HOW ROEBLING DID IT:
THE BUILDING OF THE WORLD'S FIRST WIRE-ROPE SUSPENSION AQUEDUCT IN THE PITTSBURGH OF THE 1840'S

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Keywords: Wire rope, suspension bridge, Pittsburgh, PA Mainline Canal, John Roebling, aqueduct, Allegheny River

Abstract

John Roebling was arguably America's foremost early bridge-building genius. His very first structure using wire-rope for suspension was a wooden aqueduct. Built in 1844-45, it carried the Pennsylvania Mainline Canal across the Allegheny River into downtown Pittsburgh, the western terminus of the canal. Some three years earlier he had developed wire rope of a substantially different design for the Allegheny Portage Railroad, another part of the Canal He had hand-laid-up the first ropes near Pittsburgh on his farm in Saxonburg. The ropes for the aqueduct were 1100 feet long and were made from 200,000 pounds of #10 "charcoal iron wire" produced in Pittsburgh. The ropes for the aqueducts were laid up in place by traversing 3800 individual parallel wires across the Allegheny River and bundling the wires into cables. The heavy beams were almost entirely white pine. It is important to remember that the structure was built basically by horse and by hand without mechanical equipment other than block and tackle. A significant part of the cost of the structure included keeping "smithing fires" burning for 200 days!

Roebling's Arrival And Early Years In America

John Roebling grew up in the context of early 19th century Thuringia, in Prussia, a society in which answers to engineering questions grew out of a disciplined sense of order. There was definitely a "right way" and a "wrong way" to approach problems, and a sense of who was allowed to speak up with solutions. Innovation was not encouraged. To innovate one had to break out of the mold.

Roebling was apparently one of those who felt stifled by that mold. After a top-of-the-line Prussian engineering education and a short tenure in a low-level job there in Public Works, Roebling decided to give up engineering and emigrate to the United States. There he and some of his family and friends would establish a new community and a new life as farmers.

In 1831 they set sail together as part of a group of several hundred families, landing in Philadelphia. There was considerable confusion on the plans and the group began to splinter, some heading for nearby opportunities, others sticking with John as they made their way to Pittsburgh, Pennsylvania, west of the Appalachian Mountains, a journey taking some 4 weeks at that time. Under John's leadership, a group of only three, including John and his brother Carl, purchased almost 1600 uncleared acres of land some 25 miles northeast of Pittsburgh and settled what grew into the town of Saxonburg. In 1832 other families joined them and the community grew.

The area of Saxonburg was described by some as "wild and isolated, totally undeveloped, almost inaccessible." But Roebling himself described the area in letters back to family and friends in Germany as being a "rolling plateau with many fine distant views, considerable savannahs, fine meadows alternating with young woodlands and timber forests." He was trying hard to convince the less-venturesome to join them. "In earlier days of Indians and early settlers, great forest fires had destroyed the large dense forest." He said there was "good wood for fences" and encouraged them "above all things to bring an experienced young shepherd, with a pair of shepherd dogs, of which there are none here." [1]

But a most important aspect of this country was the emotional climate. Roebling said in a letter home that "Every American, even when he is poor and must serve others, feels his innate rights as a man. What a contrast to the oppressed German population." [1]

In 1832 Pittsburgh was already known as one of the major manufacturing centers in the United States, with important iron, wool and cotton works already established. The area was known as the best wood market in America

For the new immigrants, however, it was "first things first" : clearing the land, building homes, getting enterprise going, including brick-making, that was what occupied these families at first. In 1836 he was married and in 1837 became a citizen. But John turned out to be no farmer. His heart wasn't in it. Soon he turned back to engineering and found a job on the Sandy and Beaver Canal, a sub-unit of the major project in the region, the Pennsylvania Mainline Canal, connecting Philadelphia and Pittsburgh. The Mainline canal was begun in Philadelphia in 1828 and finished in 1835. Construction actually proceeded from both ends toward the middle.

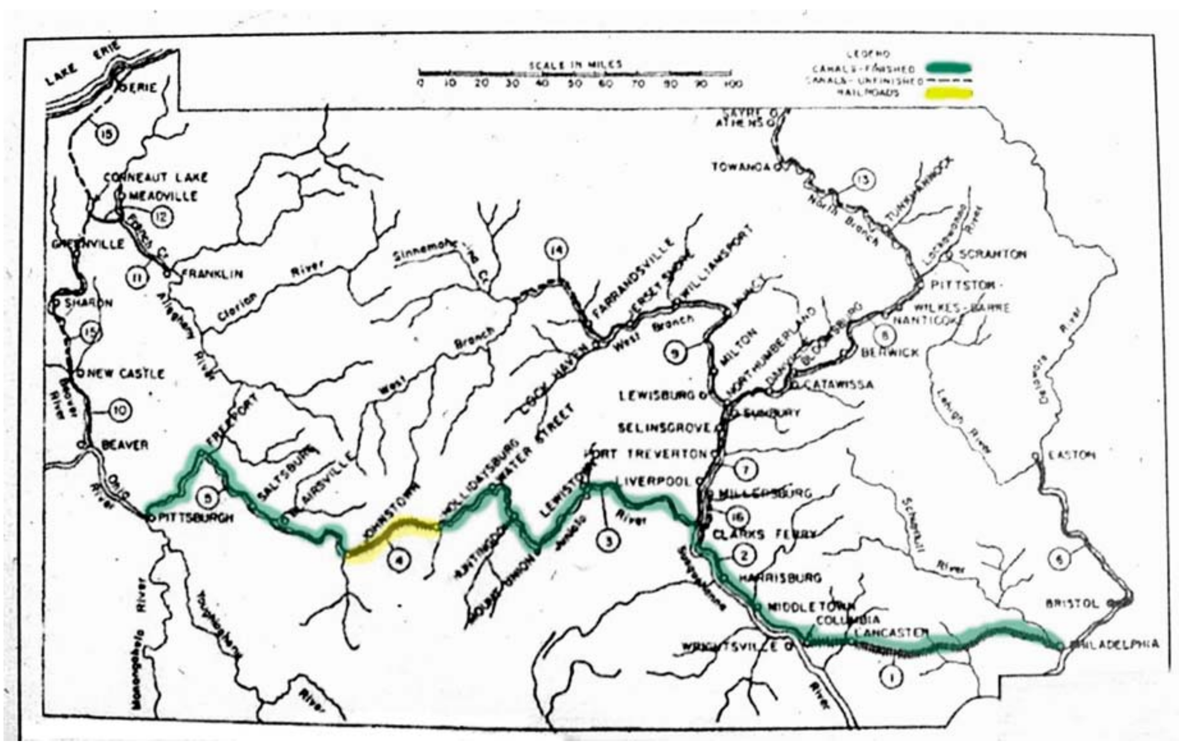

Figure 1. Map of PA Mainline Canal Route and Major PA Rivers. Green line shows canal; yellow shows Allegheny Portage Railroad.

Why An Aqueduct In Pittsburgh?

The canal route came down the north shore of the Allegheny River toward Pittsburgh. A major rivalry had grown up between "Allegheny City," now known as the North Side, and Pittsburgh proper, which occupied the Point and present downtown Pittsburgh. The big money interests in Pittsburgh wanted the western canal terminus to be downtown, on their side of the river, so the canal had to cross the Allegheny by aqueduct. A wooden structure on seven stone piers had served this function for the nine years between 1835 and 1844. During the winter of 1844 the structure was wiped out by an ice jam. Replacing the aqueduct quickly was an extremely high priority for the City fathers because the Canal was bringing thousands of tons of freight into the city. At its peak use and during the ice-free season, a canal boat passed a given spot on the canal every twenty minutes!

The Canal Commission in Harrisburg left the execution of the job to the City. In January-February, 1844, the State Legislature passed a bill authorizing the Mayor, Aldermen and people of the City of Pittsburg (sic) to rebuild or repair the aqueduct at their own expense, and then to exact whatever tolls they needed to pay for it. When the construction expenses had been fully recouped, the toll authority would revert to the Canal Commission. [2]. Dithering between Pittsburgh's Aqueduct Committee, the Canal Commission and Roebling consumed several valuable months of warm-weather construction time. Finally a $62,000 contract was approved for Roebling, acting as a sole proprietor, to remove the shattered remains of the old wooden aqueduct, repair the seven masonry piers/towers, and build a new aqueduct using wire-rope suspension, a radically new concept. Roebling accept the responsibility to provide debris removal, erection equipment, accounting, ordering, design, project management and personal responsibility for the entire project. There had been at least one competitive bid for less money and the loser conducted a fairly vigorous campaign in the editorial pages of the Pittsburgh Gazette to have his design reconsidered. But his efforts didn't catch the imagination of the City fathers [3].

On August 12, 1844, Roebling filed an acceptable 27-page handwritten set of specifications for the aqueduct with the Canal Commission, detailing the design, the materials and the calculations on which the design was based. The calculations are remarkably simple, but these are the basic principles for today's suspension bridges. By April of the next year, the job was done. Almost as soon as that job was complete, Roebling landed another contract to put in a suspension bridge over the Monongahela River less than a mile away on the site of the present Smithfield Street bridge, also completed in less than one year. And by 1859 he had built a second suspension bridge on the site of the present 6th Street bridge (one of today's Three Sisters bridges) [4]. In that bridge he used I-beams instead of wood for the major structural members.

An 1859 lithograph is one of the few views of Pittsburgh that shows it with all three Roebling structures spanning its rivers at the same time. Interestingly, the Roebling Smithfield Street bridge was replaced about 38 years later by the present iron double-lenticular truss structure, designed by Gustav Lindental, who went on to also design the Queensboro Bridge in New York. That bridge is within sight of Roebling's Brooklyn Bridge. Both are still in use today. Thus Pittsburgh was the proving ground for two of America's greatest bridge-builders.

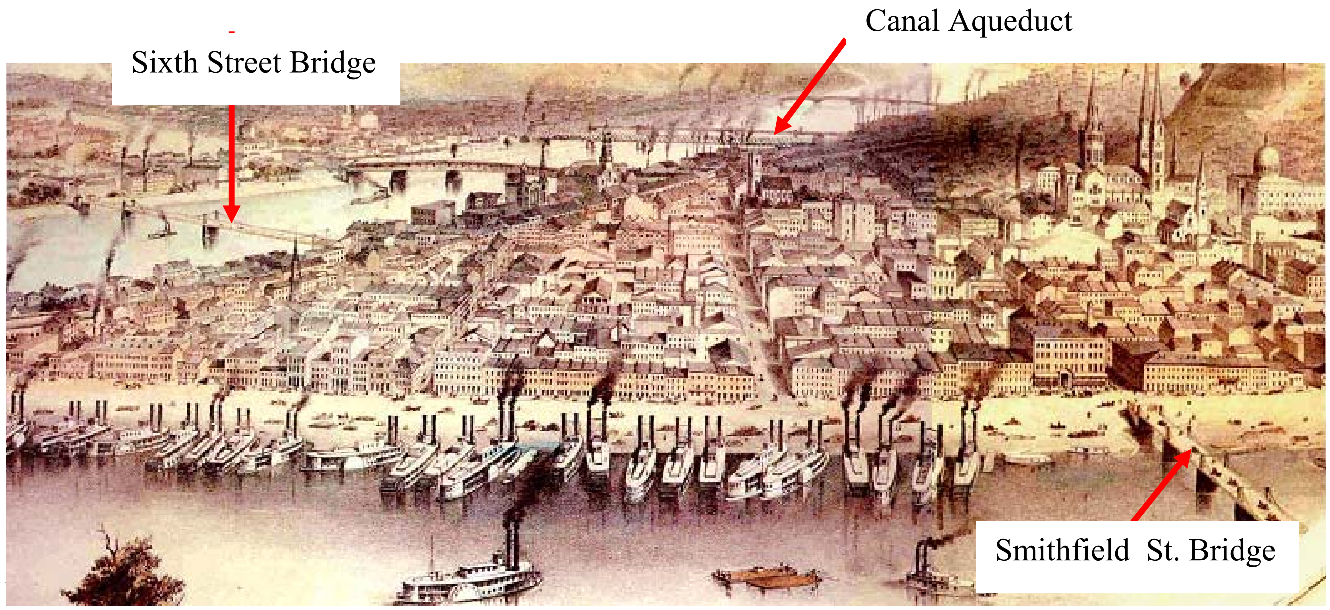

Figure 2. Roebling's Three Suspension Structures in Downtown Pittsburgh in 1859

An added point of interest in the lithograph above: note the 25 steam boats tied up along the Monongahela Wharf or out in the river. Steam was surely king on the rivers by this time.

Why Ropes? Why Wire Ropes?

Pittsburgh at that time was a major center of boat building, the boats being used for descending the Ohio to the Mississippi and beyond in the westward expansion of the young country. Ropes were a big feature of outfitting the boats and there were at least three rope walks in Pittsburgh for local manufacture of hemp ropes. The hemp was originally imported from the Philippines or Russia, but increasingly was grown in nearby Kentucky.

So, here is the first of many historico-materials features of this story: the Mainline canal used hemp ropes to haul the boats along the route of the canal as they were the only material available. When the canal reached the Allegheny Mountains, a unique engineering solution was proposed for traversing this major topographical obstacle. The boats were removed from the canal, each boat was split into two sections and pulled across the mountains on special railroad cars which rode up and down a series of inclined planes. This section of the canal was known as the Allegheny Portage Railroad (APRR), and Roebling had soon found his way to this interesting engineering challenge. (Today at the center of the route of the APRR, near the present-day town of Cresson, PA, there is a US National Park Service site preserving the history of this part of the canal). The canal boats were drawn up the mountains by stationary steam engines, then moved horizontally along the plateau by mules, then lowered down a second set of inclined planes on the other side. On one unfortunate day, Roebling saw two men die when one of the massive hemp haul ropes broke and the car got away. He reasoned that there were better materials solutions, and out of that grew the idea for iron wire ropes.

Hemp rope was traditionally hand-made in a "rope walk." This was a long open area in which the mechanical process of twisting or "laying up" the hemp fibers was carried out, a fairly labor-intensive process. But assuming you now want to make a wire rope and you already have space for a rope walk, the first order of business, if such a thing has never before been made, would be to acquire the appropriate wire. How would you do that, right there, right then?

Roebling had begun answering those questions for the Portage Railway in 1839. By 1841 he had solved many of those problems at least in a preliminary way and wrote up a patent application for his rope-making process, titled "*A new and improved mode of manufacturing Wire Ropes*" [9]. He had used wire-ropes on the Portage Railway which he had made at his farm in Saxonburg and had also begun to sell ropes elsewhere. But there's a great deal more to an aqueduct than just wire ropes.

Two questions present themselves: first, a general one: how does a genius such as Roebling translate his *idea* into on-the-ground *reality*? And more locally, what was the "cultural milieu" in Pittsburgh for performing this sort of major engineering feat? What did Roebling have to work with as he went from concept to finished job? That is, while the availability of iron wire is the first question, what about all the other components Roebling would need to do the job when he got the contract to build the structure in this post-frontier 1844 town? Not only material things, but skills to help fashion the materials into the finished structure? What were people thinking about? What did they do as routine? When they wanted to build something, what was available locally? Specifically in Roebling's case, to repeat, was it possible locally get wire of the proper quality in a timely fashion?

Consider the flow of history up to that point: Roebling's work was conceived only about 80 years after the French and Indian War opened right here. Construction of Fort Pitt, a major piece in that "first world war," as Winston Churchill had dubbed it, had begun in 1758. It was the largest fort in the entire British Empire with a garrison space for 1000 men. Political changes had caused that fort to be turned over to the colonists in 1772, but the Indians didn't give up on trying to hold on to their ancestral lands until finally quelled by "Mad Anthony" Wayne's expedition in 1794, when General Wayne led a expedition against the Native Americans. "*He so defeated the Indians as to forever relieve Pittsburgh from the devastations and raids to which it had always been subject*." Note that this took place just about 40 years before the PA Mainline Canal opened to Pittsburgh from Philadelphia and 50 years before the Roebling aqueduct was built. In that same interval the city grew from just a few dozen to over 40,000 people. Things changed fast in those days! Civilization had a firm foothold here, but it hadn't been so long since life had been much more tenuous. 12 years earlier Roebling himself had been clearing the forest on the land he bought only some twenty miles from Pittsburgh.

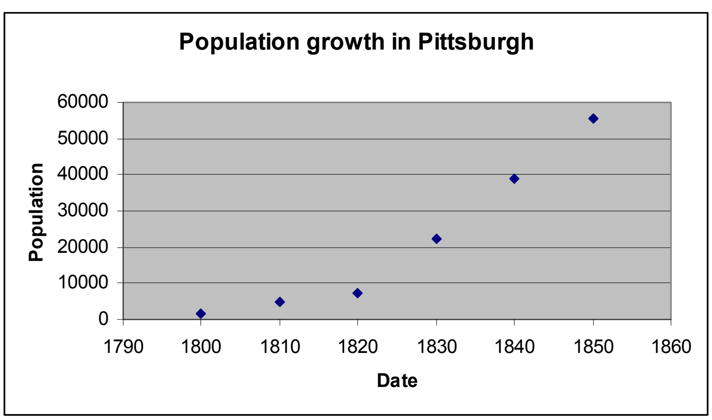

Figure 3. Population statistics in Pittsburgh, 1800 through 1850

Engineering Pittsburgh in the 1840s

So what was it like here in Pittsburgh in an engineering sense when Roebling signed the contract for the aqueduct?

Pittsburgh is fortunate to have had several dedicated private "business census takers" who put together city directories as early as 1815 [5]. The town had less than 5000 residents at that time, but the directory showed that of them a remarkable percentage were involved in engineering-related businesses. For example, Robert Fulton's second steam boat had been built here in 1811. The first had been built on the Hudson River. Here's a short history of Fulton's early boat building activity:

…After building his first steam boat in NY Fulton designed larger boats for the waters of New York State and Connecticut. Fulton and his partner, Robert Livingston recognized the importance of Hudson River and Long Island Sound opportunities. They saw, too, the very great opportunities that were open in navigation of the western rivers and lakes. In 1810 Nicholas J. Roosevelt, with Fulton and Livingston, organized a shipyard at Pittsburgh, and built the first steamboat ever floated upon the western rivers.

This boat was named "New Orleans" and was 116 feet length, 20 feet beam, and the engine had a cylinder 34 inches diameter. The cost was $38,000. The "New Orleans" started upon its first voyage in September, 1811. She had an exciting trip,…reached her destination safely, and afterward operated regularly between New Orleans and Natchez.

Fulton realized the importance of the great river waterways and the part they were to play in the opening the Middle West.. In 1816, the fleet of passenger and freight steamboats on the Mississippi River and its tributaries totaled 326,443 tons, supplying economical and fast transportation, and a service which was very largely responsible for the opening of great new territories. [6]

In the years following the building of Fulton's "New Orleans", the Pittsburgh Steam Engine Company had become a significant feature of the local "mechanical landscape." Associated with this firm one could order anchors and anvils, brass bells and machinery. There was a pattern-maker's shop and a boring and turning shop. Screws made locally were available. You could even buy complete steam engines on Watt's or boats on Fulton's plans.

So community preparation for Roebling's debut suspension structure had begun years before, though those involved probably had no idea how important their work was to the future. In 1794, the Irwin Rope Walk was operating in Pittsburgh; they moved to Western Avenue in 1813 in Allegheny Town, on the north side of the Allegheny River. They made everything from wrapping twine to the largest ships cables, with 14 men working there. There was another rope walk in East Liberty. By 1829 there were two Rolling Mills, the Pennsylvania and the Juniata, the latter on W. Robinson Street on the North Side, employing 60 men. There were engine builders and wagon makers; you could buy iron rods and nails easily. There was a paper mill in town in 1832. Iron wire was being made by R. Townsend nearby in New Brighton; he ultimately supplied Roebling with half of the wire for his ropes. Another wire factory was run by William Eichbaum, Sen.; he had started this business in 1810. [5]

More detail on the development of Pittsburgh's engineering infrastructure is contained in Appendix A.

The Wire-Rope Design Controversy

There has been a good deal of confusion about the specifics of the wire rope Roebling made for use in his aqueduct.

Wire rope of strength equal to that of hemp is lighter, smaller gauge and much more durable, lasting years as opposed to one or two seasons exposed to the elements. The individual wires can be coated with a varnish on manufacturing and then the whole rope oiled once or twice a season to minimize oxidation. An interesting consequence of is its smaller cross section is its lesser wind resistance, an important feature in a sailing vessel. It is also much more elastic than hemp, meaning that it withstands a sudden strong load without snapping.

In 1839 when Roebling first began solving the problem of making wire rope from iron wire for the Allegheny Portage Railroad, he was intending to use it for a running line, that is, one which would be in motion, as opposed to a standing line such as the stays on a sailing vessel which hold the masts in place. Thus his first rope had to be not only strong but flexible, able to pass around a sheave or pulley. It had to be able bend but not "take a set." Thus the individual wires and the collected group of wires had to have very particular material properties. He developed and patented in 1842 (US Patent # 2,720) a method for the "*spiral laying of the wires around a common axis without twisting the individual wires*" while also having them each "*under a uniform and forcible tension under all circumstances.*" In other words, they would each bear a common share of the load on the rope. They would be "in contact with one another over the entire length of the rope, thus to a great degree excluding air and water, preventing corrosion. "[6]

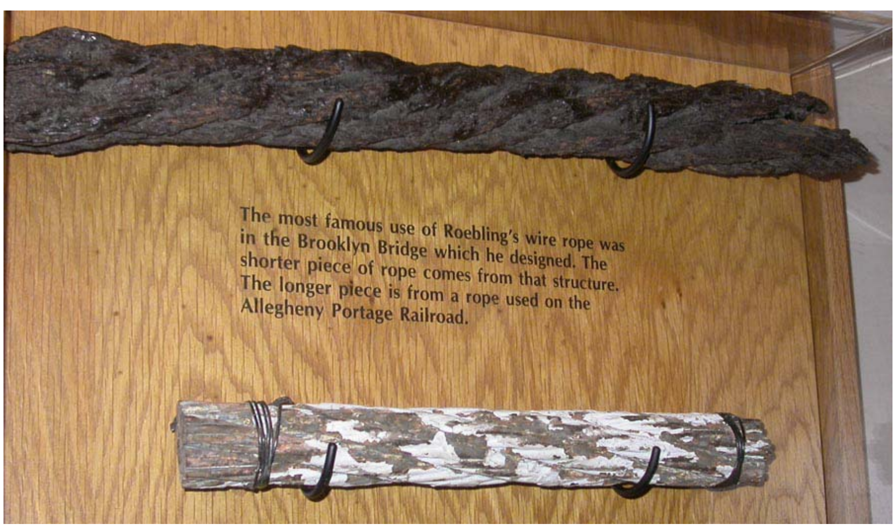

Figure 4. Original Roebling wire ropes on display at the Allegheny Portage Rail Road site in Cresson, PA. Note that the top rope, from the APRR, is twisted, as per the above patent description. This was an early "hemp replacement," possibly laid up on the Roebling farm. Note also that the bottom rope, purportedly from the Brooklyn Bridge, is much smaller than the "cables" of the bridge and is also twisted. This suggests that it may have been a "hanger" rope, not part of the major suspension cables, which are still in place. Those ropes were either "spun on site" or made in the factory in Trenton, NJ.

Only a few years after the Pittsburgh "aquaduct" (as Roebling spelled it) was built, he wrote up specifications for a structure on the Delaware amd Hudson Canal which he said was "in all parts similar to those of the Pittsburgh Aquaduct." This canal was intended to carry anthracite coal to New York City. The Delaware aqueduct is still standing, although it is now used for automobile traffic. Roebling specified that "None but the best Charcoal iron wire is to be used for the cables." "Each strand of the cable (was to) be well varnished before it goes into the cable and the latter as well as the wrapping to be well painted." The cable would be 8 ½ inches in diameter including wrapping. [7]

Reobling's first US patent in this area , #2720 mentioned above, is titled "**Method of and Machine for manufacturing Wire Rope**," dated 1842 [6]. One would think this one would completely nail down any questions about this subject, but it doesn't. His 1847 patent, #4745, titled, "**Apparatus for Passing Suspension-Wires for Bridges across Rivers &c**." [8] includes the claim that "The above mode of traversing wires, has in its main features been successfully applied in the formation of the cables of the suspension aqueduct in Pittsburgh, constructed by me." And these two patents seem to be contradictory in the design and construction of the rope itself. The issue is whether the cables consist of twisted or parallel wires, individual wires or multi-wire strands. His writings on this subject use several terms that need definition:

> *Skein or Wire*: a skein is a short piece of wire. The skeins are "spliced" together to make very long wires. The specific manner of splicing at the time of the Aqueduct is unclear.
>
> *Strands*: Multi-wire ropes. In the 1842 patent, great stress is laid on the manner of achieving equal tensile stress in each wire within a strand and of laying up the strand without applying torque stress to the individual wires in the process of laying up the strand. Thus, in 1842 there is no question that twisted wires were the norm. The drawing in this patent shows a twisted strand being wrapped by the machine he was patenting. The wrapping was done with a single wire wrapped tightly around the twisted strand. The rope is greased while it is being wrapped.
>
> *Cable*: In the 1847 patent, describing how to get the wires across the river, the method said in the patent to have been used in Pittsburgh, a single endless wire ("composed of a great many skeins, spliced") is passed across the river as an individual wire, back and forth from reels on either side and anchored at each end by passing around a cast iron "segment." In this description there is no mention of twisting or of strands. These individual wires were gathered into a "wire cable," but that process is not described in detail in the patent. By contrast, in Roebling's description of the Delaware and Hudson (D&H) Aqueduct in eastern PA cables, he details the number of wires in each of seven strands. [9]

In a long letter written in 1926 by Washington A. Roebling (WAR), John's illustrious son, the man who actually executed his father's plans for the Brooklyn Bridge after his father's tragic death from lock-jaw, WAR recalls "**The Early History of Saxonburg**," the town founded by his father. WAR describes the manufacture of wire-rope in a rope walk set up near their family home, some twenty miles north-north-east of Pittsburgh. He tells very briefly of neighbor men hired to work in the rope walk, the joining of individual short wires into longer ones, the laying up of strands of wires and the final laying up of a completed rope from those strands. However, these ropes were used in projects other than the Aqueduct, in which the cable was "spun on site." He gives no details of rope design [10].

In an unpublished manuscript, including a cover letter to the US Commissioner of Patents, Henry L. Ellsworth, Esq., dated 27(?) Mar 1841, Roebling describes his invention as consisting of "*any number of wires laid parallel to each other, so that they form a round cylinder, and occupy the same positions respectively for the whole length;… Wire ropes manufactured in the above manner, will likewise be superior to twisted wires ropes for all purposes which do not require short chord bendings over small wheels or pulleys. All the wires being placed parallel to each other, uniformly strained (sic) throughout and not twisted, the greatest strength will be obtained by the least quantity of material"* [11].

A source of more contemporaneous information on this subject is Roebling's own unpublished **"Notes on Suspension Bridges**". In these he speaks of his design for the D&H aqueduct as being " in all parts similar to those of the Pittsburgh Aquaduct (sic)". (Box 10, folder 6, RPI Archives) In the D&H he used seven strands to form the cable, each strand including from 270 to 325 individual wires. The cables were "*spun in place without support*," apparently using the method described in the 1847 patent. Following the completion of the cables, then the timber cross frames were hoisted into place from barges in the river below and the remaining suspended structure laid down. Again, he does not mention twisting the wires to form the strands or the strands to form the cable [12].

In the Nov 1845 issue of the **Journal of the Franklin Institute**, published just a few months after the Aqueduct was completed, Roebling reports that for the Allegheny Aqueduct the cables were composed of 1900 1/8th inch individual parallel wires, each 1175 feet long, compacted into 7 inch cables. "*Great care has been taken to assure equal tension of the wires. Oxidation is guarded against by a varnish applied to each wire separately, their preservation, however, is insured for certain by a close, compact and continuous wrapping, made of annealed wire and laid on by machinery in the most perfect manner. … for the first time successfully applied*." This undoubtedly refers to using the cable-wrapping device he patented in 1842, and as mentioned above that patent shows twisted cable. He doesn't mention "strands" in this article. But the words of the text confirm that the aqueduct was made from parallel-wire cables, a "standing" application [13].

Finally to close this issue Roebling's article in the **American Railroad Journal and Mechanics' Magazine**, (Nov, 1843), gives a clue to the puzzle when he distinguishes between ropes to be used for "running" or "standing" purposes, to use the nautical terminology. Wire cables for standing applications (such as in a suspension structure) could be manufactured by laying up parallel wires as they didn't need to have any substantial flexibility. On the Allegheny Portage Railroad inclined planes, fundamentally a running application, flexibility had been vital and thus a twisted construction would have been important. [14]

Roebling states that "wire rope can be spliced in the same manner as hemp rope." [14] p. 324, speaking of the manufacturing process for twisted rope. Splicing in hemp ropes involves opening up the twist on the running ends of the two rope segments to be attached to one another and interweaving the strands of both ropes over a shot distance on each rope. This makes a small bulge in the area of the joint. The strength of the splice comes from the squeezing-down of the strands on one another as the force is applied pulling on the joint, much like the old Chinese finger-trap that becomes tighter and tighter as you pull to get out of it. The problem is that twisted ropes are not used for suspension cables on Roebling bridges. What has to be learned is how to make a single wire "endless," since they are the basis for making "parallel wire" suspension cables.

The only reference thus far found considering this issue in detail is the unpublished patent application of 1841 for the "new and improved method of manufacturing of wire rope," handwritten by Roebling. Here he says:

"The joining of wire strands, (sic) can be accomplished by annealing from 3 to 6 inches of the ends and twisting them around each other in a spiral manner, while held in a vice, (sic) and then squeezing the joint straight and round. Or the wire ends may be flattened, roughened and united by wrapping fine annealed wire around. Or they may b connected by simply forming loops or tying knots. The first described joint answers the purpose very well." [11]

This first method sounds like a crude pressure weld. This may have been one of the reasons for the 200 days of "smithing fires" that had to be maintained during the bridge construction. The smiths were perhaps responsible for creating the "endless wires."

Some further clues to way the wire was used for making the cables comes in a list of the men involved in the job. This list comes from one of the many small notebooks in the Roebling Collection at RPI [15].

16 men splicing	(The first three categories of men may have been the
2 men filing	"splicing crew." The function of the "breakmen is
2 breakmen	unknown)
4 shoemen for Pittsburgh side	*(*These men were perhaps involved in attaching
3 shoemen on Allegheny side	the wires to the anchorages*)*
2 regulators on center pier	
4 to lift wires on #1 and #3 piers	
1 driver	
1 foreman	

This makes a total of 35 men for "running out" the wire for the cable. Roebling notes that it took 4-4 ½ days to make a strand, or about two months to make the cables for the aqueduct, assuming seven strands per cable as per the reference on the Lackawaksen aqueduct. [9].

An interesting omission in the 1847 patent on traversing wires across rivers [8] is that no mention is made of the process of setting up the endless wire-rope from which the whole cable-spinning device is suspended. It appears to be assumed that anyone could do that, just using common sense. This patented device actually appears to be a glorified "breeches buoy," the age-old means of transferring people or goods from ship to shore or to another ship at sea. This is set up by launching a light throw-line from one ship to another, attaching the throw-line to a heavier line capable of carrying whatever the load will be, making that heavier line fast between the two ships and then sliding back and forth, perhaps on some form of trolley. Presumably in the instance of the Allegheny Aqueduct, someone simply ferried a light line across first, then followed that with heavier lines, finally spinning the cables from individual wires towed back and forth from side to side by horsepower, following Roebling's patented method. In another aside, today's professional tree-climbers have a clever modification of this light-line-pulling-up-a-heavier-line technique: they sometimes use a glorified and very large commercial sling-shot to launch the light throw line over a branch high in the tree!

Design of the Aqueduct Anchorages

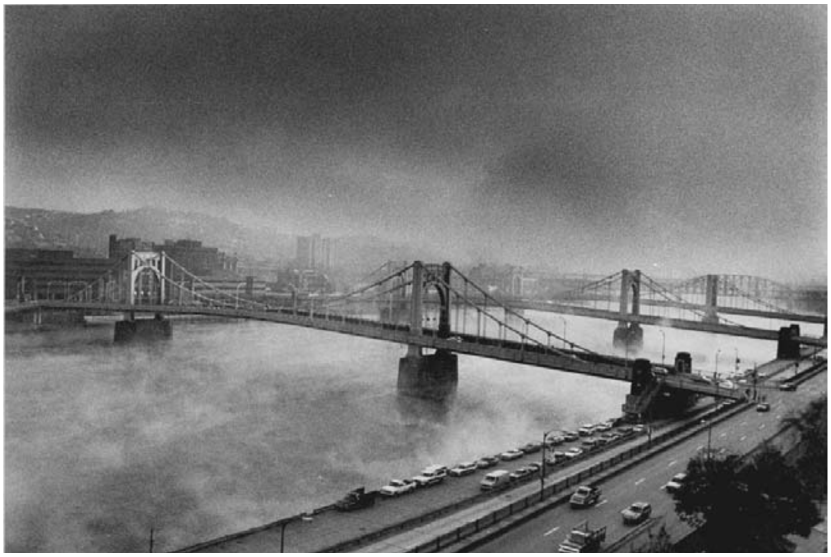

Photo by D. L. Gibbon

Figure 5. The Three Sisters – 6^{th}, 7^{th} and 9^{th} Street Bridges. Pittsburgh, 1987

The anchoring of the cables is unique and complex. For comparison, consider the Three Sisters bridges in Pittsburgh (above), three much-admired features of today's downtown Pittsburgh riverscape, and built in 1927-28 immediately adjacent to the former site of the Aqueduct. These bridges are called self-anchored suspension bridges, quite literally "free-standing", not anchored into the ground. Their chain-cables are tied into the ends of the arched beams which support the roadway, creating a self-supporting tension/ compression unit. Thus there is no heavy anchorage or abutment [16].

Roebling's design, by contrast, was dependent on support from heavy cast-iron and masonry anchorages. The cables themselves did not extend below ground, because corrosion was a constant concern. Instead each cable was attached to a cast-iron anchor chain which followed a curved path below ground to tie into a six-foot square anchor plate; itself covered by "700 perches of masonry." A "perch" in a 1913 version of Webster's dictionary is given various definitions from 22 to 25 cubic feet of stone, calculated to be twice the total mass needed to resist the greatest possible stress ever to be applied, including the weight of the cables themselves (110 tons), the wooden structure (975 tons), the water (2,100 tons) and the canal boats [17]. Of course, the vast majority of that load is carried down into the ground through the cast iron saddles on the top of the seven stone piers, not transmitted horizontally through the cables into the anchorages. Interestingly, at this point in engineering parlance, the word "strain" was used for "stress."

The Materials And Construction Of The Aqueduct

It is particularly interesting from a materials point of view to look at the components of the Roebling patents cited here [6,8]. The "sheaves" or pulleys are made of "wood" or "wood very light." The groove in the pulley is "made" (I presume this means "lined") with "sheet tin." While the endless rope could be made of "hemp, a wire rope, which would not stretch, is much preferable." The suspending arm for carrying the wire across the river, made of “wood or iron,” is attached to the rope by means of “twine.” The attachment of the arm to the guide rolled is made with “inch pine board.” The whole device is driven by a horse turning a vertical shaft. To pull the wire in one direction, the horse goes clockwise, the other direction, counterclockwise… no gears!

Roebling was very cognizant of the potential for corrosion of the cast iron anchor chains. He took pride in designing the materials of the system to avoid this. The anchor chains were painted with red lead, then embedded in and surrounded by cement. The masonry was sealed with cement and “common lime mortar.” The preservation of bars of the anchor chains was “rendered more certain by the known quality of calcareous cements to prevent oxidation. If moisture should find its way in to the chains, it will be saturated with lime and add another calcareous coating to the iron”. In addition, he stressed that oak beams in the anchorage were not to come in contact with the cast iron, as the tannic acid in the oak would have promoted corrosion. So pine was always the only wood to touch the anchor chains. [13]

The “trunk” of the structure was attached to the cables through a series of threaded U-shaped iron rods, bolted through the timbers. Wire-ropes were not used for this purpose, although rope was so used in many other bridges at other sites. The beams of the structure were of white pine, while some of the decking was white oak. The pine beams were up to 27 feet long and 6x16 inches in cross section.

Because of the newness of suspension construction in the civil engineering field, numerous questions were raised in public to cast doubt on the safety and reliability of the aqueduct. Roebling was nothing if not conservative as an engineer. He calculated and then in some cases actually demonstrated that the structure could stand alone if the wooden part of one or more of the seven spans were consumed by fire; that is, the aqueduct was not structurally dependent on the wooden components of the structure. He was also reckoning that the wooden structure might need to be replaced at some point because of deterioration from constant exposure to the water, just as wooden ships’ hulls have to be replaced. Because of the conservative design, removal of an entire span would not endanger the rest of the structure.

Summary of Materials Used in Aqueduct

Charcoal iron wire
White Pine beams
Cast iron anchor chains and anchor plates
Cast iron “pyramids” and saddles
Sandstone masonry and fill rock
Mortars and cements
Iron bolts and nuts
Tar and pitch
Twine and hemp rope
Oil, red lead and varnish
Water
Blacksmiths, smithing tools and charcoal
Picks and shovels, saws
Grindstone
Forged iron pins
Block and tackle
Masonry and carpentry tools
Oak woodwork in anchorages

The Aqueduct Construction Process

In the spring of 1844 the following ad appeared in the *Pittsburgh Gazette*, the *NY Plebian*, the *Baltimore American,* the *Philadelphia Pennsylvanian,* the *Boston Post* ,the *Harrisburg Union and* the *Cincinnati Enquirer*:

TO ENGINEERS: a premium of $100 will be paid for the best plan and complete specification of an aqueduct with wood or iron Trunk, either suspended or supported, to be constructed on the piers now standing in the Allegheny river opposite this city, provided the same be handed to the Mayor of this City on or before the 20th of June instant. For further particulars, apply in person or by letter to R. Galway, chairman of Aqueduct Committee.) [18]

Just why the phrase "suspended or supported" is included in this widely advertised request for proposals (RFP) is unknown. Perhaps Roebling helped to write the ad. But whatever its origin, Roebling's suspension design was selected from among many entries, with a contract price of $62,000. Roebling's wire-rope business was already thriving, quite apart from its successful application on the PA Mainline Canal. Shipping interests had immediately recognized its exceptional value in maritime applications. But here was a major departure: a structure rather than simply a wire rope. It was quite a gamble for the City Council.

On July 30, 1844 the PA Canal Commission approved the design adopted by Chairman Galway's Aqueduct Committee of the Pittsburgh City Council. Roebling presented his specifications to the Commission for their final approval on August 12, 1844. The job was to be completed by April 1, 1845 [2]. The job included removal of the remains of the demolished prior aqueduct, refurbishing of the old stone piers and the construction of the new structure. Never having built a major bridge of any kind before and certainly never having built a suspension structure, Roebling now had just eight months to build his first one with the skeptical eyes of the City and the state's engineering community on him.

While Roebling was an obsessive note-taker and a scrupulous planner, as far as we know he did not leave any time-lines or PERT charts for project management on this job. However we are blessed that he kept his own punctilious accounting ledger [19]. Many of the details of project management, personnel, costs and financing can be inferred from the penny-by-penny double-entry accounts made in this ledger. We know when and what his suppliers brought to the job, so assuming a fairly primitive just-in-time delivery system, we know how the job proceeded.

One of the most interesting things is that there was often a three month gap between receipt of the merchandise and payment in full. Evidently Roebling's credit in the community was quite good. A number of employees were not even paid for their labor for two or three months, evidence of a high level of trust… or perhaps of a lack of other employment! Somehow he kept them on the job

Let's go through the ledger and see some of the details.

The very first entry is September 2, 1844, acknowledging the receipt of two logs, 50 and 47 feet long from Judge Warner. On September 8 Roebling took delivery of *½ dozen spades, ¼ dozen shovels, 2 picks and 1 pair blocks*!!

Imagine the opening scene at the construction site here. The canal has been in place up to and past this point for some eight years already. The trunk of the canal comes right up to the edge of the river. The water in the canal must have been cut off, presumably at locks above and below this point, when the aqueduct went out in the previous winter. The seven piers are still standing in the river, topped with the debris from the ice jam. The job now is to re-connect the ends of the canal on both sides of the river, almost a quarter mile apart. Some of the first items brought to the site were the "heavy earth-moving equipment" (the picks, shovels and spades) and some means of mechanical advantage for picking up those heavy logs, beams and stones (a pair of blocks).

It may be interesting to note here that the three hundred mile ditch between Pittsburgh and Philadelphia (aka the Mainline Canal) was said to have been dug largely by hand by some one thousand Irish men. So the digging of the very large Aqueduct anchorage holes with picks and shovels was certainly not something particularly notable in this day. Fortunately the aqueduct site is in the Allegheny's flood plain, so that the anchorages were dug generally in unconsolidated alluvium rather than in-place shales and sandstone of the nearby valley walls.

In short order after that starting point in September Roebling received lumber, cement, posts, hammered links, anchor chains, 1040 feet of oak timber, importantly including <u>masts</u>, not for ships but for cranes. Those masts will become the cranes which would use the pair of blocks for lifting heavy weights. Evidently the first order of business was to have the anchorages prepared. Those picks and shovels would dig the holes into which the heavy anchor plates would be placed, the plates to which the anchor chains would be attached and on which the 700 perches of stone would be placed. But first he would have to have the holes in the ground.

In late September 140 bushels of cement arrived, delivered by John Linton

In early October, pins were delivered for attaching the cables to the chains. And soon the stone started arriving. Roebling had specified that the pier repairs would be carried out with the "*hardest and best sandstone which can be had on the Allegheny River about Freeport (PA)"* [20]. James Stewart, of Allegheny City Quarrying Stone delivered loads of stone to both the "Allegheny anchorage" and the "Pittsburgh side." A. Smith of Allegheny, delivered 255 perches cut and backing (facing?) stone for piers and abutments… that's almost 300 cubic yards of stone!

Over the period from October 7 to December 14, Dennis McKelby was credited with weekly deliveries of stone totaling 708 perches of building stone, 12 perches of cut stone and 44 perches of Abutment and pins, all paid for on account. In other words, Roebling's credit was good in this community. He was getting his materials, but not paying for them up front.

William Paul was credited with having provided 2063 cubic yards of excavation on the Allegheny and Pittsburgh sides, apparently at 10 cents per yard, for he was paid $206.30 While this work was done in October and November, 1844, it wasn't until April 10, 1845, that the bill was fully settled.

Starting on October 29, 1844, four City bonds for $1000 each were provided to S. M Wickersham in beginning payment for about half of the wire for the cables. Ultimately 104,000 pounds of #10 wire and 6725 ½ pounds of #14 wire were delivered by him at a cost of some $11,000.

Another vital page in the ledger is devoted to R. Townsend and Co, suppliers of the other half of the necessary wire for making the cables. The first entries here are two debits starting on October 30 for a total of $8,000. He delivered 100,246 ½ pounds of #10 wire, 3440 pounds of #14, 150 pounds of #22 and 50 pounds of #13 rivets, for a total of $10, 566.44, almost the same amount of wire and the same amount of money as for S.M Wickersham, listed above. Perhaps Roebling was being cautious, maintaining two suppliers for this vital ingredient in the project. .

One of the most interesting pages in the ledger is headed "Acct with the City." This page lists a debit of $62,000 on October 26th and bonds for varying amounts credited between then and September 19th, 1845, in total amount of $60,000. Roebling started paying for his wire some three days after these bonds began being issued.

By December heavy timbers started being delivered: 260 beams 27 feet long were brought to the site, paid for by a check on the Merchants and Manufacturers Bank to Sam Frandin, Timber Contractor. These were to be the transverse beams that supported the trunk of the aqueduct. The beams were cut to order for length, but still had to be worked for use in the structure, as described below in the Specification submitted to the Canal Commissioners:.

> *"The beams will be 27 feet long, 6x16 inches, and are to be arranged in pairs, at a distance of 4 feet from centre to centre of pair, each 2 beams to have a space of 4 inches between for the reception of the dovetailed tenons of the posts. The stringers at the corners of the trunk to be 15 inches x 7 inches, rabbited inside for the reception of the first bottom course (of planks) and notched below 4 inches deep, for letting the beams in*." [15]

Ultimately about 500,000 "BM" (board measure?= board feet?) of timber were to be used in the aqueduct. About this same time <u>*1 grindstone*</u> was delivered, an interesting and vital device not present on many construction sites today.

On December 21, 740 bushels of lime were delivered: the mortar and cement were being prepared for sealing the anchorages and grouting the piers. Henry Anshutz was paid in December for patterns and castings for the cast iron saddles to crown the seven piers and support the cables; they had to be in place before the cables would be started.

On January 3 160 gallons of linseed oil were delivered, a sign that the cables were being spun. The cables had to be in place before the wooden structure could be fairly begun, since the cables were designed to support the structure.

On February 7th Isaac Claus delivered 3200 pounds of thread for caulking the trunk of the aqueduct to make it water tight. About three months remained until the contract deadline. The cables must have been completed or almost so.

Now consider this: in the previous winter a wooden aqueduct built on these same piers had been wiped out by an ice jam. The new aqueduct was not designed to have significantly greater clearance over the water than the old one. Ice was (and still is) a fairly common feature on the Allegheny River (see the photograph below, taken on January 1, 1990, near the aqueduct site). Now the construction crew was required to be out on the river stringing wire 3800 times, back and forth, to create two seven inch cables 1100 feet long, each with 1900 wires in them. The timbers were said to be put into place in the structure from underneath, presumably picked up by cranes from above off the boats.

The timbers were fixed in place with wrought-iron spikes. One line at the end of the entries in the "Table of Aquaduct (sic) Exp(enses lists "Boats, Cranes, and River Exp." at $1000 [19], which comes to about 1.6% of the total cost of the job. In my estimate, though a small percentage of the total cost, this was one of the key challenges in the whole job: doing the river work in the winter time. It would be extremely interesting to know just how this was done, for example, if any of this work was handled by steam boats or if cable ferries were used.

Photo by D. L. Gibbon

Figure 6. Ice on the Allegheny River, January, 1990. Note shadow of Three Sisters bridge on the ice.

The timing is fitting together here. On February 24th 1070 screw bolts and nuts were delivered. These were for fastening the suspension rods through the beams. In mid-March 196 rods were delivered. These apparently were to be fashioned into the suspension rods.

Rope, cords and twine were brought in February by James Rowley, followed in April by 24 barrels of pitch In late February 70 pounds of coal tar was delivered from the City Gas Works, probably a by-product of making "town gas" from coal, a process only stopped in Britain in the 1970s when natural gas became available from the North Sea. The tar was used for sealing parts of the anchor chains and cable.

One of the latest bills of all is for the caulker who probably used the caulking twine and the pitch to do his job. Also in late March is a substantial bill for the black smith and the cost of keeping three smithing fires going for 200 days! The smiths were also responsible for using the grindstone noted earlier to keep woodworking tools sharp. Also near the end of the list is the cost of 6 wrapping machines to wrap the cables according to the 1843 Roebling patent. The job was almost done.

Opening of the New Aqueduct

On April 23, 1845, the editor of the Pittsburgh Daily Gazette happened to be walking in the neighborhood of the aqueduct and was surprised to find it nearly complete. The second layer of planking on the floor of the trunk was down on two of the seven spans and a clear idea could be gained about what the structure would look like. The editor commented that in the press of other events, the aqueduct had almost been forgotten by the public.

Most important of those "other events" had been a catastrophic fire in the downtown Pittsburgh area which had destroyed 1100 buildings, including most of the public offices, the major hotels, many factories and most of the city's warehouses. It was a disaster of major proportions. It took out the important covered wooden bridge across the Monongahela River at Smithfield Street. Roebling got the contract to replace it as a suspension structure before the aqueduct was even finished!

On May 5th the paper carried a notice of the near-completion of this "noble structure." The only thing holding up progress on the project was the difficulty obtaining workmen to complete the calking (sic) of the trunk. There were 25 men already working at that job.

On Thursday, May 22nd the first trial introduction of water into the trunk was attempted to check for leaks. Remaining leaks were closed and the trunk was finally filled. A collective sigh of relief was heard as the 2100 tons of water poured into the structure and it held under the load. A band was in attendance, playing late into the evening and a large crowd of people milled about to see the show. The job was complete. Soon canal boats resumed bringing the precious freight into downtown Pittsburgh after over a year of interruption.

Reobling's ledger shows that the total cost of the Aqueduct was $58,297.The paper noted that Roebling was reputed to have made little or nothing for all his effort, but commented that

"however this may be, he has erected a work which will secure him a high reputation, and eventually an ample return in a pecuniary sense. His next contract is for the Monongahela Bridge, which is also on the Wire Suspension plan, and we hope he will have "room and verge enough" to construct a handsome thoroughfare across that stream." [23]

That surely happened, as shown in Figure 7, below. The next twenty years or so were spent piling one engineering achievement upon another, climaxing with his design of the Brooklyn Bridge. A sad accident led to his death from lockjaw before he could complete that job, but his son, Washington, took over to fulfill his father's plans and assure the family a major place in bridge building history. But it all started right here in Pittsburgh.

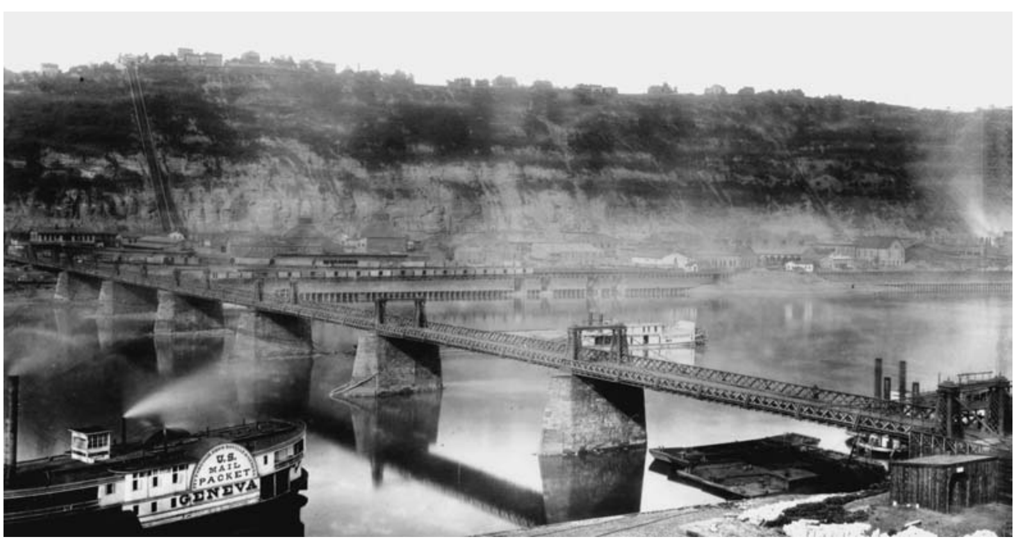

Figure 7. The Roebling wire-rope suspension bridge across the Monongahela River at Smithfield Street in Pittsburgh, built 1845-46. From Photo Collection, Carnegie Library of Pittsburgh, by permission., file #P-3109.(no date) (no photographer name).

APPENDICES

Appendix A: Business and Professional Resources of Pittsburgh, Early 19th Century

An interesting source for developing a feel for what life must have been like in Pittsburgh in the early 19th century is a series of business directories produced by enterprising, but long-suffering individuals who felt called to create these compendia of demographic statistics. They complained bitterly that in spite of the obvious value of what they were doing, the public refused to come forward with the information requested, and they then had to chase down the reluctant participants and wheedle the information our of them. Nevertheless, in spite of these sad stories, the jobs did get done and we are the richer for their diligence.

What follows are extracts from those directories, giving a feel for the resources available for engineering and construction at the times of publications of the several directories.

<u>Directory of 1815</u>

In 1796 Pittsburgh was a disorganized village. By 1815 it was a flourishing industrial town.

By 1815 Pittsburgh had a Chemical and Physiological Society and a Permanent Library Committee. There were at least two volunteer fire companies and many churches including Protestant Episcopal, 1st and 2nd Presbyterian, Roman Catholic, Seceders, Covenanters, Methodists and German Lutherans. There was even a Humane Society, for people, not for animals!

The Pittsburgh Steam Engine Company made steam engines, of course, but also had a brass foundry, air foundry for castings, made anchors and anvils and even butt hinges. There was a pattern maker's shop to make the molds for castings, a boring and turning shop, there were steam-driven lathes. There were three additional air foundries in Pittsburgh and one in nearby Birmingham (the present-day South Side), one of these including a mill for boring cannons.

William Eichbaum, Sen., had a "wire factory, propelled by steam." There was a steam-powered rolling and slitting mill, which also cut and headed nails.

R. Patterson had a steam paper mill. J. Jelly owned a steam cotton factory, said to be on "Watt's and Bolton's plan." James Arthur had a steam fulling mill. There were already three rope walks, making cables up to 4 ½ inches in diameter and weighing up to 4000# (or so they advertised!).
There were three white and two green glass houses, red and white lead and acid plants, two brush factories and three breweries! The breweries produced 10,000 barrels of beer, ale and porter per annum (that works out to about a barrel and a half for every man, woman and child in town… but doesn't count travelers!)
There were at least two major banks, Farmers and Mechanics and the Bank of Pittsburgh.
All this was supported by 9431 people in Pittsburgh proper and 5518 people across the Allegheny River in Allegheny City. There were an additional 11,000 people in Greene, Washington and Somerset Counties.

At this time it cost 37 ½ cents to mail a one page letter over 500 miles and double that for two pages!

Directory of 1826

By 1826 William Eichbaum, Sen., the wire manufacturer of 1815, had become the weigh master at the Hay scales, a powerful position in the commercial life of the growing city. The scales determined what was paid for a load of goods of any kind. The city was now said to be "*an immense smith shop*" with an "*everlasting cloud of smoke*" over it. It had many paved streets and sidewalks. It was called "*an immense storehouse for a large and extensive country." "The puffing of steam, the rattling of drays, carts and wagons, along with the noise of machinery were the equivalent of industry and extensive business of the place.*" Part of the smoke was coming from a long-time fire in the coal deposits on Coal Hill, later to become Mt. Washington.

Not all was industry in town. The Western Penitentiary was completed in 1826 with 103 6x8 foot cells for solitary confinement at a cost of $180,000!

The Allegheny River was said to have a "beautiful *pebbly channel and chrystal (sic) waters*." Its shores in town were lined with lumber rafts, iron and salt. The Monongahela contained a 2-mile-long bar of fine sand.

The directory lists all residents of Pittsburgh by name and address, along with their occupations. A partial extract of that list shows 124 different professions, including these:

pattern maker,
carpenter,
saddler,
boatman,
bottler,
senator &c,
weaver,
gentleman,
attorney,
plane maker,
brush maker,
boot and shoe black,
glass packer,
cooper,
fireman in rolling mill,
chandler,
blacksmith,
nailor,
French teacher,
wash woman,
reverend,
maltster,
glass blower,
steam engineer,
mfr cotton and woolens,
silver plater,
muslin weaver,
spinner ,
pot maker,
machine maker (James Cummins. Cummins diesel?),
stone cutter,
water-carter,
steam engineer,
hair dresser,
Captain of the Watch,
reed maker,
Crier,
Huckster and
musician.

When you read that list all at once, and realize that this is but a small sample of the people living in the area, you begin to get a feeling that this place is pulsing with energy. The directory claims that it "*is the storehouse as well of the mechanic arts, as of great commercial wealth, and is the seat of a population that supplies a vast extent of the western regions with products of ingenuity and industry*."

There were some interesting disagreements as to the impact of all this activity. A Dr. Wm Denny claimed that "*the smoke is anti-miasmatic. It is sulfurous and antiseptic and hence it is perhaps that no putrid disease has ever been known to spread in the place. Strangers with weak lungs, for a while, find their coughs aggravated by the smoke, but many asthmatic patients have found relief in breathing it.*"

The abundance, cheapness and consequently the general and even profuse use of the best fuel is certainly one great cause of our superior healthfulness."

But by contrast, the place was claimed by another visitor to be a *"half-quenched volcano covered with a sulfurous canopy, with no tall buildings or steeples, building begrimed and not a single public square except the "Diamond."* And "*there are frequent loud complaints against the filthy streets, villainous smells, licensed swine and other nuisances equally hard to endure, so peculiarly the character of Pittsburgh!*" So evidently, as usual in life, what you saw depended on where you stood.

<u>Directory of 1837</u>

The Pennsylvania Mainline Canal had arrived in Pittsburgh in 1832 and movement of merchandise in both directions had begun to transform the city. As an example, between 25 Mar and 1 Jul, 1837 the following moved east from Pittsburgh:

EXPORTS TO EAST ON CANAL – March to July1837

Type of Goods	Units of measure	Amount
Flour	K bbls	39
Wheat	K bushels	85
Tobacco	K pounds	300
Bacon	M Pounds	1.5
Coal	Tons	263
Pork (salt)	Bbls	1273
Lard Tallow	K pounds	700
Merchandise and groceries	K pounds	500
Liquor	K gallons	40
Cotton	K pounds	96

By 1837 there were 4 canal freight and passenger lines; it took only four days to get to Pittsburgh from Philadelphia. In 1844 a ticket from Philadelphia to Pittsburgh cost $8. There were steamboat and packet lines on the rivers, connecting Pittsburgh to other cities up and down the Ohio, Allegheny, Monongahela and other tributaries during times of high water. There was heavy competition based on quality of service and advertising for customers was heavy in the Pittsburgh Daily Gazette. Construction had already begun on "*slack-water improvements*" to extend the shipping season.

To see where the Canal fit in the transportation system of the day, in seven months of 1837 service, 158,000 passengers came west and 111,000 passengers went east on the canal, whereas on the Turnpike, there was an annual total of 200-250,000 passengers both ways. That is, seven months on the canal moved more people than moved in a year on the Turnpike.

The Allegheny Arsenal had been built here, adding a major push to he development of machines and mechanics. There were water works and a new coal-gas plant began to bring gas-lighting to the city. Now there were 8 fire companies, with as much as 600-800 feet of hose per company. Some eight years later all this fire-fighting equipment served little purpose as over half the town burned down in the disastrous 1845 fire.

Appendix B. A Brief History Of Suspension Structure Design Prior To Roebling

The history of suspension structures is complex and confusing and strongly influenced by personal and nationalistic biases. Roebling wrote up his own version of that history in a "**Report to the President and Board of Directors of the Covington and Cincinnati Bridge Company,**" dated 1867 [21]. That particular very successful bridge had been started in 1856, but the Panic of 1857 and the Civil War stopped construction for 8 years. Construction resumed in 1865, 6 months after the war was over and was completed in 1866. The bridge is still in full operation although its deck has been renovated for automobile traffic. As an illustration of its quality, after the flood of 1937 it was the only bridge remaining open between Steubenville, Ohio and Cairo, Illinois, a distance of about 1000 river miles.

Roebling freely acknowledged the prior construction of both chain and wire cable bridges in Europe. All of these were for foot or vehiclular traffic, none for transporting freight by water. According to Roebling, most of these were relatively light and were damaged by storms. The bridge at Freibourg in Switzerland was 870 feet long and lasted for some years, but according to Roebling was deficient in both strength and stiffness. In the time between 1830 and 1840 literally dozens of wire-cable suspension bridges were built in France, many of these by the Seguin brothers, and many others in Germany, Poland, England and other European countries. Many other suspension bridges were built using chains. [22]

Roebling's main claim was that the Allegheny Aqueduct introduced quite different principles in both the cable making, principles which have been discussed above, and in the fundamental bridge design. The point was to make the structure capable of sustaining not only vertical but lateral loads. Stiffness was a vital issue. The French system suspended the bridge floor by a number of light cables. Roebling used only two relatively massive ones, assisted by a network of stays and suspenders. Under the complex stresses of a storm, the larger cables acted as full-strength units, whereas experience had shown that the smaller cables in the earlier designs had failed sequentially, one by one. This is what happened to a suspension bridge in Wheeling, WV, which blew down in 1854, originally supported by 6 smaller cables on each side [21].

The first cable suspension bridge in this country was built by Roebling's rival, Charles Ellet, Jr., in Fairmount, PA, over the Schuykill River in 1842. The French system was used whereby the cables were constructed on land, then dragged to the site and elevated into position. But Roebling contended that in this process the wires in the cable got dislocated and bulged out, assuring that the stresses on the cable would not be equally distributed under load [21]. This bridge, however, remained in service until 1875. In contrast, all of Roebling's bridges used cables "spun in place" or spun in the spatial distribution in which they were to be used and kept under tension until final installation was complete, assuring that the individual wires would share the load equally. Roebling was very sure of the correctness of his principles and the performance of his structures bears him out well.

Appendix C: Epilogue

The Roebling personal papers are predominantly to be found in two university collections at Rennselaer Polytechnic Institute, where his son, Washington, attended, and at Rutgers University in New Jersey where his family wire-rope factory was located for many decades after he left Pittsburgh. It is a major thrill for a serious amateur historian and sometime-professional engineer to reach into a box and pull out one of John Roebling's personal note books filled with musings and calculations on which his designs were based. As a young engineer some fifty years ago I took engineering drawing as a required course at university. Roebling had taken a similar course somewhat earlier! We drew largely in pencil, as did he. We sharpened our wooden pencils with our pocket knives and a pad of fine sandpaper with a handle. I suspect he did much the same. All of his notebooks are filled with text written with an ink pen, with never a blotch (there are a few line-outs, to be sure). I don't know whether he had a steel nib or not. One of our most important pieces of equipment in those days was a set of chrome-plated steel drawing instruments. They had interchangeable tips, one for lead, the other for a pair of adjustable blades for making varying-width ink lines with your compass. Ink drawings were serious, serious business, only attempted late in the year-long course. All engineering students had to take this course, involving seven hours of class and lab each week. All of this intense application was brought back in full force as I paged almost reverently through Roebling's original note books and drawings.

In all the calculations in these many hundreds of pages of notes, the most complicated things are tables of natural trigonometric functions and square roots! Calculus is no where to be seen. There are notes of extensive experiments on strengths of materials such as wires and many calculations of bearing strengths of wooden structures, apparently based on his Prussian engineering training. Many of his calculations showed that he was designing to safety factors from three to seven times the required strengths of various components of his structures. He didn't take many chances!

While Roebling wrote in German when he first arrived in 1832, he was publishing in major journals in perfect English about ten years later. His early notebooks were intermittently in German, but by the late 1830s his written English was excellent. And his handwriting, while a bit idiosyncratic, was uniform and easily legible.

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23. "*The New Wire Suspension Aqueduct*," Pittsburgh Daily Gazette, Saturday, May 24th, 1845, p 2.

BOOKS ON ROEBLING AND RELATED SUBJECTS

D. B. Steinman, *Builders of the Bridge*, Harcourt Brace, NY (1945) 456 pp
D. McCullough, *The Great Bridge*, Simon and Schuster, NY (1972) 636 pp
R. S. Kirby, *Early Years of Modern Civil Engineering*, (1932) Yale University Press, New Haven, CT 390 pp

ADDRESSES FOR COLLECTIONS OF ROEBLING AND RELATED MATERIALS

PA State Archives, 350 North St., Harrisburg, PA 17120-0080, Archived Records of the Board of PA Canal Commissioners

Historical Society of Western PA, Library and Archives, 1212 Smallman Street, Pittsburgh, PA 15222

Rennselaer Polytechnic Institute, Folsom Library, John A Roebling Collection, 110 8th St., Troy NY 12180

Rutgers University of New Jersey, Alexander Library, Roebling Family Collection, 169 College Avenue, New Brunswick, New Jersey 08901-1163

Delaware and Hudson Canal, Lackawaxen, PA Upper Delaware Scenic and Recreational River, RR2, Box 2428, Beach Lake PA 18405-9737 570-685-4871

Franklin Institute, 222 North 20th St., Philadelphia, PA 19103-1194

Carnegie Library of Pittsburgh, 4400 Forbes Ave, Pittsburgh, PA 15213

Canal History and Technology Press, 30 Centre Square, Eaton, PA 18042

Saxonburg Borough Library, 240 Main Street, Saxonburg, PA 16056, 724-352-4810