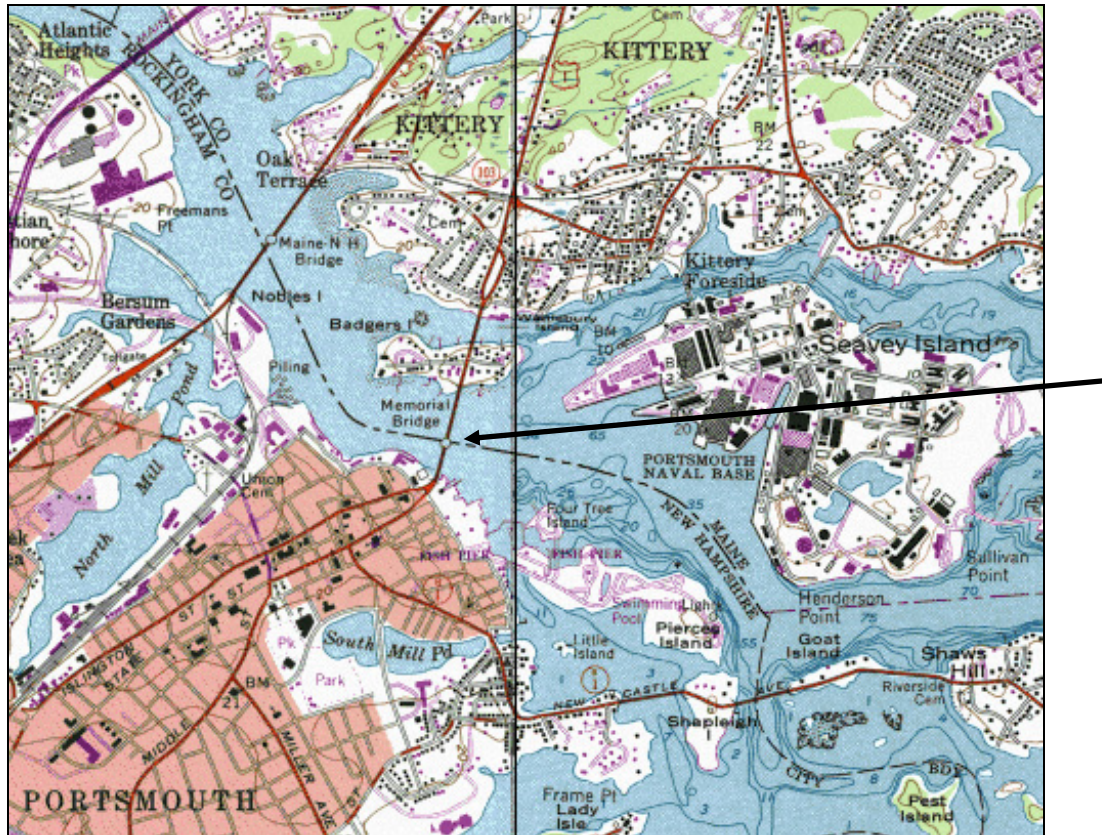


## **Tab B. Background and History of Memorial Bridge<sup>6</sup>**

### **1. Geographic/Environmental Context**

Memorial Bridge and its approaches carry Route 1 cross the Piscataqua River between Portsmouth, New Hampshire and Badgers Island, Maine. Route 1 continues on, crossing Badgers Island and Badgers Island Bridge to the mainland of Kittery, Maine. Memorial Bridge is located four miles up river from the Piscataqua's ocean outlet and a few miles downstream from the opening for Little Bay.



*Figure B-1: USGS Map (detail) showing location of Memorial Bridge*

Formed at the confluence of Little Bay and the Salmon Falls River, the twelve-mile-long Piscataqua River runs to the Gulf of Maine/Atlantic Ocean via Portsmouth Harbor and is the border between New Hampshire and Maine for its length. Other tributaries of the river include

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<sup>6</sup> Research for this section and later historical sections, was conducted at venues in New Hampshire and Maine. In New Hampshire, research was done at the Portsmouth Athenaeum, Strawberry Banke, Portsmouth Public Library, Portsmouth Public Works Department, the Rockingham County Courthouse, the New Hampshire Historical Society, New Hampshire State Library, and New Hampshire Department of Transportation. In Maine, research was conducted at the Maine State Archives and the Maine Historic Preservation Commission. A particularly noteworthy resource is a collection of photographs of the construction of Memorial Bridge taken by Walter Staples between 1920 and 1923. Many of these photographs (over 100) are located at the Portsmouth Athenaeum, and at Strawberry Banke. A selection of these is included at Tab N of this report.

## *Memorial Bridge Historic Structures Report*

the Cocheco, Bellamy, Oyster, Lamprey and Squamscott Rivers. These rivers provide ocean access via the Piscataqua to the towns of Newington, Durham, Newmarket, Exeter, and Dover.

Although the tidal current of Portsmouth Harbor has been called one of the most turbulent in North America, it has a number of characteristics, which have, over its 400-year maritime history, combined to make it a popular port and location for commerce. The Piscataqua River varies in depth and is quite deep, up to 80' in some locations. The river also varies significantly in width. Variations in its width and depth create changes in the river's current and cross currents. The maximum current (4 knots) is found at Nobles Island and off Dover Point and Atlantic Heights; the current is half that rate at other places. There is also a strong tidal influence, which results in extreme tides. This tidal influence is due to the presence of a large water body (Great Bay) upstream. The tidal influence, combined with the river's extreme depth at some points, prevents ice buildup in the river in the winter. This makes Portsmouth Harbor the closest U.S. ice-free port to Europe and its markets. The channel is maintained at 35' deep and the river has bridge clearances of 135' (Sarah Mildred Long Bridge and I-95 Bridge) and 150' (Memorial Bridge). The Port annually handles a total of 5 million tons of cargo (SeacoastNH).

As the river nears the ocean, the coastline becomes more convoluted and Portsmouth Harbor is studded by over a dozen islands both large and small. Early on, a number of these (including Badgers Island) were the site of shipbuilding operations. Seavey's Island, the site of the Portsmouth Naval Shipyard, is a conglomeration of what were originally five separate islands. During its 200-year history, the shallow channels dividing these islands have been filled to accommodate expanded facilities at the Shipyard.

The river has always been a focus of life in Portsmouth with the exporting of lumber and fish and shipbuilding. It is one of the oldest working ports in the United States. In the seventeenth and eighteenth century, the area was known for its rich marine resources including fish, oysters, clams and lobsters. However, marine resources were soon affected by industrial activities (including shipbuilding) and as early as the eighteenth century, a reduction in the salmon run was noted. Today, fish in the river include striped bass, bluefish, salmon, eels, tom cod, shad, smelt, river herring and flounder. The New Hampshire side of the river continues the industrial and port traditions. Industrial facilities include a petroleum distribution facility, electrical generating facilities and the New Hampshire Port Authority Cargo Terminal. The latter includes a 66' long wharf a 310' long barge pier, warehouses and container port operations

Geologically, the project area is part of the Seaboard Lowland physiographic region of New Hampshire, which was submerged and eroded by wave action during the waning stages of the Ice Age (Van Diver 1987:18). The bedrock in this area consists of a very hard Rye formation, mainly tough, erosion resistant schists and gneisses. Much of the City of Portsmouth lies within the Chatfield-Hollis-Canton soil association (Kelsea and Gove 1994). These soils are described as somewhat excessively drained and well drained, shallow to very deep, loamy soils that are gently sloping to steep. Soils in the project area are specifically categorized as Urban land, or land covered by streets, parking lots, and buildings. Soil surveys offer no additional information about the soils beneath these urban features.

## 2. Development of the Waterfront

As discussed above, Portsmouth is one of the oldest working ports in the United States.<sup>7</sup> The concrete piers of the Portsmouth Approach Span and Memorial Bridge's southern pier are established on the old shoreline of the Piscataqua River, where wharves, warehouses, and docks stood from Portsmouth's earliest settlement, through the commercial heyday of the nineteenth century, and until the construction of Memorial Bridge beginning in 1921.

From Portsmouth's founding, the riverfront and the area around the Memorial Bridge had been a focus of economic activity. Waterfront activity focused on the West Indies trade, and during the Revolutionary War and the War of 1812, privateering. A series of parallel wharves extended into the river at the ends of Daniel and State Streets and near what is now Prescott Park (See Tab J, Figure J-8). These long piers and wharves took advantage of channel depths of up to 69'. Storehouses were built on the wharves or parallel to the shore. Most were wood structures with gable or shed roofs, sheathed in clapboards, shingles or vertical boards, with few windows. The longer buildings were divided into sections, and a variety of tradesmen occasionally occupied them. Bulk cargo was unloaded into storehouses on the piers, to be sold in shops or directly from the warehouse (DeChard 2000:23, 26, 45). The offices and counting rooms of Portsmouth merchants were often located on the wharves or nearby. The corner of State and Water (Marcy), at the end of the Portsmouth Pier, was site of the New Hampshire Hotel. Off the end of Daniel, next to the town landing were the wharves of the Langdon family. In 1798, the Portsmouth Pier Company was established and built a massive pier off State Street, including a three-story building, over 300' long, containing fourteen stores (DeChard 2000:49).

Much of this area burned in the fire of December 22, 1813. It destroyed the waterfront, everything along State Street, the south side of Daniel Street, and north of Daniel beyond Bow Street, where the power plant was later built (Hales 1813). These properties were replaced by new mostly brick buildings during the 1810s. Every building over 12' high was required to be of brick by Portsmouth's Brick Act of 1814. Permission to build in wood was granted in some cases for utilitarian buildings.

During the mid-nineteenth century, coal became a major waterfront commodity, needed as fuel for the steam-powered factories and, later, railroads. Ferry service to Maine, which had previously run from Portsmouth's North End, resumed in the late 1860s from the end of Daniel Street. A ferry house was built around 1872 (Fentress 1876:76).

During the nineteenth century, this section of the city near the waterfront contained primarily working class housing, multi-family tenements and boardinghouses. Water (Marcy) Street and the adjacent ends of Daniel and State Streets fell within Portsmouth's renowned "red light district." At this time, Daniel Street was lined primarily by two story dwellings, while buildings on State Street were three-stories, and included boardinghouses, a saloon and restaurant. In an effort to clean up the area, the brothels were shut down in 1912, and at the same time Water Street was give a more refined name, Marcy Street.

The gas works on Bow Street became the Portsmouth Gas and Electric Light Works in the 1890s (Hurd 1892) and in 1901-02 an electric power plant was built on the riverfront north of Daniel

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<sup>7</sup> This section is an introduction to the history of the area around the site of the Memorial Bridge. More detailed information about the site and the specific resources associated with the location, are located in Tab J (Visual Study of Memorial Park) and Tab I (Archaeological Investigations) of this report.

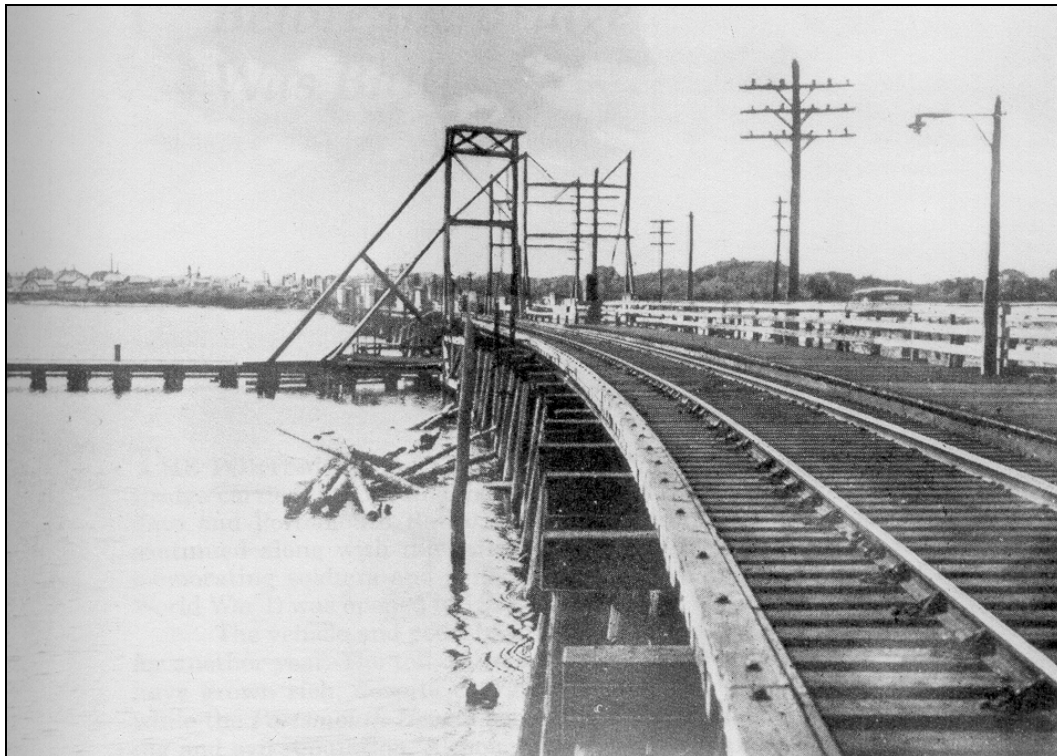
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Street. The Rockingham Light and Power Company and later Public Service Company operated the power plant through most of the twentieth century.

The 1920s bridge construction entirely removed one wharf and replaced the adjacent ferry landing that had been in operation since at least the 1860s. The extended bridge approach required the removal of an entire block of domestic and commercial buildings as well.

### 3. Early Concepts for Replacing 1823 Bridge (Pre-1916)

The first, and for many years the only, means of crossing the Piscataqua between Portsmouth and Kittery were boats. Between 1806 and 1823, the many New Hampshire men who worked at the Portsmouth Naval Shipyard took a ferry (the North Ferry) or smaller boats to reach work. With the expansion of the Shipyard during the War of 1812 and thereafter, however, a bridge was needed to supplement the ferry that crossed the river from Portsmouth's North End (near the intersection of Market and Russell Streets). In 1823 a pile bridge, known as Portsmouth Bridge, was built at the north end of Market Street in Portsmouth to Nobles Island and then to Kittery, Maine (Plate B-1). The bridge was owned by The Proprietors of the Portsmouth Bridge which was chartered by the New Hampshire State Legislature in 1819 and by the State of Maine in 1821<sup>8</sup>. The bridge extended 500' from Portsmouth to Noble's Island, then 1,650' to Kittery, making it a total of 2,150' long. It was an "ordinary open, railed, wooden bridge" constructed on piles with a draw. It originally cost \$40,000 to construct (Joint Bridge Commission 1919). With the construction of the bridge, ferry service was discontinued.



*Plate B-1: 1823 Bridge (Openo 1988:xix)*

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<sup>8</sup> The bridge was chartered by Massachusetts in 1820, the same year Maine separated from Massachusetts.



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In 1841, the bridge was purchased by the Eastern Railroad of New Hampshire, which built another span immediately adjacent to the original bridge and ran its tracks on this bridge while maintaining pedestrian and carriage traffic on the old span. Around 1880, the Boston & Maine Railroad purchased the bridge and ran their trains over it while still collecting tolls from pedestrians and carriages (Bridge Commissioners 1906: 39-42)<sup>9</sup>. With rail service via the bridge, Navy Yard workers who lived in New Hampshire could commute by way of train.

From the beginning, there were significant problems with the bridge. The bridge was simply not convenient for shipyard workers to use, as it was over two miles from Market Square north to the bridge, across the bridge and back down river to the Navy Yard. (This was over twice the distance of a route directly across the river.) Because it was not walking distance, workers and enlisted men crossed the river using a variety of means. In addition to the train service, ferry service was one possibility. In the 1890s, the Portsmouth, Kittery & York Electric Street Railway's ferry known as the Kittery, took passengers from a terminal at Bow and Ceres Streets to Badgers Island where a bridge crossed to the mainland. In addition, the Navy Yard ran a schedule of ferries from a slip located on what is now the site of Memorial Bridge. This launch, however, was limited in its capacity, only operated during limited times of the day, and could be used only by enlisted men and a small portion of Yard employees. Workers at the shipyard also took smaller, private boats, and by the turn of the nineteenth century, the afternoon spectacle of the fleet of boats racing across the Piscataqua attracted a sizeable audience. (Brighton 1994:227-8) By the early twentieth century, a majority of workers took the train that crossed over the 1823 bridge (U.S. House of Representatives 1919:1113). Once at the shipyard, workers could reach the mainland via a bridge that had been constructed in the early nineteenth century.

Another problem, however, was generic to toll bridges. Toll bridges, common in the nineteenth century, were never popular with the residents who had to pay to use them. As a result, "Free the Bridge" movements advocating the construction of free bridges were common wherever toll bridges were found. Local governments were pressured to either buy existing toll bridges or build new free bridges with taxpayer monies. In Portsmouth as early as 1895, objections to the 1823 toll bridge resulted in a bill being introduced in the New Hampshire legislature by Fernando W. Hartford, the publisher of the Portsmouth Herald.<sup>10</sup> The unsuccessful legislation aimed "to Free the Portsmouth and Kittery Toll Bridge." This appears to have been the first, but it was certainly not the last, of the Herald's many determined attempts to get the 1823 bridge replaced.

More concerted efforts at replacing the aging 1823 bridge began after the turn of the century. In 1905, the Portsmouth Herald had Col. William H. Keefer come to Portsmouth to view the river and make a recommendation as to what type of bridge to build and where to build it. Keefer, whom they incorrectly identified as the designer of the 1,200' long Niagara Suspension Bridge "stated the best location for a new structure would be from Church Point to Badgers Island and thence to the mainland by way of Newmarch Street."<sup>11</sup> He proposed a suspension bridge with

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<sup>9</sup> At the time of the B&M purchase, the New Hampshire legislature "removed the bridge from the jurisdiction of the railroad commission, thus making the railroad not subject to any rules and regulations of any state body, other than the legislature" (Portsmouth Herald Nov 7, 1917).

<sup>10</sup> Fernando or F.W. Hartford, one of the major figures in the Memorial Bridge story, was also a powerful figure in Portsmouth in the first few decades of the twentieth century. In addition to being the owner of the Herald, he was Mayor of Portsmouth from 1921-22; 1928-29 and 1930-32 and was involved in a number of Portsmouth businesses.

<sup>11</sup> The single lane Niagara Suspension Bridge was actually built by Samuel Keefer in 1868. William Keefer probably worked on the bridge under his father's supervision. The scheme had at least one major problem;

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towers on Badgers Island and near the Portsmouth shore of the river (Portsmouth Herald November 7, 1917). No known drawing exists for the suspension bridge design.

Likely responding to lobbying from the Portsmouth Herald, in 1906, the Bridge Commissioners of the New Hampshire State Legislature issued a report on the state of the 1823 bridge and prospects for replacing it.

[I]t is now very old and much out of repair, it has sagged or bent down in the middle, and the piles have given way in some places, on which account some accidents have happened, and it can now hardly be considered safe for the great strain of heavy trains which are constantly crossing it. Its condition of almost dilapidation now makes constant repair necessary; and it is kept up to a tolerably safe condition at a great cost (Bridge Commissioners 1906:39-42).

A major challenge, however, was the railroad's control of the crossing. Given this factor, the report concluded that "it would be advisable for all concerned to let the freeing of the Portsmouth bridge rest for the present, until the situation shall assume a different phase, and the relation of the railroad to the bridge is such as to dispose that corporation to some favorable terms with the public" (Report Bridge Commissioners of the New Hampshire State Legislature December 31, 1906:39-42). The railroad was not receptive to plans to replace the 1823 toll bridge with a free bridge without being compensated for its charter rights. In fact, in 1907 the B & M offered to sell the bridge and its rights to Rockingham County, NH and York County, Maine for \$134,000 (Interstate Bridge Commission 10/10/1917).

In the spring of 1907, the Herald, in a large headline, optimistically declared a "Great New Bridge to be built across the Piscataqua River by the Boston and Maine Railroad Corporation a New Station for Portsmouth Is Also a Certainty" (Herald April 22, 1907). The story indicated that the B & M had approved a new bridge that would be a suspension bridge for both rail and carriage traffic.

The bridge will end on the Maine side at a point known as South Eliot Junction, nearly opposite the paper mill. On this side (Portsmouth) of the river, the main line tracks of the Eastern division will branch off at Dover street and will cross the North Pond, the filling of which by the railroad company is included in the plans as now outlined. The tracks will strike a point on the Dover branch above the paper mill... A new station for Portsmouth is promised in connection with the work now being planned, probably on an entirely new site. If the track arrangement is changed as it is said it will be, the Portsmouth station will be located on Maplewood avenue near the Christian Shore bridge (Herald April 22, 1907).

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approaches to the bridge would have had to have been extremely steep to raise the deck over the shipping by the 150' required.

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The railroad estimated that the entire project would cost \$3,000,000 with about half of that amount being for the bridge and the rest allocated to the relocating of the railroad lines (Interstate Bridge Commission October 19, 1917).<sup>12</sup>

The first solid accomplishments towards a new bridge, however, came in 1911 when both Maine and New Hampshire passed legislation authorizing construction of a new bridge. On March 28, 1911, Maine passed legislation which granted authority “to the city of Portsmouth, in the town of Rockingham [sic], state of New Hampshire, and the town of Kittery, either or both of them to construct a bridge across the Piscataqua river at such a place and of such material and design as the secretary of war and congress may hereafter approve...In lieu of building a new bridge, either or both of the above municipalities are authorized to lease any existing bridge over said Piscataqua river” (Maine State Legislature 1911). New Hampshire responded, and passed similar legislation in 1911, “An Act for a charter for a bridge across the Piscataqua River” which stated “Authority, is hereby granted the city of Portsmouth, to construct a bridge across the Piscataqua river at such a place, and of such a design and material, as the secretary of war and congress may hereafter approve” (New Hampshire State Legislature 1911).

Having official authorization to build such a bridge did not make it immediately materialize however. In 1914, Major David Urch, proposed a “transporter” bridge similar to ones he had read about that were built in Wales and the Arnodin Bridge in Rouen, France over the Seine River (Plate B-2). Transporter bridges, a type of ferry in which the car carrying people and vehicles is hung from an overhead carriageway with steel cables, have a very limited capacity. Although they are not subject to the river currents, they are subject to high winds. All told, it would not have much advantage over the ferry. Urch proposed building this bridge at the same site proposed by Keefer (Herald January 14, 1920). This plan, like the many previous ones, was never acted upon.

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<sup>12</sup> It would be 1940 before the Interstate (Long) Bridge was built on this site accommodating both cars and the railroad.



*Plate B-2: Transporter Bridge, Duluth Harbor (Turner 1905)*

In 1915, Congress, in the River and Harbor Act of March 4, 1915, authorized the survey of Portsmouth Harbor to determine what modifications to the channel were needed to enhance the ability of the harbor to handle large shipping. The conclusion of the Chief of the Corps of Engineers was that “the improvement by the United States of Portsmouth Harbor, N. H., is not deemed advisable at the present time” (U.S. House of Representatives 1916:2). The map attached to that report gives an overview of the topographic condition of the Harbor, Portsmouth and Kittery in 1916 when serious discussion began on the new bridge across the river (Figure B-2).





Figure B-2: Portsmouth Harbor Map (U.S. House of Representatives 1916:2)

#### 4. Planning Memorial Bridge- 1916-1920

Late 1916 saw the beginning of what was the final and successful effort to get a new bridge. It, like all the previous efforts, was complicated by the fact that the proposed toll free bridge would be an interstate bridge requiring cooperation by the states of New Hampshire and Maine as well as the United States Navy. The Portsmouth Herald once more led the efforts. Oversize headlines on the December 6, 1916 edition exclaimed, “The Herald Will Conduct Live Campaign for New Bridge Across Piscataqua.” The article below the headline went on to say, “The Herald proposes the coming year to use every effort possible to secure erection of a new bridge across the river...The Herald will not only urge the work of freeing the present bridge but it has another plan for an entirely new bridge. The plan will, it is believed, prove a solution of the present difficulty” (Herald December 6, 1916).

As a first step, in early 1917 Herald editor, F.W. Hartford, sent a letter to Secretary of the Navy, Josephus Daniels, informing him “we have started a movement here to do away with the toll bridge that connects the state of Maine and New Hampshire.” He went on to say that taxing the two adjoining towns would be unfair given the benefit to the government of such a bridge. “The construction of an up-to-date bridge would practically exclude the necessity of ferry service from here to the Navy Yard, and would save the Government thousands of dollars a year...” (quoted in Herald December 2, 1920). Hartford, in addressing the Maine Press Association urged Maine editors to join the Movement, “to remove one of the relics of the dark ages, the toll bridge between this and the Granite State” (Herald January 20, 1917).

On April 6, 1917, the New Hampshire legislature passed a law appointing a commission, which, acting in conjunction with a similar commission from Maine, was charged with coming up with a “definite proposition” to the legislature of 1919 for a free bridge between Portsmouth and Kittery (Chapter 82 of the Resolves of 1917) (Herald April 6, 1917). Maine, on April 18, 1917, passed a similar resolution (Chapter 246, Acts of 1917). Each legislature appropriated \$2,500 to make a preliminary survey. The Commission consisted of three members from each state. The New Hampshire Delegates were Governor Henry Keyes, Jacob Gallinger and Calvin Page. The Maine delegates were Philip Deering, William Ayers and Frank Peabody.<sup>13</sup>

The first meeting of the commission took place on October 10, 1917. At this meeting, the commissioners discussed the 1823 bridge and looked at two potential sites for a new bridge. One site was 1,000' above the old bridge and the other site went from downtown Portsmouth to Badgers Island and the Maine mainland. The Commissioners discussed the fact that the Boston & Maine Railroad had studied a number of schemes to replace the 1823 bridge and decided that they would examine the plans and meet with the Railroad at their next meeting. The next meeting was held in Boston at the offices of the Boston & Maine at North Station on October 26, 1917. The chief engineer of the B & M, A. B. Corthell, explained the various schemes the railroad had developed over the many years they had been contemplating the problem. Corthell indicated that it would cost over \$60,000 to repair the old bridge and noted that the “highway and railroad bridges are braced together laterally for support” (Interstate Bridge Commission October 26, 1917). He then presented a plan for “a double-deck bridge to accommodate railroad and highway traffic, the highway traffic to take the upper floor of the structure...” The cost at that

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<sup>13</sup> The Commission was variously known as the Joint Bridge Commission of Maine and New Hampshire and the Interstate Bridge Commission. The composition of the commission changed over time but always included members from New Hampshire, Maine, and the Navy. See Plate B-3 for its composition in 1920.

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time to complete the project was \$4,500,000 (Interstate Bridge Commission October 26, 1917). The meeting clarified the fact that the B& M's charter granted them the exclusive right to build and maintain a bridge across the Piscataqua "between Rindge's wharf<sup>14</sup> and the town of Newington." In order to build a bridge within that area, it would be necessary to purchase the railroad company's franchise. After listening to the B&M's various plans, the value that the B&M placed on the existing bridge, and clarifying that they had no jurisdiction to consider a toll bridge, the Commissioners voted to have the engineering department of the State Highway Commission of Maine proceed with collecting data and preparing a design and estimate for a bridge at the Badgers Island location (Interstate Bridge Commission Oct. 26, 1917). The engineering department, during the summer of 1918 began work. Data related to foundation conditions were collected and estimates were prepared.

In December 1918, a major effort to secure federal funding for the project was initiated. On December 5, 1918, the Commission now referred to officially as the Interstate Bridge Commission, met in Boston to discuss "the status of the interstate bridge investigation" prior to meeting with Secretary of the Navy Josephus Daniels the next day (Interstate Bridge Commission December 5, 1918). The Maine bridge engineer who had been working on the project, L. B. Jones, explained the preferred Badgers Island alternative. "[A] steel bridge on masonry piers and abutments ... The estimated cost of this structure is \$2,700,000. With a plank floor and no provision for cars the estimated cost of the bridge will be \$2,500,000..." (Interstate Bridge Commission, December 5, 1918). He also discussed an alternative site above the Atlantic Shipbuilding yard at the old paper mill. Because the river was narrower at this site, a shorter bridge could be built at considerable savings. It had the disadvantage, however, of being further from the Navy Yard.

The next day, a large and influential group was assembled to meet with Secretary Daniels. It included the Commission, along with the governors of Maine and New Hampshire, a large delegation of New Hampshire and Maine Senators and Representatives, and Samuel Gompers of the American Federation of Labor. In the meeting, the Governor of Maine pointed out that his state would prefer the cheaper upper location (the site of the current I-95 bridge) but could be persuaded to go with the lower site if there was a "fairly liberal appropriation." Reaction from the Secretary was limited, "The Secretary expressed himself as interested and in a sympathetic frame of mind with respect to this improvement" (Interstate Bridge Commission December 6, 1918).

A few months later, on January 28, 1919, the House Committee on Naval Affairs held a hearing on the subject of a new bridge, with a number of members of the Interstate Commission in attendance. Secretary of the Navy Daniels led the discussion of the need for a bridge in this location, the utility to the federal government of a new bridge and information about the different sites for the bridge. Representative John A. Peters (from Maine) stated that the idea of combining forces with the railroad would be impossible and should be "eliminated." The committee recommended that there "ought to be a little more definiteness" as to the location and the plans for the bridge and that it would be necessary for the two states to begin the process by appropriating funds. The Chairman and others concluded that it would be "fair" for the federal government to pick up one third of the cost of the bridge. Coming just a few months after the end of World War I on November 11, 1918, members of the House Committee also

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<sup>14</sup> Rindge's wharf was located north of where Memorial Bridge was finally built, off Market Street just north of Green Street.

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enthusiastically endorsed the concept of the bridge being a memorial to the veterans of the war (U.S. House of Representatives Committee on Naval Affairs 1919).

A month later, in March 1919, the “Joint Bridge Commission” issued its official report to the Maine and New Hampshire legislatures. After discussing the history of their efforts, they estimated the cost of bridge to be “somewhat less than three million dollars.” Despite this estimate, and the “one-third” figure offered by the federal government, the commission recommended that the legislatures of each state appropriate only \$500,000 for the purpose of constructing the new bridge. The commission did not specify a specific bridge type or plan in the report (Joint Bridge Commission 1919).

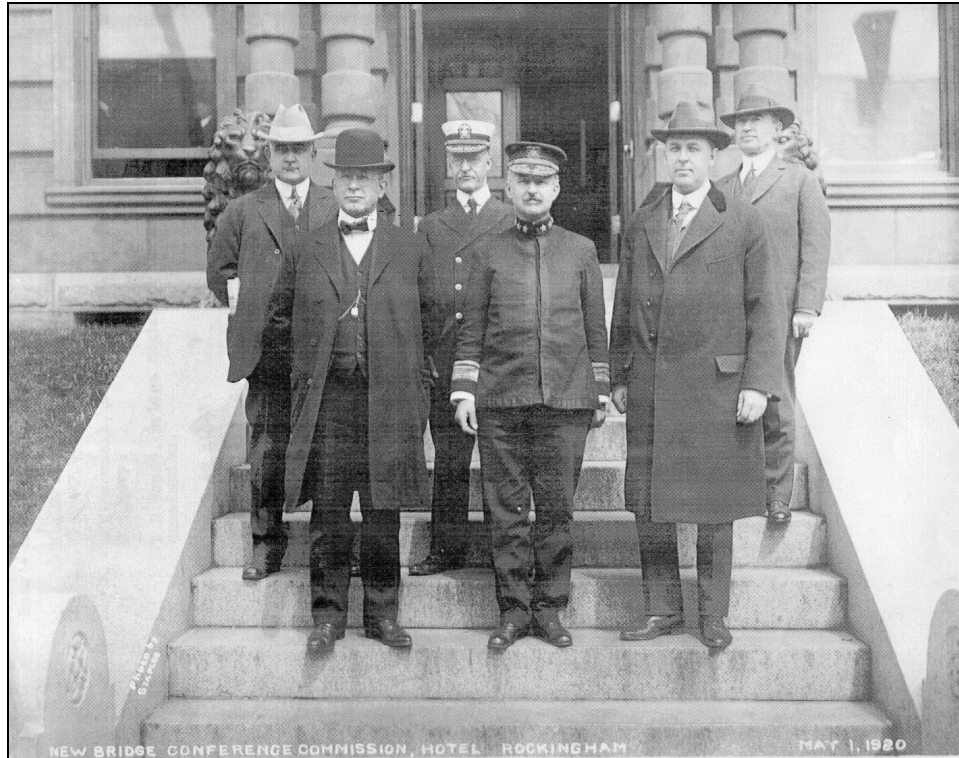
It was Maine that acted first on the recommendations of the commission. On March 13, 1919, Maine voted to appropriate \$500,000 “conditional upon action of New Hampshire State Legislature” and requested the Federal Government to make an appropriation (Maine State Legislature 1919). Two weeks later, on March 27, 1919, the New Hampshire legislature followed suit, appropriating \$500,000, as their share of construction costs, provided the Federal Government appropriated a sufficient amount to cover building the bridge where it would do the most good for the Navy Yard (New Hampshire State Legislature 1919).

The final third of the cost of the bridge, which was to come from the federal government, followed soon thereafter. Through the efforts of Senator Keyes (former Governor of New Hampshire), who had been appointed to the Naval Affairs Committee, and Secretary Daniels, \$500,000 was added as a rider to the Naval Appropriations Bill. President Wilson signed the bill on July 11, 1919 with the proviso that “the location of said bridge shall be approved by the Secretary of the Navy for a convenient access to the Portsmouth Navy Yard.” Throughout all of these efforts, however, there was still a large and obvious gap in funding. With the estimated cost “less than three million” and only \$1.5 million available, there had to be adjustments.

In October 1919, government engineers recommended a modification in bridge style from a pure suspension bridge. The Herald reported on October 2, “The latest graphic representation will call for the building of a suspension bridge from the Portsmouth side to a location in the river about where the eddy flows near the Maine side. At this point it is planned to locate the draw and from the draw to Kittery a cantilever structure will be built. This combination of bridgework is said to be the most feasible and will better meet the conditions. Owing to tides, a draw in the center of the bridge is out of the question” (Herald October 21, 1919). No known illustration of this proposed bridge exists and it is difficult to visualize how the three different bridge types strung together would touch down on Badgers Island and the mainland in New Hampshire and Maine.

Adjustments in the choice of a site were still being discussed late in 1919. Engineer Jones of the Maine Highway Commission located a new site described as: “somewhat below that previously being considered, where the deep water may be bridged by the span and a landing made on the land side over Badgers Island and on the Portsmouth side in a location less expensive than the other, [which] would be in the business section” (Herald December 9, 1919). The bridge commissioners approved the current site of the bridge on May 1, 1920. The Herald reported that the bridge would be “from the foot of Daniel and State Street, that is the old Broughton wharves now owned by C. E. Walker Co., across to the end of Badgers island and then probably swinging easterly to the mainland at Kittery coming out as near the Navy Yard bridge as is possible, although the complete details of the Kittery site have not yet been fully decided upon” (Herald May 3, 1920).





*Plate B-3: New Bridge Conference Commission 1920. Rear L to R: W.A. Grover, E.H. Brownell, L.B. Jones. Front L to R: J.H. Bartlett, C.W. Parks, Carl Miliken (Maine DOT)*

Late in 1919 or early in 1920, the design of the bridge was changed once again from the combination suspension/cantilever/draw bridge to a bascule design. Between 1900 and 1920, particularly in the east, the bascule bridge had become the most popular design for movable bridges, and the Commission entered into a contract with the Strauss Bascule Company to design one of their patented bridges for the crossing. As shown in a May 1920 drawing (Figure B-3) a significant portion of the stream channel was dammed up, with the approach from the Portsmouth side contained by concrete retaining walls and another retaining wall running from the end of the bridge to Badgers Island. The flanking trusses were subdivided Pratt Trusses with spans of 300'. The twin bascule spans were 150' from center of pier to center of span with a clear opening, when both leaves were raised, of 268'. The bascule spans, with their large counterweights, would rest within the flanking trusses and effectively block traffic when raised. The bascule spans ranged in depth from 22' at mid-span to 32' near the ends. The pivot for the bascules was on the same line as the pins for the flanking trusses, which had a depth of 50' at mid-span and panel length of 19' to 22' with all the long verticals braced at their mid heights. The plan of this bridge is shown below.

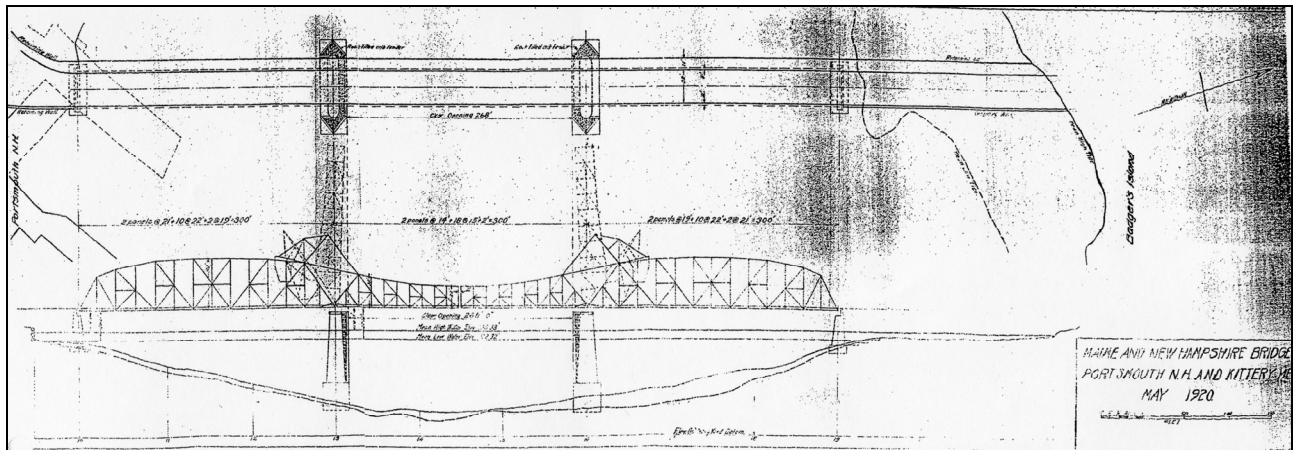


Figure B-3: Design for Bascule Bridge (Strawbery Banke) [Larger scale plan at Tab O]

Bids were received for the foundations and bascule superstructure in September 1920. At a key meeting on October 30, 1920, the “Board of Engineers,” consisting of William Grover, the bridge engineer from New Hampshire, Walter H. Norris, bridge engineer for Maine, along with Commander Brownell of the Naval Shipyard, met with representatives of Holbrook, Cabot & Rollins (a bidder on the substructure of the bridge) (hereafter Holbrook Cabot), the Strauss Bascule Bridge Company, and Bethlehem Steel. At the meeting, Holbrook Cabot and Bethlehem Steel gave the Board revised figures for constructing the bascule design with a narrower (24') roadway, one sidewalk and “very light” steelwork. The revised bids, however, still added up to \$1,500,000., equaling the total of the three appropriations and leaving no money to pay engineering fees and other expenses. “With all these changes, which are all sacrifices in usefulness, strength, long life and appearance it still cannot be built for the appropriation” (Norris 1920). The agent of the Bethlehem Steel Company had another idea. According to him, a 300' vertical lift span with two fixed spans, could be completed for a price within the appropriation, and “moreover the bridge will have a 28' clear roadway and a sidewalk six feet wide.” In writing to get the approval of the Commissioners for the change in design, the Maine engineer indicated that after the Commissioners’ okay, bidding plans could be prepared in an amazing “about two weeks’ time” (Norris 1920).



Plate B-4: J. A. L. Waddell (Harrington 1905)

## *Memorial Bridge Historic Structures Report*

The patents for vertical lift bridges were held by John Alexander Low Waddell (J. A. L. Waddell) (Plate B-4). Born in 1854, Waddell was a Canadian who received his engineering education at Rensselaer Polytechnic Institute (RPI) in Troy, New York.<sup>15</sup> Graduating in 1875, he worked as a draftsman and engineer in Canada and a surveyor in the United States for a few years before returning to RPI to teach. In 1881, he began his bridge building career as Chief Engineer for Raymond and Campbell, of Council Bluffs, Iowa. Immediately thereafter, he took a position as chair of Civil Engineering at the Imperial University in Tokyo.<sup>16</sup>

While in Japan, he published two books, the first of many books he would write on civil engineering topics during his lifetime. When he returned to the United States in 1886, he worked for the Phoenix Bridge Company in the Phoenixville Shops and later as their agent in the west. Beginning in 1887, in addition to the work for Phoenix, he also had his own engineering consulting business in Kansas City. While at Phoenix Bridge, he designed several major bridges including the Red Rock Cantilever Bridge over the Colorado River that was the longest single span cantilever in the country at the time. In late 1891, with his own consulting work thriving, he dropped the work for Phoenix. At this time, he began his long career in the design of long span lift bridges.

Waddell trained many men who later became partners with him in the bridge building business. The names of his firms are as follows:

J. A. L. Waddell	1887 - 1899
Waddell and Herrick	1899 - 1907
Waddell and Harrington	1908 – 1914
Waddell and Son	1915 - 1927
Waddell and Hardesty	1927 – 1945 (Waddell died 1938)
Hardesty and Hanover	1945 – present

Waddell's partners generally came up in the firm. Ira Herrick was Waddell's engineer and chief draftsman for many years before becoming a partner in his firm. John Lyle Harrington filled a similar position and with his knowledge of machinery collaborated with Waddell on several patents. He left in 1914 to form his own firm that was to become Waddell's main competitor.<sup>17</sup> In 1908, Waddell's son Everett graduated from RPI and came into the business along with a classmate, Shortridge Hardesty. By 1919, Waddell was devoting more time to writing and lecturing, while Shortridge Hardesty was running the firm. Given that a majority of their work had been in the Midwest and West, in 1920 the home office moved from Kansas City to New York City to be closer to the market the firm hoped to penetrate. Lift bridges had not been adopted in the East, and most movable bridges there were swing or bascule types. After Waddell's son died in 1927, Hardesty became Waddell's partner and the company name changed to Waddell and Hardesty. Hardesty retained the same company name after Waddell's death in 1938. Clinton Hanover became a partner in the firm in 1945 and the company became Hardesty and Hanover.

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<sup>15</sup> In 1882, he received a bachelor's and master's degree from McGill University.

<sup>16</sup> At Rensselaer, Waddell had taught the first two Japanese students to attend an American engineering school and his appointment may have been related to this connection.

<sup>17</sup> Originally known as Harrington, Howard and Ask (1914-28), Harrington's firm later became Harrington & Cortelyou (1928-present).

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The Commission and Bethlehem Steel must have approached Waddell and his partner Shortridge Hardesty to design a vertical lift bridge in place of the bascule soon after Norris' early November letter to the Commission. Given the price differential, it seems likely that the Commission had no qualms about the design change. The economics of the bascule versus vertical lift bridge were clear. In most situations when there was a need for a movable span with 300' shipping clearance, a lift bridge was significantly less expensive than the bascule. Shortridge Hardesty summed up the calculation, "the Portsmouth Bridge, where erection conditions greatly favor the bascule and bids for both a lift and a double-leaf bascule were received, the low bid on the superstructure alone erected in place, was \$66,000 less for the lift" (Howard 1921:686).

The news of the change in plan was reported in the November 11, 1920 Herald with the headlines, "Commissioners Also Accept Modified Straight Draw Plans for New Memorial Bridge." The article reported the commission's approval of the new design and the fact that it expected to be able to have the contract amount be "within the appropriation" (Herald November 11, 1920). At this same meeting, the foundation contract with Holbrook, Cabot & Rollins, was approved for the amount of \$612,000.<sup>18</sup> Because the foundations necessary for the lift span and the bascule designs were similar, the bids for the substructure did not have to be redone for the new design and Holbrook, Cabot & Rollins could start work.

On November 19, 1920, just a few weeks after the idea of a lift bridge was first proposed, Waddell signed a contract with the Commission for the design of a lift bridge and "general inspection of the work on the superstructure and for final inspection when completed" (Waddell 1922). However, work on the drawings was, without question, well underway by this time. The preparation of plans and specifications for a major bridge in "about two weeks" was unheard of even at this time. To accomplish this it would be necessary for Bethlehem Steel and American Bridge to prepare bids on less than complete drawings. The Commission's request for proposals indicated that proposals were due by noon on Monday, December 20, 1920 (Piscataqua River Bridge Commission 1920). Given the fact that the Commission did not approve the change in bridge style until November 10 and bids were due only slightly more than one month later, Waddell was under great time pressure to produce the plans necessary for bidding.<sup>19</sup> The first bid drawings were prepared by Waddell's shop on November 16, 1920 and re-traced on November 17 two days before they had signed a contract with the Commission to prepare the design. The plans were checked by Shortridge Hardesty on December 1, 1920. It is likely that the Commission had to formally approve the bid documents before they were made available to the bidders. Allowing time for review by the commissioners and time to reproduce the drawings and get them out to the prospective bidders, the plans were probably not in the hands of the bidders until the first or second week in December.

Waddell, apparently with the permission of the Bridge Commission, and agreement with the bridge building companies only prepared eight drawings for the project. They were:

General Layout (see Tab O, Drawing 7)

Stress Sheet for Truss Spans (see Tab O, Drawing 8)

Stress Sheet for Towers and Counterweights (see Tab O, Drawing 9)

General Drawing of Lift Span (see Tab O, Drawing 11)

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<sup>18</sup> A contract was signed November 24, 1920. The contract amount was modified on July 25, 1921 to \$698,823.

<sup>19</sup> Although it is unknown when the request for proposals was released, normally, for major projects such as this, plans had to be available for a two-week period to give the fabricators time to prepare their bids.



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### Details of Deck and Floor System (see Tab O, Drawing 12)

### Details of Main Sheaves, Shafts, and Bearings (see Tab O, Drawing 13)

### Details of Equalizer and Ropes (see Tab O, Drawing14)

General Layout of Operating Machinery (see Tab O, Drawing 15)<sup>20</sup>

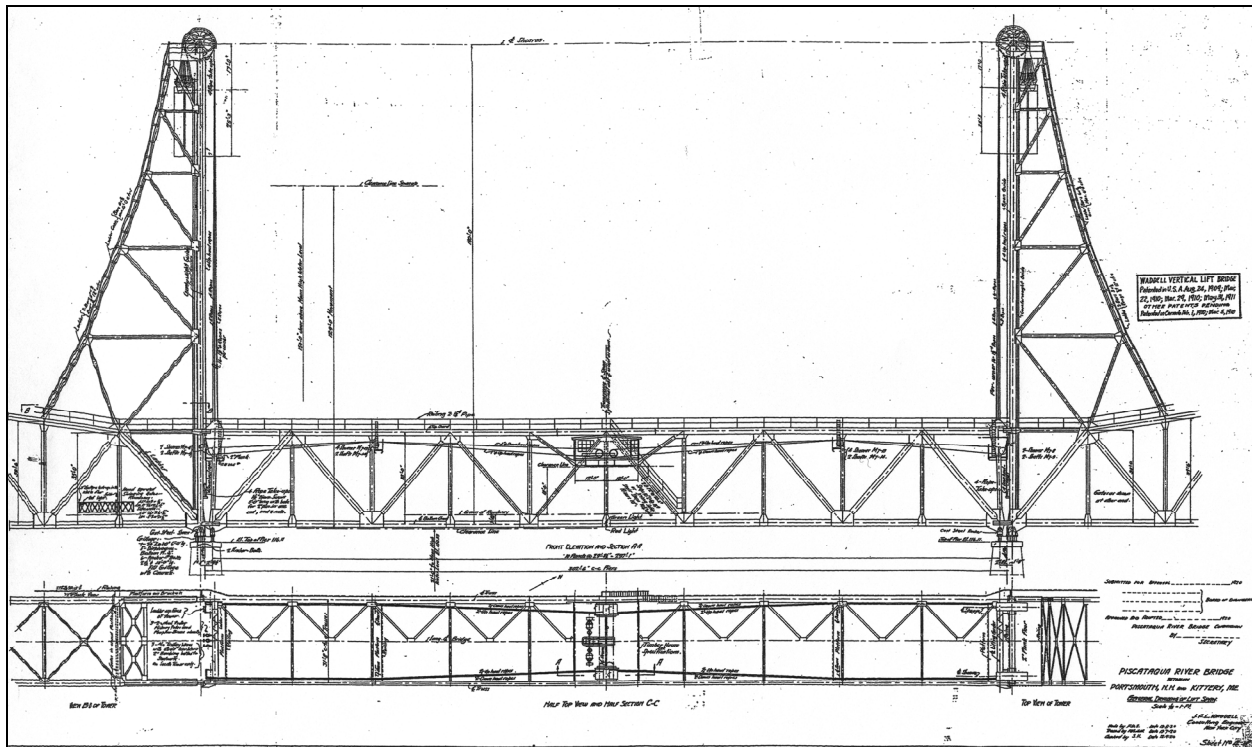


Figure B-4: Lift Span/Towers (NHDOT) [Larger scale version at Tab O Drawing 11]

To provide the contractors with additional information, Waddell included eight drawings from the Louisville Bridge illustrating the operating machinery. He also included six drawings from the Columbia River Bridge. These drawings gave the construction details of the three spans and two towers. Section 11 of the Specifications stated “As soon as practicable after the contract for building the superstructure is signed, the Consulting Engineer will furnish complete detail plans, in strict accordance with which the Contractor shall prepare his shop drawings or working drawings” (Piscataqua River Bridge Commission 1920:14).

The superstructure bid package gave two alternates. The first was for the elimination of one sidewalk and the second was “for constructing lift span similar to fixed spans (Piscataqua River Bridge Commission 1920:53). The low bid on the steel work was submitted by the American Bridge Company, which bid \$619,000. American Bridge’s bid package included an alternative bid with a price reduction of \$9,000 to eliminate the sidewalk and a reduction of \$3,500 to make all three spans similar in plan. Waddell had estimated that 60,000 pounds of steel could be saved by making all three spans the same way (Piscataqua River Bridge Commission 1920:49). The date of completion was set at December 31, 1922, with a \$200 per day penalty for every day past this date. The Commission did not accept either of the alternates and signed the contract with American Bridge for the base bid of \$619,000 on December 28, 1920. Bethlehem Steel, which

<sup>20</sup> See Tab O for these drawings.

## *Memorial Bridge Historic Structures Report*

had proposed the lift span design that made construction of the bridge possible, bid \$634,000 and lost the project.

Founded in 1900 by J.P. Morgan and Company, the American Bridge Company represents a textbook example of the growth of monopolies in the early twentieth century. In its first year of existence, the company purchased twenty-four bridge companies, representing half of the country's fabricating capacity (Darnell 1984). The company became a subsidiary of the United States Steel Company in 1901. The headquarters of the company were located in New York. It remained the largest structural fabricator in the country well into the twentieth century. Still in business today, it has constructed a variety of buildings and bridges varying from the Hell Gate Bridge, to the 7<sup>th</sup> Street [Pittsburgh] Bridge to the George Rogers Clark Bridge. It also was contractor for the Empire State Building.

In December, the Herald wrote in support of the new bridge design trying to dispel the notion that the lift design was "cheaper" than the earlier plan. The article concluded, "the first [design] was far more complicated and naturally much more expensive, but the present plans while of simpler construction are in every way just as good and in the minds of some engineers better for this kind of a location" (Herald December 24, 1920). The article went on to describe the bridge as follows,

The travel way is 28 feet from curb to curb, this means, three traffic width, that is trolley cars, and two automobiles may pass at one time or for two lines of traffic and room for a passing car on either side. The new plan calls for two sidewalks, one on each side, where as the old plans called for but one sidewalk. The draw is one that lifts the required height to allow river traffic, rising from a few feet to 150 feet above low water mark, and it is the same type that is used in rivers where there is a great amount of traffic. One bridge of this type in Washington state being lifted 2000 times in one year for river traffic. It is very quickly operated and the delay to traffic, by either land or water will be cut to the minimum.

### 5. Construction of Memorial Bridge (1920-23) and Subsequent History

With a significant head start over the superstructure, the first major work on the bridge related to the substructure. The substructure design consisted of four main concrete supports: two deep (85'-90') piers in the middle of the river (at either end of the lift span) and two shallower piers (or abutments) located at either end of the flanking spans (at the junctures with the approach spans).

In December 1920, the Herald reported that the lighter <sup>21</sup>and scow that would be dredging out the foundations of the piers had arrived and that Holbrook, Cabot & Rollins would be starting work immediately. At the same time, buildings at the old Broughton's Wharf at the foot of Daniel Street were razed "for work on the shore abutment" (Herald December 24, 1920) (see Plate N-6,7). In early January, Holbrook Cabot was dredging the site of the Badgers Island Pier (Herald Jan 5, 1921).

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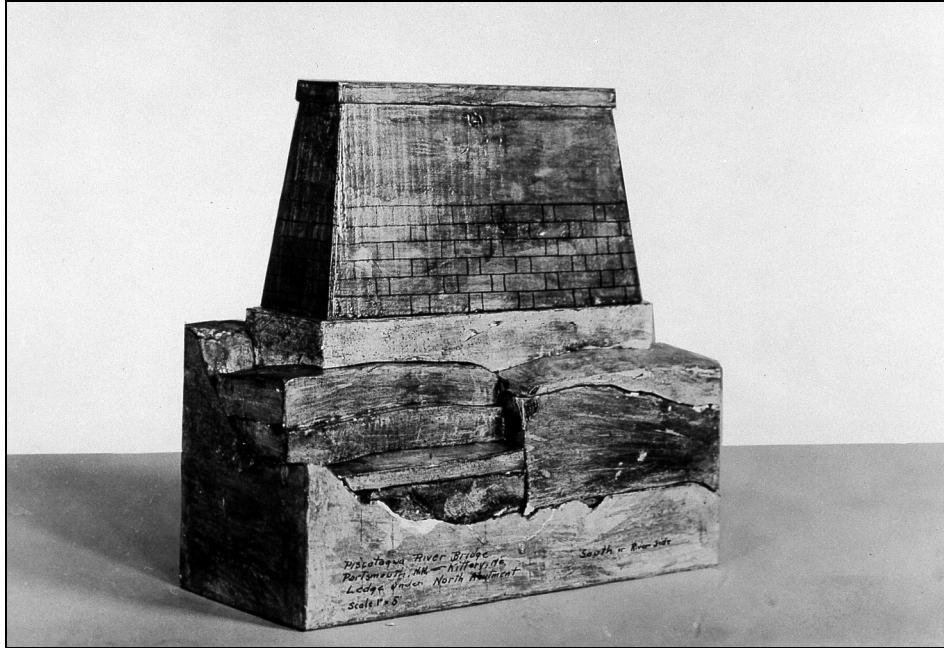
<sup>21</sup> A lighter is a flat-bottom barge usually used for loading and unloading ships.

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The two piers in the channel were constructed using large wooden pneumatic caissons (the equivalent of an airtight, bottomless box) that were floated into place and anchored on to rock on the river bottom (Plate B-5). After the caissons were sunk and the water inside the caisson was removed by air pressure (using a large floating air compressor), the soil inside was excavated and concrete was poured in a specified layering system. A big floating concrete mixer, with a capacity of twenty-five yards an hour, poured concrete inside the caisson walls, up to an elevation of 2' below mean low water. Work on the piers was done using six shifts operating both day and night. Because of the air pressure in the caisson, workers could work only four hours at a time to escape the effects of the bends (Herald November 30, 1920). In order to avoid the heavy erosion that occurs at water level, the piers were armored with granite blocks up to a top-of-pier elevation of 116.11' (or 114.58' at the two bridge abutments). A wooden fender pile system was designed to protect the two main lift span piers. The extreme depth of water (in some places 60') required that the wooden piles be spliced and strongly cross-braced to absorb the impact of any shipping accident.



*Plate B-5: Caisson for South Pier (June 4, 1921) (Portsmouth Athenaeum)*



*Plate B-6: Model of North Abutment (ca. March 1922) Maine DOT*

Foundation work took about one year, beginning in earnest in March 1921 and continuing until February 1922. Throughout the process, the contractor, Holbrook, Cabot & Rollins, faced problems with the tidal current and the conditions of the river bottom. Initially, they had problems placing the pneumatic caisson for the Kittery pier due to the rapid current and bedrock bottom of the river at this location. The caisson for this pier was launched in April but had to be towed back to the fabrication area due to problems keeping it in place. The Herald reported on May 23 “the caisson began giving trouble.... when the hausers and cables holding her anchor blocks were broken by the force of the flood tide” (Herald May 23, 1921). After several days of trying to hold it in place, even with additional cables, it was returned to its berth to prevent it floating away. It was towed back to its location on June 16 and set in place.

In October 1921, the Portsmouth lift span pier caisson was positioned. (Plate B-6) It gave Holbrook, Cabot significant difficulty, as there was virtually no soil overlaying the bedrock on which to seat the caisson. The Herald reported

They found that the pier site, at a depth of nearly eighty feet, was such that the caisson would have no hold on the bottom. Their divers found that it was just a mass of boulders of various sizes and with no gravel, or mud of any kind to hold the foot of the caisson. This made it necessary to build a false bottom or a mattress for the caissons to set on, so that it would hold. This had been done this week by the use of clay and gravel fill. The clay was brought down the river in barge loads and placed as near as possible on the site of the pier. The clay filled in around the boulders and formed a mat. This was not a simple matter for the tide at this point is very strong and all work had to be done at low water, slack, to get the best results, with no security that the next tide would not sweep it all away” (Herald October 7, 1921).



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The same article indicated that the contractor was having trouble sinking the sheet piling for a cofferdam at the Kittery abutment and had to redrive many pilings due to a very irregular bedrock profile. Even with this host of troubles, the elements of the substructure were in place in early 1922 with the American Bridge Company being notified on March 1, 1922 that they were ready for the superstructure.

The fabrication and erection of the flanking and lift spans were the cause of many discussions between Shortridge Hardesty and engineers from the American Bridge Company. Standard operating procedure at this time was to allow the contractor to determine the means and methods of erecting the bridge with the review and concurrence of the engineer. The bid documents specified that although “the logical manner of erecting all three spans is by flotation” the choice was left up to the contractor although he had to get permission “from the proper authorities” (Piscataqua River Bridge Commission 1920:13). Hardesty, however, had a different view. In 1921, before steel work commenced, Hardesty reported,

Two erection schemes have been considered. First, building all three spans on falsework near one bank about 1/2 mile from the site, and floating them into position; and, second, erecting the end spans on falsework and cantilevering the lift span out from both sides. Owing to the dangers attending the use of the first scheme at this location, the second plan is preferred. The spans are of riveted construction, but the central bottom chord member in each truss of the lift span is pin-connected. This member will be omitted until all the other joints are riveted, and the towers, ropes, machinery, and counterweights are in position, in order to provide a restricted channel for the infrequent river traffic. When all is ready, the omitted members will be put in. The abutment shoes of the fixed spans jacked up to relieve the stresses in the temporary cantilever members over the piers, and these members removed. The span can then be lifted at once (Hardesty, quoted in, Howard 1921:632).

The method that Hardesty was advocating, using flanking spans as anchorages for erecting a central span using cantilever methods, had been developed by Waddell for the Nippon Railway in Japan and the Northern Pacific Railway in British Columbia across the Fraser and Thompson Rivers. American Bridge evidently did not agree that the “dangers attending” the floating in of all three spans was as serious as Hardesty and they opted to build all three spans upstream and float them into place.

The erection site was near the old ferry site at the Concord (B & M) Wharf at the north end of Market Street in Portsmouth (Figure B-5). The site, close to the railroad, was selected to cut down on material handling and to permit the erected spans to be floated down the river. (The prefabricated bridge parts, including the three truss spans, were delivered by rail from where they were fabricated in Pennsylvania.) Platforms on wooden pilings were erected off the end of one pier, and erection travelers, built running on rail, were installed to place the prefabricated members in place prior to riveting. When the truss members had been assembled and marked at the shop, all rivet holes were reamed to ensure a tight fit on the rivets.

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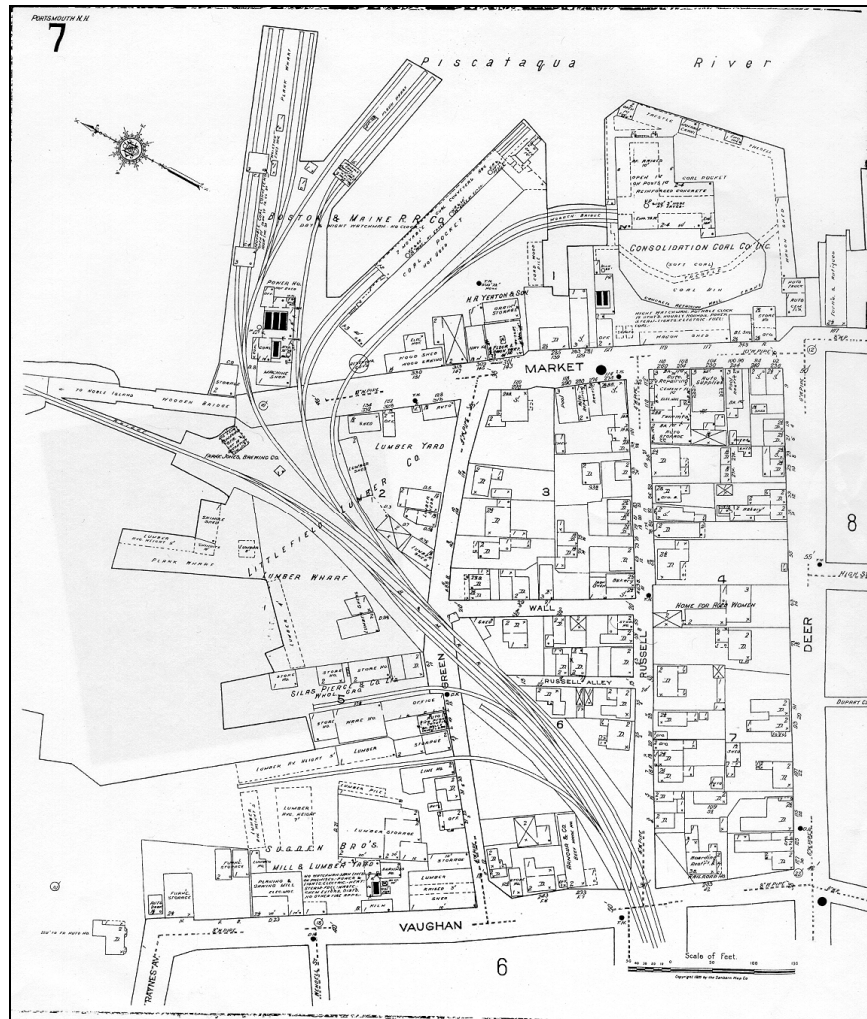


Figure B-5: 1920 Sanborn showing Concord Wharf, staging area for construction of Memorial Bridge truss spans



*Plate B-7: South Span on Concord Wharf, August 7, 1922 (Portsmouth Athenaeum)*

After the riveting was complete and the piers were ready to receive the truss, the process of moving the bridge spans began. By the 1920s, the process of floating a span into place was a standard method and was complicated only by the speed of the current. To move the span, two barges were floated into place under the truss at low tide. Timber cribs were built on the barges up to the lower chords of the truss and the rising tide lifted the span off its falsework. (Plate B-8) For the flanking spans, the wooden cribs were placed so as to make contact with the trusses at the third and fourth panel point (from the end of the truss closest the shore) and the second and third panel point (from the end closest to the draw span). This prevented the barge from running aground as it neared the shallower shore area. This required temporary support of the vertical at the fourth panel point, as those members were designed as tension members under normal loading but in this case had to support compressive loadings.

American Bridge used powerful tugboats to move the spans off the falsework. After lifting the spans they waited for the tide to begin dropping and used the slowly moving outgoing tide to help float the span into place. Upon reaching the pier and abutment, the bridge was held in place by the tugs until the tide ran out and the span settled slowly onto its supports. The tugs then pulled the barges out from under the spans



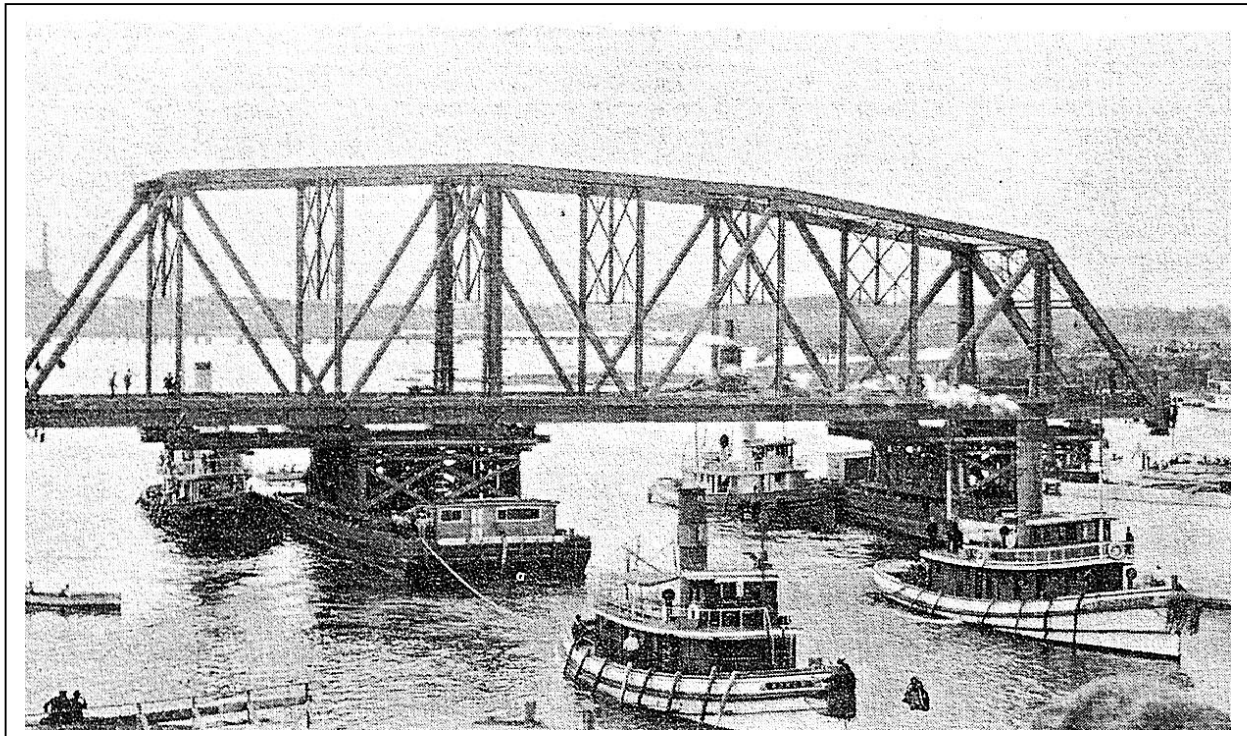
*Plate B-8: Raising South Span on Lighters, August 12, 1922 (Portsmouth Athenaeum)*

American Bridge requested an adjustment to their contract for modifications to their plan to fabricate and float the spans into place when the Commission had not removed Walker's Dock on the Portsmouth shore in a timely manner (see Plate N-5). A decision was not made on this matter until after May 1922 when the Commission decided to remove the dock on their own. In the meantime, however, American Bridge had fabricated the span without the end two panels so as to avoid the dock when moving the span into place (Plate B-10). American Bridge was forced to construct a temporary pier to support the (shortened) south end of the south flanking span (see Plate N-29). They then built out the two missing end panels from the temporary support to the shore abutment.

On July 3, 1922, the flanking span on the Kittery side was the first span of the bridge to be placed. The base frame for the stiff-leg derrick that would be used to erect the Kittery Tower of the lift span and associated sheaves, counterweights, cables, etc was mounted on the south end of the span's top chords. The Portsmouth flanking span, set into place on August 12, 1922, was handled in exactly the same way, with the exception that the two end panels were built on falsework (Plate B-9).



*Plate B-9: Moving South Span to Piers, August 12, 1922 (Portsmouth Athenaeum)*



*Plate B-10: Portsmouth span in transit, note left two panels missing and barge closer to center of truss (Dufresne 1961:17)*

While the lift span was being fabricated, the derricks were erecting the towers and placing the sheaves and counterweights. Normally lift spans were placed or erected in the down position and the counterweights erected/placed in the up position. Although Waddell had planned to use his typical counterweight design, consisting of concrete placed around a steel framework that

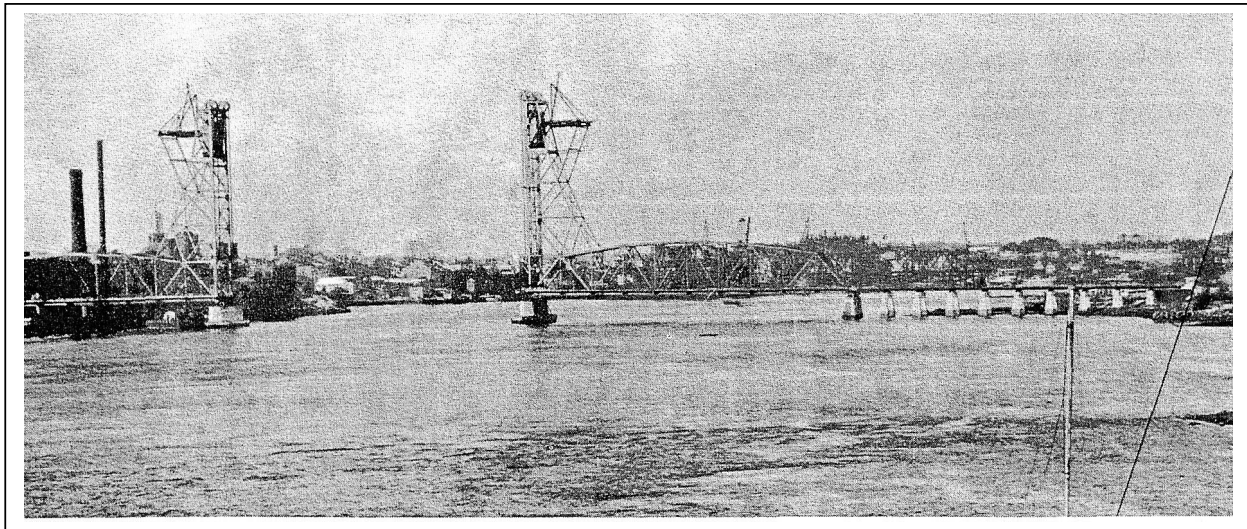
## *Memorial Bridge Historic Structures Report*

connected to the equalizers, American Bridge suggested another method. Hardesty approved the change, reporting,

In working out the erection plan, however, it was found advisable to be able to swing the span and raise it without having to wait for the counterweight concrete to set, and also to be able to add to the counterweights later when the deck was being placed, without preventing the operation of the span. For these reasons it has been decided by the contractor to cast each counterweight in a steel box suspended from the equalizers making the box strong enough to carry the wet concrete. The saving in erection cost and time will be sufficient to pay for the extra metal in the steel boxes (Hardesty, quoted in, Howard 1921:632).

Prior to connecting the counterweight cables, the tower members were strengthened to carry the additional load of the steel boxes filled with concrete. This was also a part of the extra metal referred to by Hardesty. With all this work performed prior to moving the lift span into place, all that was required to make the span operational was to connect the counterweight cables using the derricks and connect the operating cables from the machinery house to the towers

The lift span was fabricated on the same falsework as the tower spans but it included the machinery and machinery house as well as associated equipment. The erection however, occurred some four months later. This delay was apparently due to problems getting materials for the tower on the Portsmouth end. A railroad strike slowed the transport of the steel from the plant to the site (Herald August 1, 1922).



*Plate B-11: Flanking Spans in Place, Derricks in Place on Towers, Counterweights in Place.  
Looking Westerly (Dufresne 1961:18)*

In December, everything was finally ready for placing the draw span. The Herald, with the headline “Last Span of Memorial Bridge Placed Today” described the process as follows:

The draw span, last of the Memorial bridge connecting Portsmouth and Kittery, left the docks where it was constructed at 1:30 o’clock this afternoon and a half hour afterwards was in place. The work was carried out with speed and the regularity of clockwork. During the morning at low tide, the barges Rose R. and Laura R., were eased under the span and the supports and

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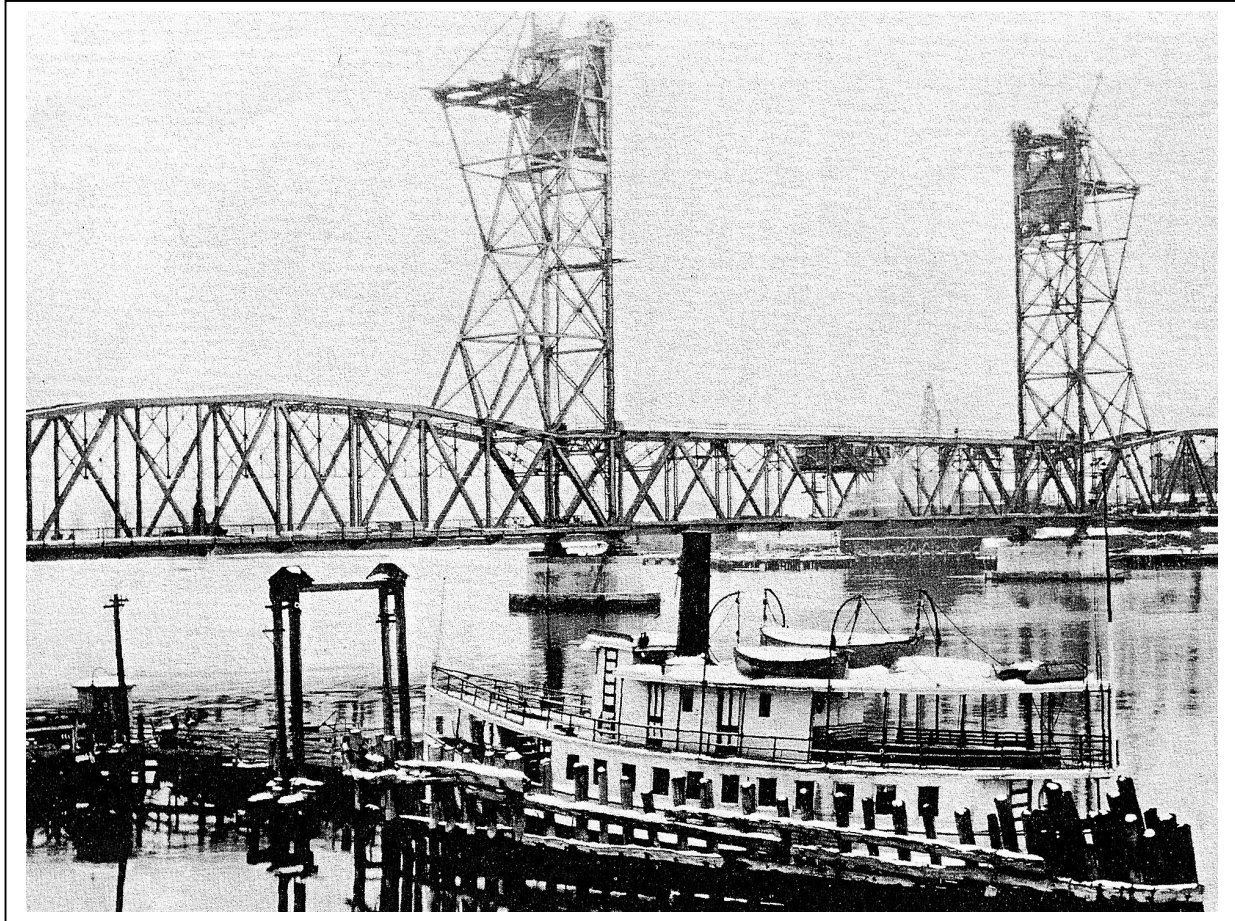
uprights placed. A crew went to work immediately to secure the barges against possible mishap and by 11:30 o'clock, the span was floating free of its previous support. The day was ideal for placing the span. No wind marred the program of the monster floats from the dock to the bridge site. The tide was extremely high. In fact, the span was not moved until an hour after high tide to take advantage of the slack and the drift of the current on the trip down. The floats were assisted down the river and into place by the tugs Brightsboer and Mitchell of the local fleet, and the government tugs Penacook and Wooley. Without a hitch and without incident, the last span of the Memorial Bridge was placed..." (Herald December 20, 1922)

Although crowds observed the arrival of each of the spans, the floating in of the last span was a major spectator event. In addition to thousands of lay observers, the Herald noted that:

Among those who are here today witnessing the placing of the span are: Shortridge Hardesty, designer of the bridge; Mr. Williams from the New York city office of the company; Mr. Harris, city engineer of Trenton, N. J.; Mr. Record, superintendent of bridges of Trenton; Mr. Davis contract manager of the Company, Mr. Waldron, eastern contract manager formerly of Portsmouth; State Engineer Sargent of Maine, State Engineer Everett of New Hampshire; W. A. Rowell, engineer Portland Cement Association; several army and navy officers and city officials" (Herald December 20, 1922).

The officials from Trenton, New Jersey were present because Waddell was about to build the Southard Street Bridge crossing the Delaware and Raritan Canal. That bridge, with a span of only 70', opened in 1922, and another, the Olden Bridge, very similar and just down the canal, with a span of 74' opened in 1924. Being canal bridges, the lift was only 28' giving a clearance above the canal surface of 50'.





*Plate B-12: Lift Span in place before cables attached, derricks still in place (Dufresne 1961:16)*

With the main spans in place, it was estimated that the entire bridge project would be open soon, even though it had missed the projected December 31, 1922, completion date. The Herald reported, “The river will be closed to all vessels that cannot pass under the span until about January 9 when it is expected that the draw will be ready for raising” (Herald December 20, 1922).

What remained to be done at that time was to connect the counterweight ropes to the equalizers on the counterweights and the lift span, install the uphaul and downhaul ropes, and make any required electrical connections. In addition, the wooden deck on the roadway and sidewalks needed to be placed, along with the railings. It is likely that the decks on the flanking spans would have been in place by that time. From construction photographs, it appears that the sheaves were in place, and the derricks that were needed to lift and place the ropes were still mounted to the tops of the towers. The wooden floor of the lift span was completed on January 27, 1923.

The bridge was largely completed by February 1923, three months after the completion date. However, in May when the bridge was still not open, the Herald and the residents of Portsmouth were getting impatient. One headline summed it up, “Public Want Bridge Open to Foot Travel.” The paper decried the “unexplainable reason” for the holdup, given that the “draw has been operating like clock work for the past few months.” What then went wrong, pushing the opening date back almost seven months to August 17, 1923? The question was answered in the July 23, 1923 Herald when it reported, “the crew from the American Bridge company... have pinned the

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sheaves on the north towers and will have the two on the south tower pinned by Monday or Tuesday. This work is all a matter of precaution for all of the bridge company's engineers state there was absolutely no reason why the bridge should not have been in operation for the past month at least and there would have been practically little if any delay even if this extra work had to be done." Three days later, on July 26, the Herald reported,

Today the workmen of the American Bridge Co. succeeded in putting back in place the sheave on the Kittery side for the Memorial Bridge tower. This movement was 5/8 of an inch and made by use of hydraulic jacks. Drilling for the 1- 1/4-inch steel pins to hold the same was commenced this afternoon. Consulting Engineer Starr for the bridge company and Engineer Hardesty for the designers was present while the work was being carried out. The job was accomplished in much less time than was expected by the contractors and designers (Herald July 23, 1923).<sup>22</sup>

As this exchange would seem to indicate, there was disagreement between Waddell, Hardesty and the American Bridge Company about the construction of the bridge operating machinery. The problem of keeping the sheaves pinned to the shafts that was evident at this time was to plague the bridge many times in the future. American Bridge Company saw small movements of the sheaves with respect to the shafts as a minor problem, while Waddell/Hardesty saw it as a long-term problem that needed to be fixed before accepting the work of the contractor. If this movement was allowed to go uninhibited, the sheave could eventually slide off the shaft and bind up or break the shaft. With this repair completed, final last minute painting, installation of traffic gates etc. was undertaken. The approaches were paved and lined and preparations made for the Grand Opening.

The bridge was opened on August 17, 1923 with a variety of dignitaries, including the Governors of New Hampshire and Maine, the Bridge Commission, and representatives of the US Navy in attendance. After the speech making, five-year old Eileen Dondero, was selected to cut the ribbon, officially opening the bridge. Both Dondero and her mother, Mary, would later become Mayors of Portsmouth. After cutting the ribbon, a select group was given the chance to be in the machinery room while the span went up and down. After that, thousands of jubilant Portsmouth and Kittery residents walked across the bridge. Thus, the decades-long struggle to connect the two towns and the Portsmouth Naval Station via a modern, safe, free bridge was over.

In the years that followed, Memorial Bridge proved popular and it played a role in increased traffic up and down the East Coast. In its first few weeks of operation, an average of four and a half times more people used the bridge every day than had used the old 1823 bridge (U.S. House of Representatives 1919:111; Herald October 5, 1923). Memorial Bridge, in fact, quickly proved too popular. Within years of its opening, backups and traffic tie-ups were common on the section of Route 1 in New Hampshire, largely due to Memorial Bridge (Openo 1987:20). Backups were particularly prevalent on summer weekends when there was an influx of vacation travelers and when the Memorial Bridge draw span was open. These delays fueled arguments for a new bridge that eventually was constructed further up river in November 1940 (today the Rt.1 Bypass/Sarah Mildred Long Bridge).

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<sup>22</sup> See also 1940 letter from Hardesty to American Bridge Company describing the sheaves' "tendency to crawl along their shaft." (Hardesty 1940)

## *Memorial Bridge Historic Structures Report*

Although difficult to quantify, Memorial Bridge clearly played a decisive role in increasing local Maine-New Hampshire travel and, perhaps more significantly, travel along the entire eastern seaboard. The bridge's role in increasing long distance travel can be seen in the fact that in the bridge's first seventeen days of operation, only 24 percent of the vehicles using Memorial Bridge were from New Hampshire. Although vehicles from almost all states were present during this period, the greatest number of non-Maine or New Hampshire cars was actually from Canada (Herald October 5, 1923).

### 6. Engineering Context of Memorial Bridge/Evolution of Vertical Lift Bridge Design

By the early twentieth century, when contemplating how to span a water body while at the same time permitting the passing of sizeable ships, there were basically four options: retractile, swing, bascule and lift bridges. Retractable bridges, which slide back horizontally onto the adjacent roadway, required extensive land to accommodate the moving part of the bridge when open. By the turn of the century their use had waned. Swing Bridges, which open by pivoting on a horizontal plane from a central pier, had a drawback because the central pier (and its island) were an obstruction to navigation and occupied too much of the channel. Given these problems, by the turn of the century, the two most popular designs for moveable bridges were the bascule and vertical lift bridges. Bascules, which date to the 1890s, open like gates, by having the lift span(s) raised to a vertical position. These bridges, developed primarily for the rivers of Chicago, became the preferred movable span in the U.S. between 1900 and 1920 for longer spans. The vertical lift bridge, which became widely used for extended spans only after 1910, opens when the central span, which is connected on either end to towers, rises vertically while remaining horizontal. The lift design and the bascule design were in competition throughout the United States during this period for a variety of crossings. The selection of one design over another was largely a function of economics, aesthetics and the local preference of engineers.<sup>23</sup>

The first recorded design for a vertical lift bridge dates to the 1500s and Leonardo da Vinci. It was, however, the seventeenth century before one was actually built: a 30' span over the Danube River at Vienna that lifted 6.5'. Although a few short spans with low lifts were subsequently constructed in Europe, the next major advance in the design came about by the work of the man often referred to as "the father of American bridge building," Squire Whipple. Whipple, initially with the Baltimore & Ohio Railroad, invented a number of early iron bridge designs, built a sizeable number of bridges over the Erie Canal, and authored the influential book, A Work on Bridge Building... and Practical Details for Iron and Wooden Bridges. In 1873, Whipple constructed the first vertical lift bridge in the United States across the Erie Canal at Utica, New York. Whipple was asked to design and build the bridge as an alternative to the swing bridges which when opened occupied excessive amounts of valuable canal frontage. Whipple's patent #134,338, (Figure B-6) issued on December 24, 1872, claimed the following unique characteristics:

1. In the construction of lift draw-bridges, the combination of the counterpoised vertical movable way or platform, the trusses, the suspension rods, chains, or ropes, the longitudinal shafts on each side of the bridge, and the transverse shaft

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<sup>23</sup> Which bridge type was less expensive depended on the individual nature of the site. Bridge engineers in a particular locality often were most familiar with one type of movable bridge and thus were more apt to use that variety.

## Memorial Bridge Historic Structures Report

or shafts and gearing, substantially as and for the purposes specified.

2. The longitudinal and transverse shafts connected by gearing to effect the simultaneous rotation of the shafts and a uniform vertical movement of all parts of the platform, substantially as specified.
3. The combination of the power-weight and winding-drum *m* upon the transverse shaft *f* for the purpose of working the draw, substantially as set forth.

Whipple identified the chief advantages of his design as the fact that it was inexpensive, easily worked and occupied less space (or channel) than swing bridges.

Whipple built one other bridge across the canal before his patent expired in 1887. After that, many bridges were built on Whipple's plan but with electric motors replacing a man-powered system.

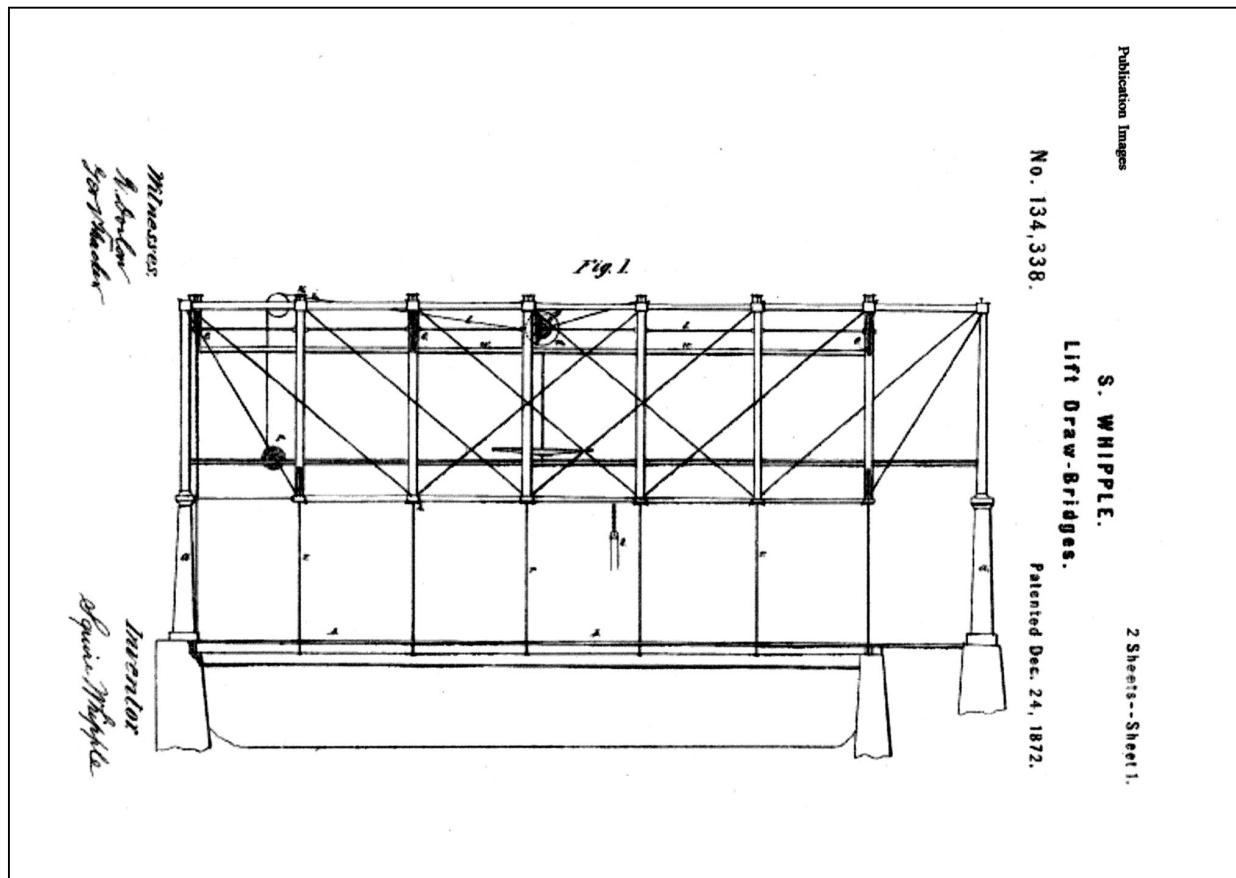


Figure B-6: Whipple Patent Drawing (U.S. Patent Office, Patent No. 134,338)

## *Memorial Bridge Historic Structures Report*

Until Waddell's influential design, the patents following Whipple's did little to advance the technology of the long span lift bridge. The following patents for lift bridges followed Whipple's:<sup>24</sup>

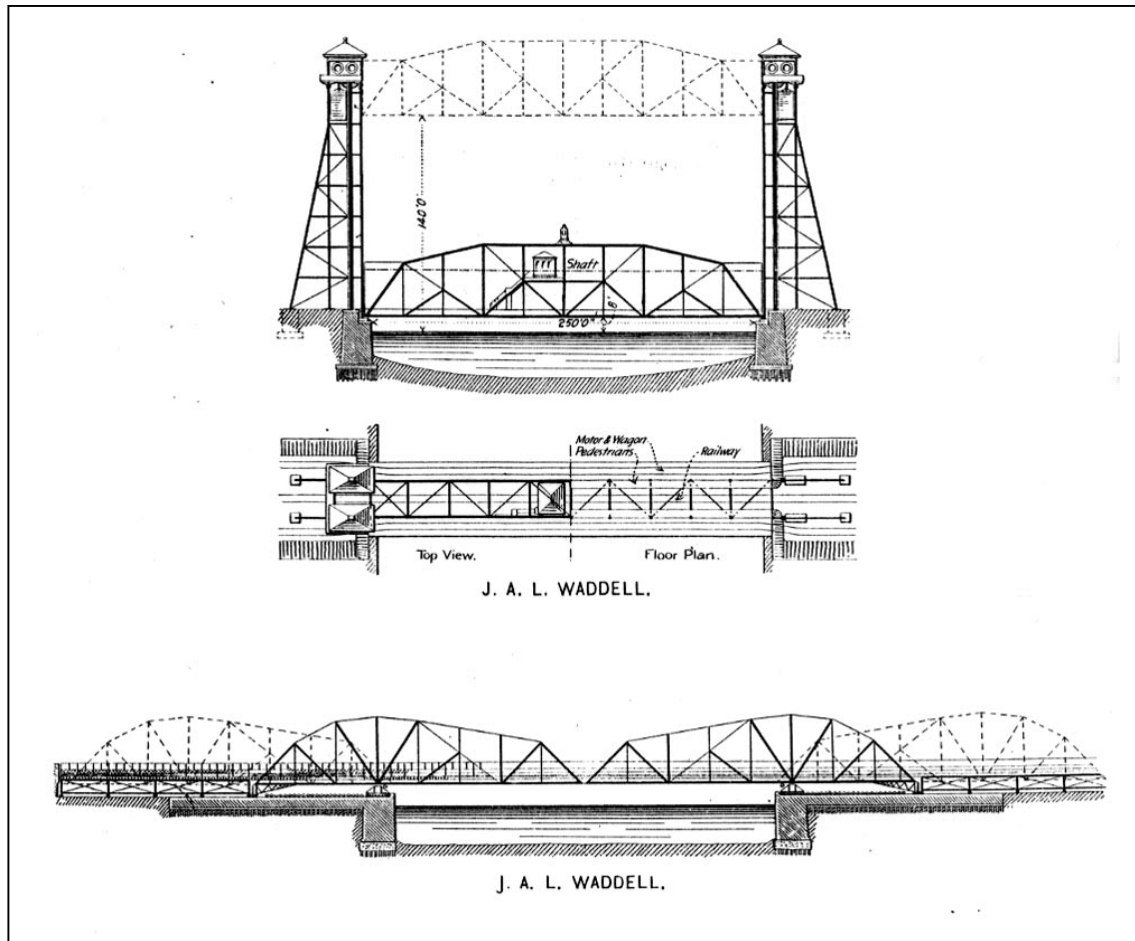
Patentee	Number	Date
Soulerin, L.	153,729	August 4, 1874
Post, A. J.	162,576	April 27, 1875
Whitemore, E. B.	225,775	March 23, 1880
Alden, J. F.	431,101	July 1, 1890
Waddell, J. A. L.	506,571	October 10, 1893

*Figure B-7: Post-Whipple Patents*

John Alexander Low Waddell's first efforts associated with a vertical lift design were unrealized. Responding to a notice of a design competition for a drawbridge in the November 12, 1891, issue of Engineering News, Waddell submitted two designs that satisfied the quite stringent conditions of the competition, including the one that "plans submitted for swing bridge will not be considered" (Engineering News 1892:168) (Figure B-8).

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<sup>24</sup> Soulerin's patent, while called a lift bridge, actually had the bridge sink into the water and the boat pass over it. Post's patent was for a street bridge crossing a canal similar to Whipple's; there is no evidence that his bridge was ever built. Whitemore's patent was for a low lift bridge over a canal with a deck supported by two beams that was lifted a short distance above the water surface. Alden's patent, which was issued after Whipple's had expired, was very similar to Whipple's in that it had a fixed overhead truss with a deck that was lifted by similar shafting and gears.



*Figure B-8: Waddell's Two Proposals for Duluth Harbor Crossing*

Waddell's lift bridge design, which had a span of 257' between centers of bearings providing a clearance for shipping of 140', was unique. Nothing of this size had ever been proposed in the United States.<sup>25</sup>

In his proposal, Waddell described his lift bridge, in part, as follows:

At each side of the canal there will be a strong, well braced and guyed tower about 195 feet high above the water level, carrying at its top built steel and iron pulleys 15 feet in diameter. Over these pulleys 48 steel cables 1-1/2 inches in diameter will pass. One end of these ropes will be attached to an end pin of the truss, and the other end to one of the counterweights which will be so proportioned as to just balance the dead weight of the span. The weight of the cables will be counterbalanced by cast-iron chains. On account of this counterbalancing all the work that the operation machinery will have to do is to overcome friction, inertia of the mass and the variable dead load on the bridge due to dirt, snow and water.

<sup>25</sup> Several bridges of similar span had been proposed in Europe, although none had been built.

## *Memorial Bridge Historic Structures Report*

The power to operate the bridge will be supplied by two electric motors, either of which will be sufficient to operate the machinery. From 20 to 30 horse-power will be required...The motion of the armatures is to be communicated by a worm gear to a shaft on which are keyed two 5-foot drums, having on their peripheries spiral grooves for coiling up the four steel wire rope cables, each of which is fastened at one end to the top the tower, at the other end to the masonry of the pier and at the middle of the operating drum. These ropes are kept taut at all times by adjusting rods at both ends...The approximate weight to be lifted is 950,000 pounds consequently that of the counterweights must be the same. As the weight of the cast-iron counterbalancing chains is about 62,000 pounds the total moving load will be 1,962,000 pounds. At the top and bottom of the towers there will be hydraulic buffers capable of bringing the structure to rest from its maximum velocity without injurious shock. After the bridge is down it will be held in place by a locking gear attached to the ends of the spans and operated from the machinery house. (Engineering Record 1892:398)

In this first design, Waddell addressed most of the problems that would face the development of a unique bridge. Lifting a weight of 950,000 pounds was unheard of at the time but using a simple pulley at the top of a tower and a counterweight using gravity to do the heavy lifting made the task possible in Waddell's design. The steel wire rope needed to support the span and counterweight was twisted around a central rope of wire or oil-saturated hemp. Waddell generally suggested a hemp core, as it was more flexible and would permit a smaller diameter pulley system. Wire rope then had an ultimate strength of almost 200,000 psi. The use of electric motors was also an innovative step as most engineers were still thinking of steam power as the preferred mode. In the end, the War Department decided that a bridge in this location, was "a menace to navigation" and no bridge was built at the time. Waddell, in frustration, remarked that it was an example of "the general futility of having engineers compete on plans."

Shortly thereafter, in 1892, the Commissioner of Public Works of Chicago retained him to design a similar, but smaller, lift span over the south branch of the Chicago River to replace a damaged swing bridge. The South Halstead Street Bridge was to have a lift span of 130' with a lift of 140' (Figure B-9).<sup>26</sup> The bridge would carry a double-track street highway as well as pedestrian and carriage traffic on a clear roadway width of 34' with the sidewalks cantilevering off the main deck. Waddell's design used 12' diameter sheaves on top of the towers with thirty-two wire ropes connecting the counterweights with the movable span. As a precaution, he placed four water-containing steel boxes under the lift span in which he could add or remove water to maintain the balance between the span and the counterweights. He used a cast-iron chain with one end connected to the movable span and the other connected to the counterweight. With this mechanism he balanced the weight of the suspending cables in a continuous manner such that when the span came down with more cable on the movable span, the chain would place a similar amount of weight on the counterweight and vice versa. He used guide wheels running in special tracks to keep the span in place laterally and longitudinally. These wheels were mounted on a spring-loaded mechanism that kept them in contact with the guides.

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<sup>26</sup> The Corps of Engineers required the clearance be increased to 155', which is interesting, as it only required a clearance of 135' on the Brooklyn Bridge over the East River where larger ocean going ships predominated.



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However, there was serious opposition to the design from local engineers, including the then-Dean of American bridge building, George S. Morison. Given this opposition, the City Engineer tried to cancel the contract, although some of the substructure had already been completed and much of the metal work had been manufactured. According to Waddell, the bridge would not have proceeded except for the fact that “the city of Chicago would have had to pay the full contract price for the structure whether it were built or not” (Van Cleve 1919:1035). Waddell’s troubles, continued however, when the company building the lifting mechanism, with city backing, would not guarantee the operation using electric motors. Waddell was forced to use two 78 HP steam engines rather than the two 65 HP electric motors he had hoped to use. It was clear that Waddell consented to these changes in large part because he wanted to demonstrate the overall reliability and suitability of his lift bridges, particularly in settings with large volumes of river traffic. Of particular importance was the fact that his bridge could be raised in under one minute (Waddell 1895:60).

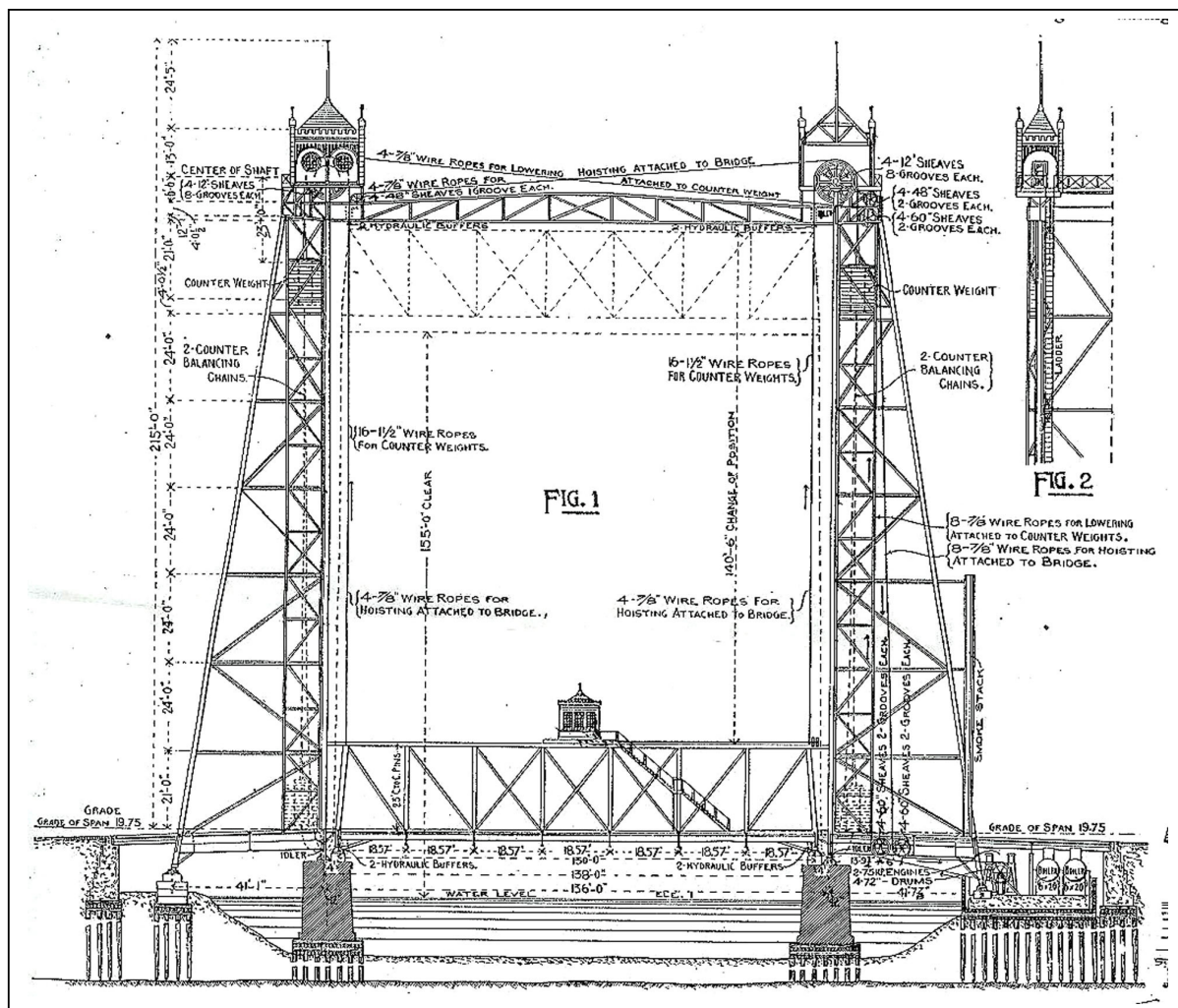


Figure B-9: Halsted Street Bridge, Chicago, IL (*Engineering Record*, March 4, 1893)

After the bridge opened and had been operating for a while, Waddell indicated that in the future if he had “carte blanche in the designing, he would make the following improvements”:

1. Curve the rear column and arch the overhead girders at the tops of towers so as to improve the general appearance.

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2. Operate by electricity instead of by steam.
3. Place the machinery house in one of the towers and dispense with the operating house on the span.
4. Omit the water tanks as an unnecessary precaution and rely on the great capacity of the electric motors to overcome any temporary unbalanced load.
5. Use a simpler and less expensive adjustment at feet of rear columns.
6. Use cast steel instead of cast iron for all machinery.
7. Catch the balancing chains in buckets placed on top of the span instead of hanging them to the counterweights.

With the bridge opening and its successful operation, the era of the vertical lift bridge began. It is impressive that as a first attempt the bridge was so successful and incorporated so many of the features that were to become a part of most future lift spans.

Before he began construction of the bridge, he submitted a patent application for a Lift-Bridge on November 16, 1892. The patent was granted on October 10, 1893, as #506,571 (Figure B-10). It contained many of the Halsted Street details but included changes he would make in future bridges. In order to make his patent as broad as possible he listed twenty-three items which he claimed were new and which he wanted protected by the patent (patent application). Waddell's application consisted of seven sheets of drawings and three pages of description. This was in contrast to many patent applications of this period that were very brief with few drawings, descriptions or claims. Waddell tailored his application to guarantee that his patent would cover almost any type of lift bridge considered over the next fourteen years by other engineers or owners of bridges.

He wrote,

My invention relates to lift bridges, especially designed for both a maximum span and a maximum lift, and is especially adapted for ship canals and harbors where masted vessels are required to pass beneath the lift span when it is elevated, and where, if required heavily loaded trains and railway engines may pass over the lift span, when it is lowered to grade and which furthermore may have sufficient capacity to provide for the separate passage of vehicles and pedestrians over the bridge. The bridge, therefore, requires simplicity and great strength in its structural organization, and its operating mechanism must be such as to secure a superior method of counterbalancing all moving parts as well as for compensating and equalizing the various strains which may come upon the mechanism..." (U.S. Patent Office 1893).

With a successful patent in hand, and the Halsted Street Bridge in place, Waddell might have thought the future looked very bright for the design and construction of many similar bridges. Instead, Waddell had to wait a torturous fifteen years before more orders came in. The reasons for the lack of interest in the design are open to interpretation. According to some, the delay was due to the recalcitrance of the engineering community; according to others, it was the operation of the Halsted Bridge itself that was to blame. Waddell attributed his lack of commissions during this period to the fact that he, "often ran into political and financial conditions of such a nature that his engineer's conscience prevented his dealings with the parties interested" (Waddell 1916 Vol. 1: 723).

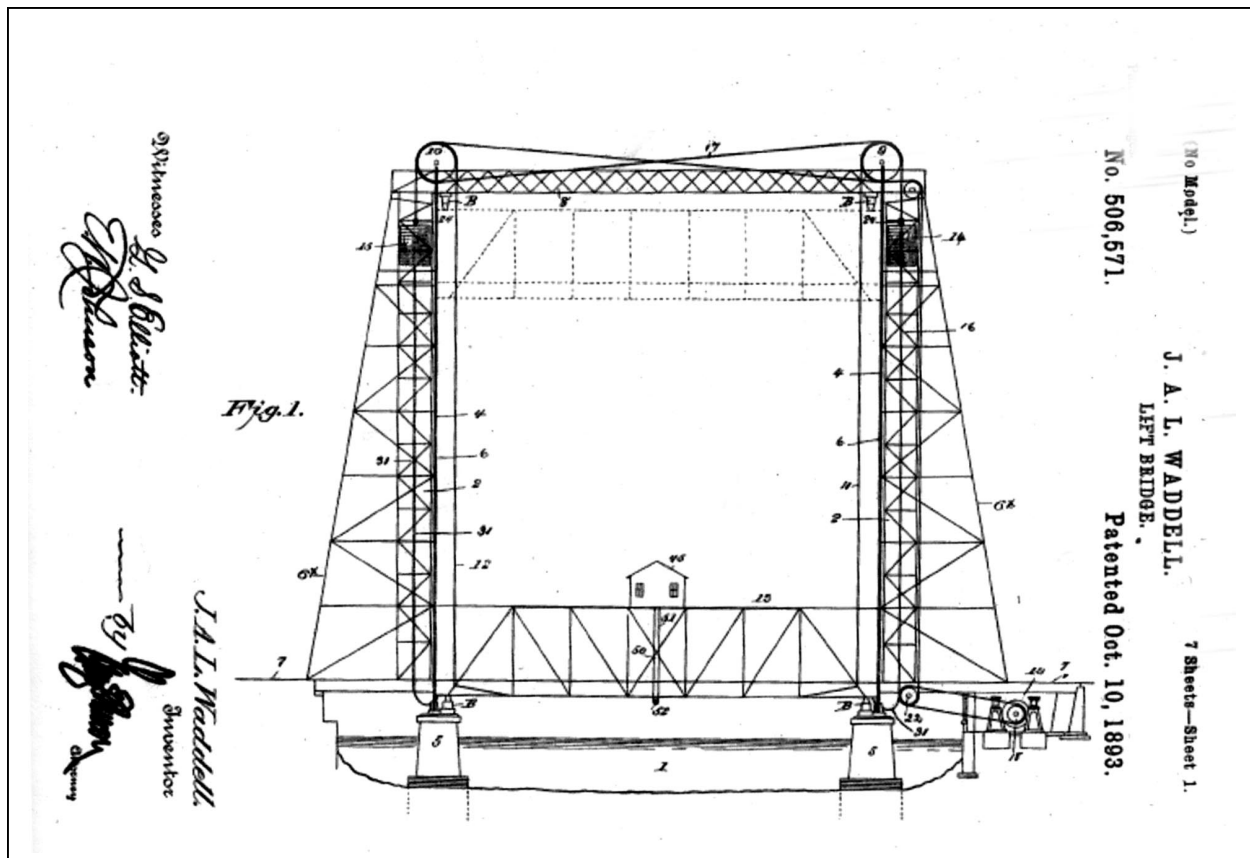


Figure B-10: Waddell patent #506,571 (U.S. Patent Office)

Engineers particularly criticized the initial cost of the bridge and the cost of operating the steam engines. Illustrative of the design's detractors was C. C. Schneider who wrote on "Movable Bridges" in the *Transactions of ASCE* on April 3, 1907. In this paper, Schneider, one of the leading bridge engineers of the era, promoted swing and bascule bridges, writing of the vertical lift bridge: "...Its disadvantages are heavy first cost and maintenance, and expensive operation. The vertical lift bridge is most suitable for spans which require only a small lift, such as bridges over canals" (Schneider 1908: 269). Schneider's views were likely influenced by the Halsted Bridge's reputation, warranted or not, for being difficult and expensive to operate.<sup>27</sup> However, with changes made to the Halsted Bridge, including converting it from a steam powered lift span to an electric motor system, as Waddell had initially intended, the bridge improved greatly in operation, making it the "most satisfactorily operating movable bridge in Chicago" (Waddell 1916:723).

Things also went better after 1907, with the formation of Waddell and Harrington. Some of the problems identified with the Halsted Bridge design were rectified by a number of improvements

<sup>27</sup> Some, including contemporary historians of technology, believe the reputation was deserved. "Waddell's bridge was poorly designed in its mechanical engineering features; he used unbushed, cast-iron bearings, cast-iron gears with moulded [sic] teeth, and other deficient equipment...Waddell's design had only a poor connection between the machinery and the structural supports, inadequate brakes, and a lack of adequate signaling and safety features." Edwin Layton, letter to Frank M. Cortelyou, Sr, 5 November 1969, in John L. Harrington Material, MG 2731, Western Historical Manuscript Collection, Ellis Library, University of Missouri, Columbia, MO, quoted in Spivy, Justin HAER documentation for Pittsburg, Fort Wayne & Chicago Railway, Calumet River Bridge (HAER No. IL-156) page 24. 2001 }

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in the design by Waddell and his partner John Lyle Harrington. Waddell's affiliation with Harrington resulted in four patents for lift bridges between 1909 and 1913. Particularly significant were improvements shown in patent #953,307 issued March 29, 1910. It was for a lift span "in which the movable span is raised and lowered from separate and disconnected towers; to provide a plurality of motors or drivers that may operate simultaneously or singly for actuating the lifting mechanisms; to provide improved brake, stop, and lock mechanism for automatically controlling the action of the movable span, and to provide improved tension regulating parts" (U.S. Patent Office 1910). The patent made nine claims dealing primarily with the mechanisms used to raise and lower the span. It was in this area that Harrington, working under Waddell's guidance, particularly improved on the working of the lift bridge.<sup>28</sup>

With these patents and experience, Waddell and his partners became the pre-eminent, and, virtually the only, lift bridge design firm in the United States. With the support of several railroads and western developers, Waddell began to build a large number of his bridges between 1910 and 1920. A list of the bridges leading up to the Memorial Bridge follows:

<i>Bridge Name</i>	Length of lift span – ft.	Weight of Lift span-#	Height lifted - ft.	Year Constructed
Halsted Street, Chicago, IL	130	600,000	140	1893-95
Mississippi River, Keithsburg, IL	229	940,000	48	1909-10
Sand Point, ID	83	60,000	50	1909
Hawthorne Avenue, Portland, OR	244	1,770,000	110	1909-10
Missouri River, KC, MO (Fratt Bridge)	425	1,560,000	50	1909-11
Arkansas River, VanBuren, AR	192	1,500,000	50	1911-12
Sacramento River, Tehama, CA	167	266,000	63	1910-11
M. L. & T. Railway, LA	50	69,000	43	1911
OWRR& N Harriman, Portland, OR	220	3,420,000	89	1910-12
OWRR& N Harriman, Portland, OR	220	1,060,000	46-89	1910-12
City Waterway ,Tacoma, WA	214	1,640,000	78	1911-13
Puyallup River, Tacoma, WA	161	943,000	115	1911-13
PennRR,#443, Calumet River, Chicago	210	1,837,000	101	1912-13
Trail, Columbia River, BC Canada	171	266,000	50	1911-12
Little River, Jonesville, LA	116	380,000	44	1912-13
Black River, AR	165	620,000	56	1912
St. Francis River, Memphis, TN	162	620,000	73	1912
Illinois River, C&NWR, Pekin, IL	173	698,000	43	1912
Red River, Index, TX	140	120,000	25	1919
Pennsylvania RR, #458 Chicago River	273	3,006,000	114	1913-14
Willamette River, Harrisburg, OR	200	656,000	63	1912
Willamette River Salem, OR	131	462,000	54	1912

<sup>28</sup> Waddell always acknowledged Harrington's contribution, writing, "Mr. Harrington's extended experience in various lines of mechanical engineering, especially as engineer to the C. W. Hunt Company of New York, enabled the firm to effect many valuable improvements in operation..." (Waddell 1916: 724)

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C. N. P. R. R. No. 10	90	236,000	56	1912-14
Mississippi River, St. Paul, MN	189	850,000	56	1913
L. S. M. S. R. R. No. 6	210	1,410,000	101	1912-15
International Falls, MN	75	200,000	50	
Missouri River, GNRR, Snowdon, MT	296	1,560,000	43	1913
Grand Rapids, MI	83	78,600	30	
Yellowstone River, Fairview, MN	271	1,370,000	43	1914
Oslo, MN	155	112,000	25	
N. Thompson River, Kamloops, B. C.	93	236,000	53	1914
Oromocto, N. B., Canada	58	147,000	59	1913
Don River, Russia	210	1,600,000	131	1917-18
Caddo Lake, Mooringsport, LA	92	218,000	53	1914
Columbia River, Vancouver to Portland	272	2,400,000	139	1917
PennRR Ohio River, Louisville, KY	264	3,200,000	33	1918
Cross Bayou, Shreveport, LA	54	280,000	30	
Tallahatchie River, Charlestown, MS	76	160,000	46	
Osage River, Jefferson City, MO	100	175,000	38	

Figure B-11: Table of Waddell Bridges 1893 to 1918<sup>29</sup>

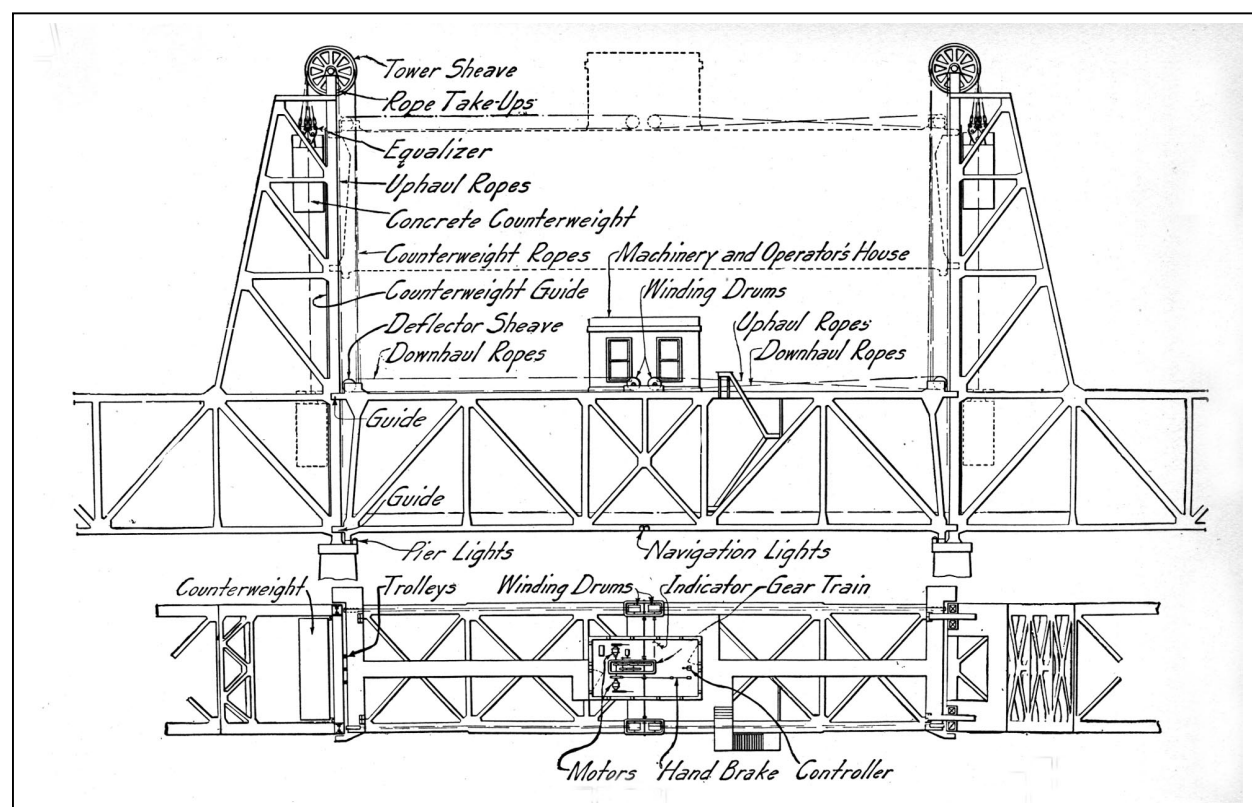


Figure B-12: Waddell-Harrington Vertical Lift Bridge (Hovey 1926:155)

<sup>29</sup> Sources for the information in the table include Hovey 1926, Nyman 2001, Skinner 1928, Waddell 1916.



*Plate B-13: Columbia River Bridge, Portland, OR to Vancouver, WA 1917, 1958*

Many of Waddell's earlier bridges were short spans with small lifts. The railroad bridges were much heavier since the trusses needed to carry the heavier traffic. The longest span was the Fratt Bridge with a fixed/permanent truss where the deck only needed to be lifted, thus the long span and low weight. Although his early bridges like the Halsted Street Bridge had separate towers, in 1910 Waddell started building his towers integral to his flanking or tower spans with the Hawthorne Bridge over the Columbia River in Portland, which is today the oldest extant vertical lift bridge. The style was perfected with his two Montana Bridges over the Yellowstone and Missouri Rivers. But it was the Columbia River Bridge, called by Waddell his "Pacific Bridge," that contained all of the innovations in design and construction to that period (Plate B-13). When completed in 1917, the Columbia River Bridge served as the pattern for many subsequent bridges both by Waddell (including Memorial Bridge) and former partner Harrington. Although designed by Waddell and Harrington, the firm of Harrington, Howard and Ash supervised its construction.

The developments over the period 1892 to 1919 resulted in what was known as the Waddell-Harrington Vertical Lift Bridge and are contained in the illustration shown above. The key elements of the bridge can be seen in Figure B-12.

## **7. Design/Comparative Analysis**

Waddell's design and design rationale for Memorial Bridge are described below. Sections include the Flanking/Tower Spans, the Lift Span, the Towers, Lifting machinery, Counterweights and operating cables. For a physical description of the bridge, see Section E-1.



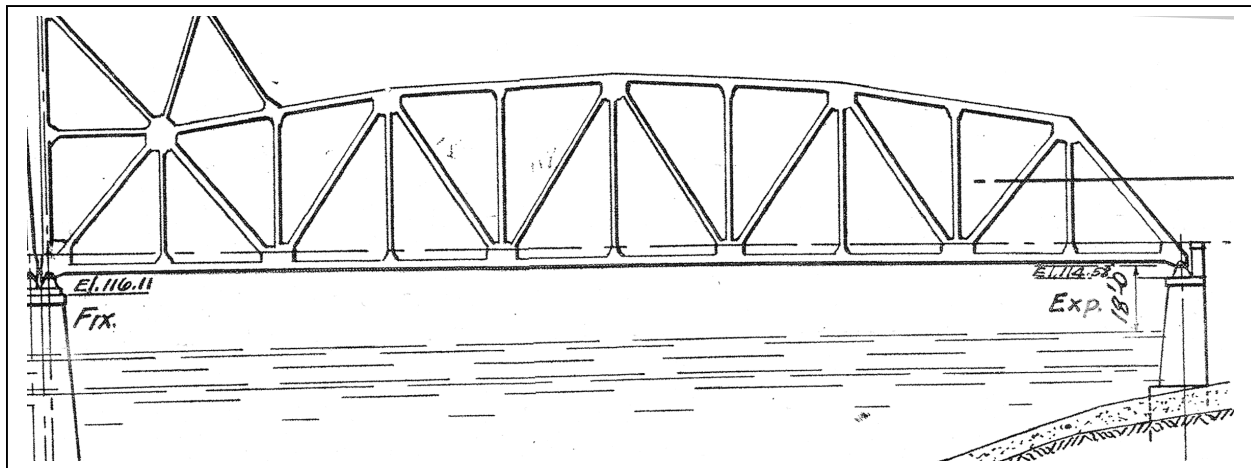
**a. Flanking/Tower Spans**

For Memorial Bridge, Waddell for the first time used a Warren Truss with a polygonal top chord with alternating tension and compression diagonals (Figure B-13). Waddell's choice of truss type for a project was usually based upon the relative costs of steel and fabrication.<sup>30</sup> He preferred Pratt trusses, with tension diagonals and compression verticals, as he could rivet his floor beams directly to the verticals of the truss members, which had to be heavier since they were long compression members. In his paper "Highway Bridges of Iron and Steel" he wrote, "The Pratt Truss, in my opinion, is preferable to the Warren for two reasons. 1<sup>st</sup>. It is slightly more economical of material; and 2<sup>nd</sup>, it permits the riveting of floor beams to posts, which is decidedly preferable to suspending them as they are generally suspended. Beams suspended by non-adjustable hangers and securely stayed against all motion make undoubtedly good construction; but it is expensive construction and not better than that afforded by riveting beams to posts" (Waddell 1888: 474). It is likely that Waddell's decision to use the Warren truss rather than the Pratt truss for Memorial Bridge was a result of fabrication issues.

All connections in the spans were riveted. For spans of 100' to 300', Waddell generally specified that highway bridges should be riveted and spans in excess of 300' should be either riveted or pinned (Waddell 1916). Most members were to be fabricated with medium steel with an ultimate tensile strength of 55,000 to 65,000 psi. Waddell specified that the elastic limit was to be no "less than fifty (50) per cent of the ultimate tensile strength." (Piscataqua River Bridge Commission 1920). Medium steel with these specifications was commonly called A7 steel.

Waddell's top and bottom chords, as well as his verticals and diagonals, were fabricated of plates, angles, channels and lattice bars. The truss consisted of ten panels of 29'-7½". Waddell designed all his compression members using the straight-line formula:

$f_c = 16,000 - 60 l/r$  where  $l$  is the unsupported length and  $r$  is the least radius of gyration.



*Figure B-13: Flanking/Tower (Warren) Truss (NHDOT) [For full plan see Figure O-7]*

All tension members were designed using an allowable stress of 16,000 psi. Live Loading consisted of an electric railway of two 50-ton cars with axle loadings of 25,000 pounds, a single 20-ton truck with 10,000-pound wheel loads (20,000 pounds per axle) or 80 psf for the floor system and truss hangars. For truss members, 1,200 pounds per lineal foot was used for the

<sup>30</sup> On page 1641 of his book, he recommends a Petit (a type of Pratt) for spans over 250' but notes the length was "not fixed absolutely."



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electric railway, 1,200 pounds per lineal foot for the roadway and 80 pounds per square foot for the walkways. Increases for impact loading on the live loads varied from 15 percent for truss members to 30 percent for deck members.

Wind loadings on a pound per lineal foot basis was based upon Figure 9c, page 153 of Waddell's 1916 book, Bridge Engineering.

### **b. Lift span**

To save money and to maintain symmetry, Waddell generally designed his flanking/tower and lift spans to be identical in profile. However, with Memorial Bridge, the Consulting Architects of the Bureau of Yards and Docks of the Navy Department proposed parallel chords for the movable span and polygonal top chords for the flanking spans, to differentiate the varying purposes of the spans. Waddell considered this to be, "in the line of esthetic improvement" (Skinner 1928: 744).

As he did in the Memorial Bridge design, Waddell most often had his hoisting equipment mounted in the middle of the lift span. This maintained equal strains on his uphaul and downhaul cables thus keeping the lift span horizontal throughout the lifting and closing process. He tried placing his hoisting equipment near the end of the lift span on one of his bridges to cut down on the dead load at the middle of his span. In that bridge, however, he found the unequal length of the cables resulted in unbalanced lifting forces on each end of his bridge. He never repeated this design. On Memorial Bridge, for the first time he placed his hoisting equipment and control house within the trusses of the lift span rather than on top, as was his usual procedure. In his specifications he indicated, "In truss spans the house shall be located above the top chords, or between the trusses below the top chords if the truss depth is sufficient to permit this construction" (Waddell 1916:1696). This results in lower wind loads with lower moment arms on the lift span trusses which in turn results in less wind bracing and lower cost. His entire lifting apparatus and housing was supported by modification to the two center truss panels as shown below in Figure B-14.

The height of the lift span truss was a constant 35' while the flanking spans had a maximum truss height of 47'. Panel lengths on the lift span were the same as on the flanking spans. The lower truss height required much heavier members in the lift span. The cross sectional area of the top chord of the flanking truss at mid-span was 73.72 square inches while the lift span required 105.36 square inches at its mid-span. The length of diagonal members, verticals and top chord was less than on the flanking span.

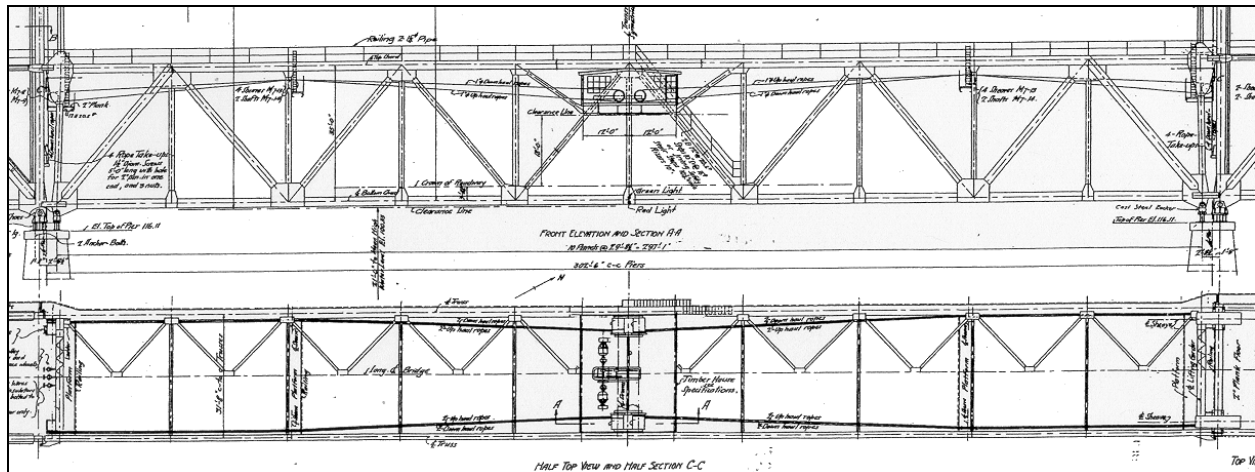


Figure B-14: Elevation (above) and Plan (below) of Lift Span [For Full Plan See Figure O-11]

The lift span, with hoisting equipment, weighed 1,710,000 pounds. This broke down as follows

Bridge Element	Weight in #s
Deck	450,000
Structural metal	1,160,000
Machinery and motors	60,000
House and Walkways	40,000

Figure B-15: Weight of Bridge Elements

The deck consisted of seven riveted stringers, with two stringers (24- I- 80) for the electric railway larger than the other five (20- I- 65). Creosoted wood ties 16' long and 6" x 8" (changed to 6" x 10" in 1921) on 2' centers crossed the stringers and were anchored to them by hooked bars. The deck was 3" thick untreated oak plank laid diagonally. The plan indicated that in the future a 3" thick wood block pavement could be added. The sidewalks were covered with 3" untreated spruce planks.

### c. Towers

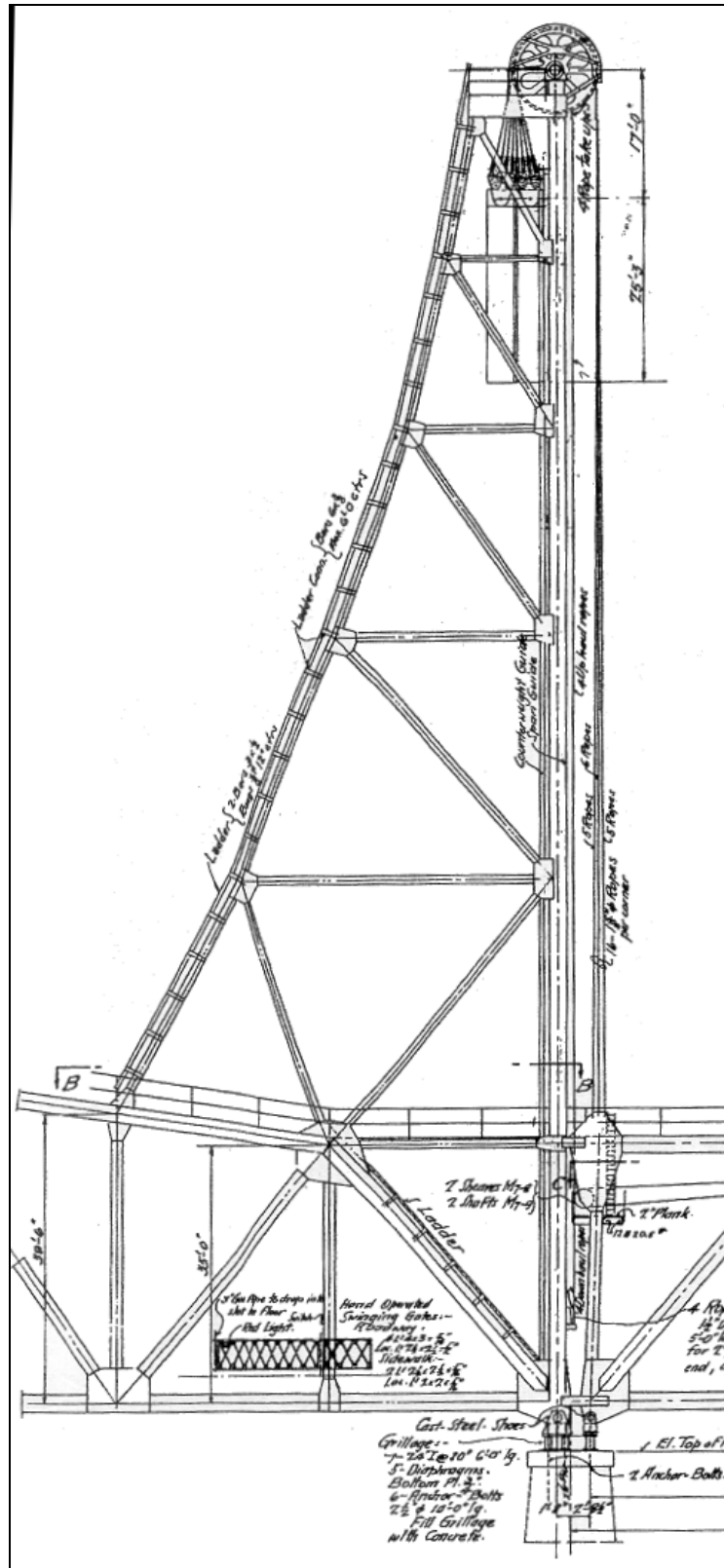


Figure B-16: Tower, typical (NHDOT) [Full plan at Figure O-11]

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The towers serve three primary functions (Figure B-16). The first is to support the sheaves over which the cables run, connecting the lift span with the counterweights. The second is to provide guides through which the lift span and the counterweights track to keep the lift span from swinging laterally. The third is to provide attachments for the uphaul and downhaul ropes used to initiate movement of the lift spans.

Waddell's towers on the Memorial Bridge were very similar to those of the Columbia River Bridge with one face perpendicular and the other broken from the top of the tower to the second upper panel points of his flanking trusses. The towers were braced in all four surfaces to resist lateral and vertical loads. The members were built up of riveted angles, plates and lattice bars similar to the flanking and lift spans.

For erection purposes, the second horizontal member down from the top of the tower was strengthened to support the dead weight of the counterweight prior to the connection of the cables from the lift span. The main loading of the towers was the combined weight of the lift span and counterweights and the wind loading on the lift span when at the full open position. Additional loads were placed on the towers when the uphaul ropes were engaged to raise the bridge.

### **d. Lifting machinery, Counterweights and Operating Cables**

To design the lifting machinery, Waddell, under severe time constraints, first determined the weight of concrete counterweights needed to balance the lift span. To do this he subtracted the weights of the equalizers and counterweight steel boxes from the weight of the lift span, arriving at a required weight of 810,000 lbs at each end of the lift span. Knowing this weight and the safe operating strength of his cable he determined he required thirty-two cables of  $1\frac{5}{8}$ " diameter made of Improved Plough Steel with nineteen wires in each of six strands with a hemp center. The sixteen cables at each end of the counterweights were connected with steel brackets riveted on the lift span and looped up and over the sheaves down to equalizers attached to the counterweights. His equalizers and sheaves are shown below (Figure B-16).

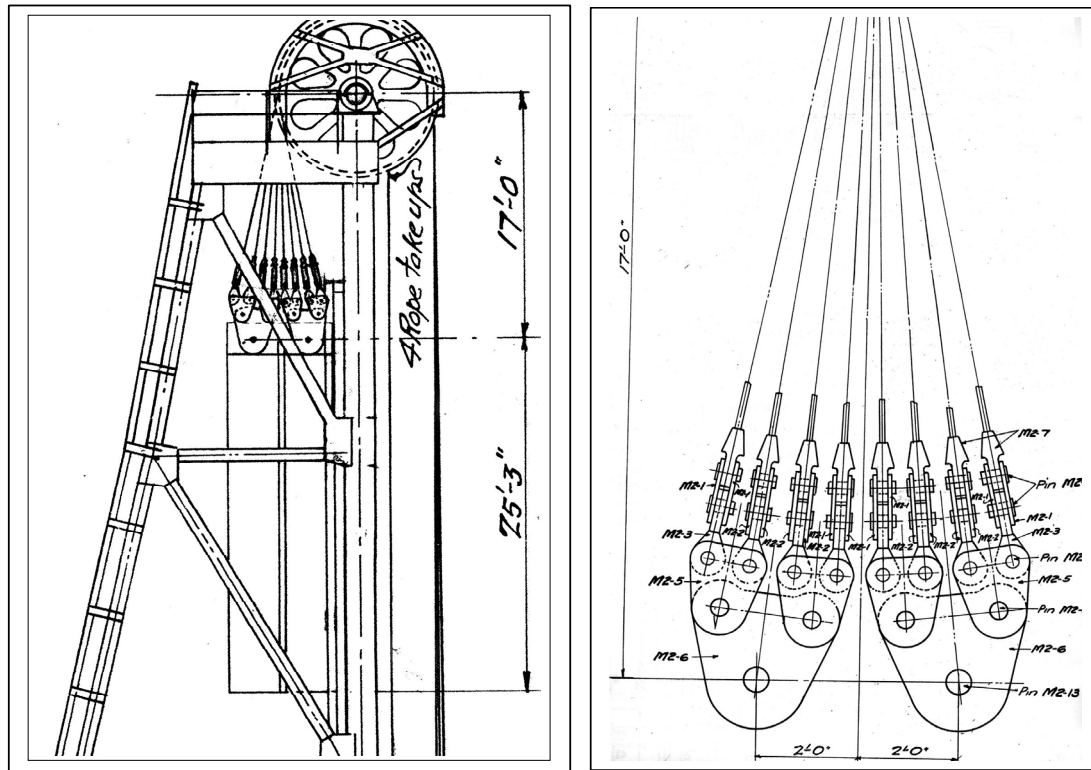


Figure B-17: Hoisting Sheave and Counterweigh (left) and Equalizer Detail (right) (NHDOT)

Waddell adopted the rule that the diameter of his sheaves should be 60 to 80 times the cable diameter. In this case he adopted the diameter of 10.5' for his cast steel sheave that turned on a shaft with diameters of 15½" (bearings) and 17" (through the sheaves). The shaft set into a cast steel yoke with a bronze bushing that had access for grease cups to minimize friction between the polished shaft and bronze seat. The sheaves were cast with 16 grooves to receive each of the 16-counterweight cables.

#### e. Hoisting Machinery

The machinery required to operate the Memorial Bridge lift span was first developed by Waddell and Harrington for their Columbia River and Louisville Kentucky (Ohio River) Bridges. These designs incorporated the latest in the evolving technology. Not only did Waddell/Hardesty and the bridge commissioners use the same machinery that Waddell had used on the Louisville Bridge (built for the Louisville Bridge Company), but drawings from that project were included in the bid package for Memorial Bridge sent out to American Bridge and Bethlehem Steel. Hardesty also scheduled a visit to Louisville by members of the Memorial Bridge Commission on March 13, 1922. Commander E. H. Brownell of the United States Navy Civil Engineer Corps wrote the Chief of the Bureau of Yards and Docks that using machinery identical to that used for the Louisville Bridge would result in "considerable economy in patterns. . . and at the same time providing for the Piscataqua River Bridge machinery of somewhat greater capacity than would be provided normally while at a saving in cost. The Louisville draw is shorter than this (260 feet span against 300 feet) but it is heavier" (Brownell 1922).

By the 1920s, electric motors, sometimes with the assistance of gasoline motors, had become standard on all major movable bridges. Usually there were two motors, even though one motor would provide the necessary lifting power, so one could serve as backup if the primary motor

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failed. In the event of a total power failure a gasoline motor could be started and bring the bridge to a fully open or fully closed position. For Memorial Bridge the gasoline motor was listed as a “to be added” feature<sup>31</sup>. To provide emergency power, Waddell provided a capstan-operated system that was normally swung up and attached to the bottom of the machinery house. The linkage with gearing at the top that connected to the operating shafts could be dropped down to the deck level where its base would be set in a hole in the deck. Long bars would then be placed in the capstan and several men working the bars from the deck level could raise or lower the lift span.

The plans called for two 100 HP Westinghouse wound rotor induction electric motors and four drums for the uphaul and downhaul cables. A system of gears transfers the torque from the motor to shafts and thence to the uphaul and downhaul drums. The pitch diameter of the drums was 3' with 18.5 or 19.5 turns of spiral grooves to handle the length of cable to go from the drum out along the lift span on rollers and thence up to anchors at the top of the towers for the uphaul cables and from the drum out along to lift span to a sheave and down to the base of the tower for the downhaul cables. Both cables would have to be approximately 325' long, or enough to go from the base of the tower up to the top of the lift span when in an open position and thence back to the downhaul drum with a few turns remaining on the drum before they were anchored to the drums. Since the shaft from the electric motors engaged gears on both drums (one to the south end and one to the north end of the lift span) the drums would turn in opposite directions, one clockwise and the other counterclockwise. The cables would have to cross one another on one side of the machinery house to ensure that all the uphaul cables were passed around sheaves to the top of the tower and all of the downhaul cables passed over sheaves down to the base of the tower. This method was adopted in most of Waddell's later bridges, including the Columbia River Bridge.

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<sup>31</sup> A diesel engine was added but it is not clear when this was done.

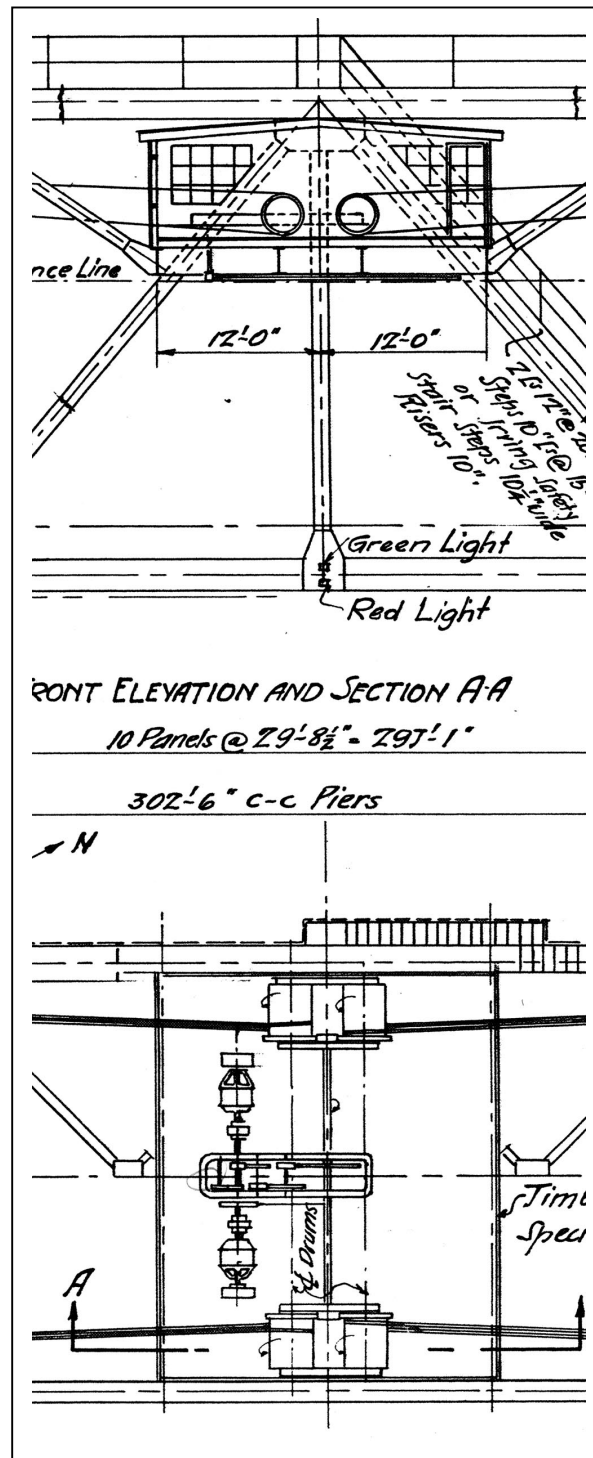
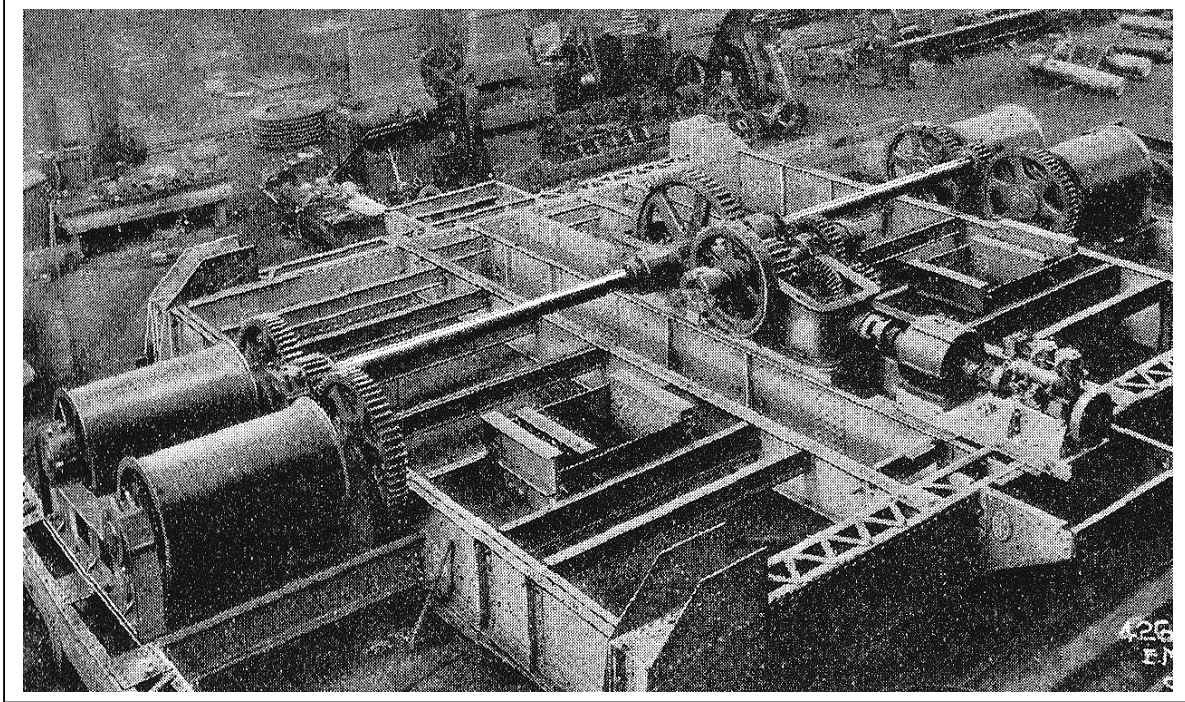


Figure B-18: Hoisting Machinery (NHDOT) (See Full Plan at Figure O-11)





*Plate B-14: Columbia River Lifting Machinery Photograph. Similar to Portsmouth Machinery (Howard 1921)*

To control the speed of movement of the lift span, solenoid brakes could be applied to the shafts of the electric motors as well as a mechanical friction brake applied to the shaft between the electric motors and the gear train to the uphaul and downhaul drums.

All of the controls were located near the operator who had a switch to activate the electric motors, and a brake handle to slow the motion of the lift span. An indicator dial that gave the elevation of the lift span was mounted near the drums. Electric power to run the motor was routed from the shore to the vertical leg of the towers where “three 4/0 trolley wires with strain indicators” ran up the tower. On the lift span three “2 – wheel trolley hickory poles and Phosphor bronze wheels” made contact and transmitted power to the electric motors and machinery house. This is the same mechanism then used to power electric trolley cars from overhead electric lines.

