
Site Marking: Unmarked
Cables: Ten factory-made wire ropes, five each side.
Wire Source: Unknown

Reference for description: Alfred P. Boller, "Williamsport Suspension," *Journal Of The Franklin Institute*, Vol. 5, No. 4 (April 1866), 217-219.

56. (1866 ?) Oil City

Built over the Allegheny River at Oil City, Venango Co. Pennsylvania in 1865-66. No other details. Similar bridge was built at same site in 1876. Possible involvement of Charles G. Roebling in design & construction of the second bridge. No other details.

Span = Supposedly two spans, 300 feet and 150 feet
Site Marking: Uncertain
Cables: Said to use "two cables" equipped with "suspending rods".
Wire Source: probably Roebling Sons wire mill, Trenton, New Jersey

Reference for description:

1. "Bridge Across Allegheny", *American Railway Journal*, v.38, n.1528, (July 28, 1865) cited by Jakkula;
2. Washington A. Roebling "Charles Gustavus Roebling" copied by Hamilton Schuyler in *The Roeblings*, Princeton NJ, Princeton Univ. Press, 1931, 312.

57. (1866 ?) New Portland

Crossing Carrabassett River near New Portland ME. Design and construction attributed to David Elder and Charles Clark to connect two existing town roads on either side of the river between East New Portland and Kingfield. Daniel Beedy, local bridgebuilder, also suggested to have been builder. The bridge was completely rehabilitated 1960-61. As a result, only the main cables remain from the original structure. Every expert that has examined the bridge affirms a belief that the two iron wire cables were made at the site when the bridge was built, 1864-66. Despite this, an unsupportable local myth persists insisting it is of older vintage, and that the parallel-wire cables are made of "steel" brought to Maine from "Sheffield, England". Still in use as a highway bridge.

Span = 187 feet 6 inches; width 11 feet 9 inches
Site Marking: Uncertain
Cables: Two parallel-wire, fully wrapped, 3-1/4 inch diameter main cables. Cables have been refurbished.
Wire Source: Unknown

References for description:

1. File prepared by Charles A. Whitten, Maine Department Of Transportation, in support of Maine Legislative Document 988, dated February 26, 1959;
2. Photos in HAER Collection

58. (1867) Meadow Creek

Constructed in 1867 over the Salmon River in Idaho County, Idaho, on the road between Florence, Idaho and Warrens, Washington, replacing a ferry at the mouth of Meadow Creek (now Wind River) operated by James M. Hunt. Collapsed in 1879. Rebuilt, but then the structure was swept away by river in 1880. No other details.

Span = Unknown
Site marking: Uncertain
Cables: Unknown
Wire Source: Unknown

Reference for description: Richard Sanders Allen, "The Bridges Of Idaho County", *The Golden Age*, v.1 n.1 (1995).

59. (1867) Covington & Cincinnati or John A. Roebling Bridge

The world's record span suspension bridge at the time of completion, and the masterpiece of John A. Roebling, construction of this spectacular bridge was begun 1856. Completion was interrupted at first by financial problems, then delayed by the Civil War. Roebling was assisted by George W. Fulton and Prof. John Gower and later by his son Washington Roebling. First opened for traffic on January 1, 1867. Originally built with a wooden flooring for horse-drawn vehicle and foot traffic only. The success of this bridge was a deciding factor in awarding the contract for the Brooklyn Bridge to John A. Roebling. Owing to this, he departed from the site prior to actual completion, delegating the finishing work to his son Washington A. Roebling. The entire bridge was completely reconstructed in 1895-97 according to the plans of William Hildenbrand who added two steel wire main cables. Purchased by the Commonwealth of Kentucky in 1953; again rebuilt, this time with steel flooring. Still in use as a highway bridge.

Span = Originally 1057 feet

Site Marking: National Historic Civil Engineering Landmark

Cables: Originally suspended by two cables, each 12-1/3 inch diameter, fully wrapped Roebling-style, each comprised of 5180 wires .148-inch diameter, assisted by wire rope stays. The original stone towers, cables and anchorage chains are still in place, augmented by numerous complex additions. The original roadway has been totally removed.

Original Wire Source: Richard Johnson & Nephew, Manchester UK

Reference for description:

3. John A. Roebling, *Report to the President And Board of Directors of the Covington & Cincinnati Bridge Company, April 1, 1867*, (Trenton NJ, Murphy & Bechtel, 1867);
4. Joseph F. Gastright, "Wilhelm Hildenbrand and the 1895 Reconstruction of the Roebling Suspension Bridge", *Proceedings,* The Fifth Historic Bridges Conference, (Columbus, Ohio: Burgess & Niple, 1997) 24-37.

60. (1868) Afton

Two brothers named Fishler built this bridge over the Susquehanna River at Afton NY in 1868. The design is credited to James Crowell. (According to information uncovered by Richard Sanders Allen, the Fishlers may have built another bridge exactly like this one over the Chemung River at Wellsburg NY). This bridge replaced a wooden truss bridge on the same site. New steel truss erected on same site in 1904, followed by present bridge on site built in 1948. No other details.

Span = approximately 335 feet

Site marking: Plaque formerly said to be on site

Cables: Six wire rope cables with suspender rods. Three ropes on either side of span. Diameter of ropes unknown. Construction of ropes 7 by 19? The ropes were said to have been made at Trenton NJ which would indicate Roebling' s product.

Wire Source: probably Roebling wire mill, Trenton, New Jersey

Reference for description: J. H. Smith, *History Of Chenango & Madison Counties*, (1880), (cited by Richard Sanders Allen).

61. (1868) Hamilton

Built in 1868 by Gray, Morse & Young of Covington KY over the Greater Miami River in the center of the city of Hamilton, Ohio.

Span = 400 feet; width 18 feet.

Site marking: Uncertain

Cables: Two fully-wrapped, Roebling-style parallel wire, "Number 10" wire, with Roebling-style continuous anchor chains, augmented with stays.

Wire source: probably Roebling wire mill, Trenton, New Jersey

Reference for description: Files of Ohio Historical Society, Columbus, Ohio

62. (1868) Whitewater River

Built in 1868 by John Gray(?) over Whitewater River, Hamilton County, Ohio. Near Elizabethtown, Ohio. No other details.

Span = 460 feet
Site marking: Unmarked
Cables: Two 7-inch diameter (parallel-wire?) cables?
Wire Source: Unknown

Reference for description: Files of Ohio Historical Society, Columbus, Ohio

63. (1868) Clifton & Niagara Falls or Upper Suspension Bridge

Built across the Niagara Gorge 1867-68 by Samuel Keefer. It was first opened for traffic in January, 1869. The span set a new world's record. The main cables were unusual because they were built up from factory-made wire ropes traversed across the frozen river ice during the winter, then raised into position, tensioned, and socketed into place. The bridge was equipped with an elaborate system of wire ropes as wind stays. The most famous English wire rope factory, R.S. Newall, made the ropes for the main cables. Wire ropes for guys, stays, and suspenders was made by another English rope factory, the Queens Ferry Wire Rope Co. Some of the shorter suspenders were iron rods. After the bridge had opened, a windstorm caused 21 stays to pull out of their sockets. In 1885, the wooden floor and wooden towers were completely rebuilt with steel. This was thought to strengthen the bridge; therefore the wind stays were not replaced. The flooring was destroyed by wind in 1889 when some of the stays failed. Immediately rebuilt using the identical plans. In 1898, it was used as a work platform during construction of a replacement steel arch bridge. The arch bridge, in turn, was wrecked by the ice floe of 1938.

Span = 1260 feet
Site Marking: Site obliterated by the two later structures.
Cables: Two main cables, each comprised of seven wire ropes, each wire rope 7 by 19 construction, making a total of 931 helical wires in each main cable. Augmented with a variety of wire ropes as suspenders, stays, and guys.
Wire Source: (a) Main cables - Richard Johnson & Nephew, Manchester, UK; (b) Stays - Rylands Brothers, UK

References for description:

1. William Maw & James Dredge, *Modern Examples Of Road & Railway Bridges*, (London UK, Engineering Magazine Press, 1872), 102;
2. George A. Seibel, *Bridges Over Niagara Gorge*, (Niagara Falls, Ontario, Niagara Falls Bridge Commission, 1991), 121-134.

64. (1870) Waco

Built across the Brazos river by the Waco Bridge Company. Engineer in charge Thomas Griffith. Opened January 6, 1870. Flooring replaced 1878 and again 1886. Totally renovated, and still in limited use in a park as a pedestrian bridge.

Span = 475 feet
Site Marking: Plaque at existing structure.
Cables: Fourteen factory-made wire rope cables manufactured by Charles Swan at the factory of John A. Roebling in Trenton NJ.

Wire Source: Roebling wire mill, Trenton, New Jersey

Reference for description:
1. Roger N. Conger, *The Waco Suspension Bridge*, (Waco TX, 1992 -reprinted from *Texana* Vol. 1, No. 3);
2. HAER Photos in Library of Congress Collection.

65. (1872) Branch Hill

Built across a county line over the Little Miami River in Clermont County and Hamilton County, Ohio in 1870-72. Designed and built by John Gray, who received a patent for his towers which were very unusual hollow metal columns filled with grout. (U.S. Patent 134,269, December 24, 1872). Demolished in 1914. Cable sample has been preserved and is being analyzed in 1999.

Span = 305 feet
Site Marking: Unknown
Cables: Two 3-inch diameter, parallel-wire cables, augmented with stays.
Wire source: Uncertain

Reference for description: Files of Ohio Historical Society, Columbus, Ohio

66. (1871 or 1872 ?) Gilchrist's Bridge at Inglewood

Private bridge across the Hudson River between towns of Johnsburg and Chester, New York, financed in 1871 by Robert C. Gilchrist of Charleston SC who had inherited the site. Located south of Wevertown. Designed and built by Charles McDonald of N.Y. City. Collapsed in 1873. Traces are said to remain at the site.

Span = Unknown
Site Marking: Unmarked; site uncertain
Cables: Two wire rope cables; manufacturer unknown. Possibly steel?
Wire source: Unknown

Reference for description: Rosemary Miner Pelkey, *The Life and Times of Robert Cogdell Gilchrist*, (Utica NY, North Country Books, 1993).

67. (1871 or 1872 ?) Warren

Built in 1871 or 1872 over the Allegheny River at Warren, Pennsylvania. Reported in the source found by Jakkula to have implemented "steel" wire ropes, which is very possible. If so, this would have been one of the earliest examples of the transition from iron cables to steel cables. Built by George Fishler? No other details.

Span = 430 feet? or 475 feet?
Site Marking: Unmarked?
Cables: Two main cables composed of seven, parallel, 2-inch diameter "steel" wire ropes banded together at the points of suspension. Manufacturer unknown.
Wire Source: Unknown

References for description:
1. *Scientific American*, Volume 30 Number 8 (February 21, 1874) 118, cited by Jakkula;
2. Files of Ohio Historical Society, Columbus, Ohio

68. (1872?) Harrison

Built in 1872? Over the Whitewater River on the state line between Dearborn County, Indiana and Hamilton County, Ohio. Apparently this was a "catalog" bridge designed by Roebling Sons. Built by James W. Shipman of Cincinnati, Ohio. Listed in a catalog of the Penn Bridge Co., Beaver Falls Pennsylvania, dated 1886, as having been built by J. W. Shipman, "Eastern agent" for the company.

Span = 420 feet; width 18 feet.
Site Marking: Nearby road is named "Suspension Bridge Road"
Cables: Two, 6-inch diameter cables comprised of "steel" (?) wire ropes.
Wire source: Roebling Sons wire mill, Trenton, New Jersey

Reference for description: Files of Ohio Historical Society, Columbus, Ohio

69. (1872) Turners Falls - Lower Bridge

Known locally as the White Bridge, (the color it was painted), this bridge was built by Charles MacDonald at what is now the lower end of Fifth Street adjacent to the factory of the Turners Falls Paper Company of Massachusetts. The bridge company was incorporated in 1870. Construction began in November 1871. Opened on May 13, 1872. Wooden towers and flooring? When the bridge was first opened it was limited to foot traffic as there was no highway approach to it on one side of the river. Replaced by a truss bridge after a severe flood in 1936. At the time of its replacement, the bridge was reported "perilous, with rusted strands and cables"

Span = Uncertain
Site Marking: Unmarked
Cables: Surviving photos show two main cables apparently comprised of seven wire ropes bundled together, augmented with diagonal stays. Possibly steel wire ropes, not iron.
Wire Source: Unknown

Reference for description: *Town Of Montague Massachusetts Historical Review 1754-1954*, (bicentennial program) 110.

70. (1873) Franklin

Built in 1873 over the Great Miami River at Franklin, Ohio by J.W. Shipman's Cincinnati Bridge Co.

Span = 365 feet
Site marking: Unmarked
Cables: Two, each comprised of seven 1-5/8 inch "steel wire ropes"
Wire Source: Factory-made wire ropes by Roebling Sons, Trenton, New Jersey

Reference for description: Files of Ohio Historical Society, Columbus, Ohio.

71. (1876) Linwood

Erected in 1876 at Linwood, Ohio near Cincinnati. Also known locally as "Union" Bridge. Designed and built by J.W. Shipman's Cincinnati Bridge Co. Listed in a catalog of the Penn Bridge Co., Beaver Falls Pennsylvania, dated 1886, as having been built by J. W. Shipman, "Eastern agent" for their company. One anchorage destroyed by floodwater in 1913.

Span = 350 feet; width 20 feet
Site Marking: Unknown
Cables: Uncertain. Possibly steel wire ropes.
Wire Source: John A. Roebling's Sons, Trenton, New Jersey

Reference for description: Files of Ohio Historical Society, Columbus, Ohio

72. (1878) Turners Falls - Upper Bridge

Known locally as the Red Bridge (the color it was painted) the bridge was completed in December 1878 above the falls at what is now the upper end of Second Street in Turners Falls, Massachusetts. Dismantled and scrapped 1942. Listed in a catalog of the Penn Bridge Co., Beaver Falls Pennsylvania, dated 1886, as having been built by J. W. Shipman, "Eastern agent" for their company.

Span = 550 feet; width 20 feet
Site Marking: One abutment on the north side of the river remaining?
Cables: "Roebling" wire ropes? No other details. Probably steel wire ropes.
Wire Source: Roebling Sons wire mill, Trenton, New Jersey

Reference for description: *Town Of Montague Massachusetts Historical Review 1754-1954*, (bicentennial program) 110.

73. (1878) Minneapolis - Version 2

Designed and built in 1877-78 over the Mississippi River at Minneapolis by Thomas Griffith, replacing the previous iron wire suspension bridge at the same site.

Span = 675 feet
Site Marking: Father Hennepin Bridge at same site?
Cables: Four main cables, parallel-wire, fully wrapped. Two cables of the cables each contained 3648 wires and two cables each contained 450 wires, assisted by diagonal stays.
Wire Source: Uncertain

References for description:
1. Thomas Griffith, *Van Nostrands Engineering Magazine*, (New York, March 1878), 248-251;
2. "The New Minneapolis Suspension Bridge", *Scientific American*, v.38, n. 3, (January 19, 1878) 31.

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In addition to published texts, much of the detail in this report rests upon extended research into several important collections of unpublished texts, documents and manuscripts at the following archives:

AS&W Collection, Baker Library, Harvard University, Cambridge, MA.

Ellet Collection, Transportation Library, University of Michigan, Ann Arbor, MI.

Engineering Societies Library (formerly New York, NY - now disbanded).

Hallidie Collection, California Historical Society, San Francisco, CA.

Roebling Collection, Alexander Library, Rutgers University, New Brunswick, NJ.

Roebling Collection, Folsom Library, Rensselaer Polytechnic Institute, Troy, NY.

Suspension Bridge Collection, Library of the Ohio Historical Society, Columbus, OH.