Lowell Waterpower System

Not many projects have had such wide-ranging effects as this engineering project had on the industrialization of America.

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FEW ENGINEERING achievements have had greater impact on American life than the waterpower system developed at Lowell, Massachusetts. By making possible the generation of power at diverse locations rather than at a single damsite, the way was opened for the growth of the mill complex that became a feature of American life, especially in New England. Starting with Lowell, located some 20 miles northwest of Boston on the Merrimack River, mill towns grew into industrial cities. The advent of Lowell's waterpower system was a decisive factor in shifting America from a rural to urban society.

Demand for increased production capabilities caused the mill to develop from a small, relatively simple industrial plant to a large and complex manufactory in the 19th century. However, both the small plant and large manufactory were still dependent on waterpower for their operation. The invention of new types of production machinery helped spur this transformation, especially in the textile industry. The production machinery used in these new and larger mills required far more power than did the old small mills. In addition, there developed a need for power to be distributed beyond the practical limits of shafting and belts. Thus the civil engineer was called upon to make far-reaching contributions to the industrial revolution and to the resulting economic progress of this country.

Initially, increased power requirements were met by expanding on proven practices. Higher dams were built, and more and larger water wheels of the old types were used. The pioneer Slater Mill, built in 1793 at Pawtucket, Rhode Island, differed little basically in its power generation system from the small, earlier mills. Subsequent mills made incremental advances. At Slatersville, a few miles up the Blackstone River from the historic Slater Mill, there is still evidence of a somewhat more elaborate waterpower system. However, the engineering breakthrough that transformed American industrial life took place at Lowell, an accomplishment appropriately commemorated by the Lowell National Historical Park and the Lowell Heritage State Park.

Background

Two enterprises converged in 1821 that laid the framework for the development of the

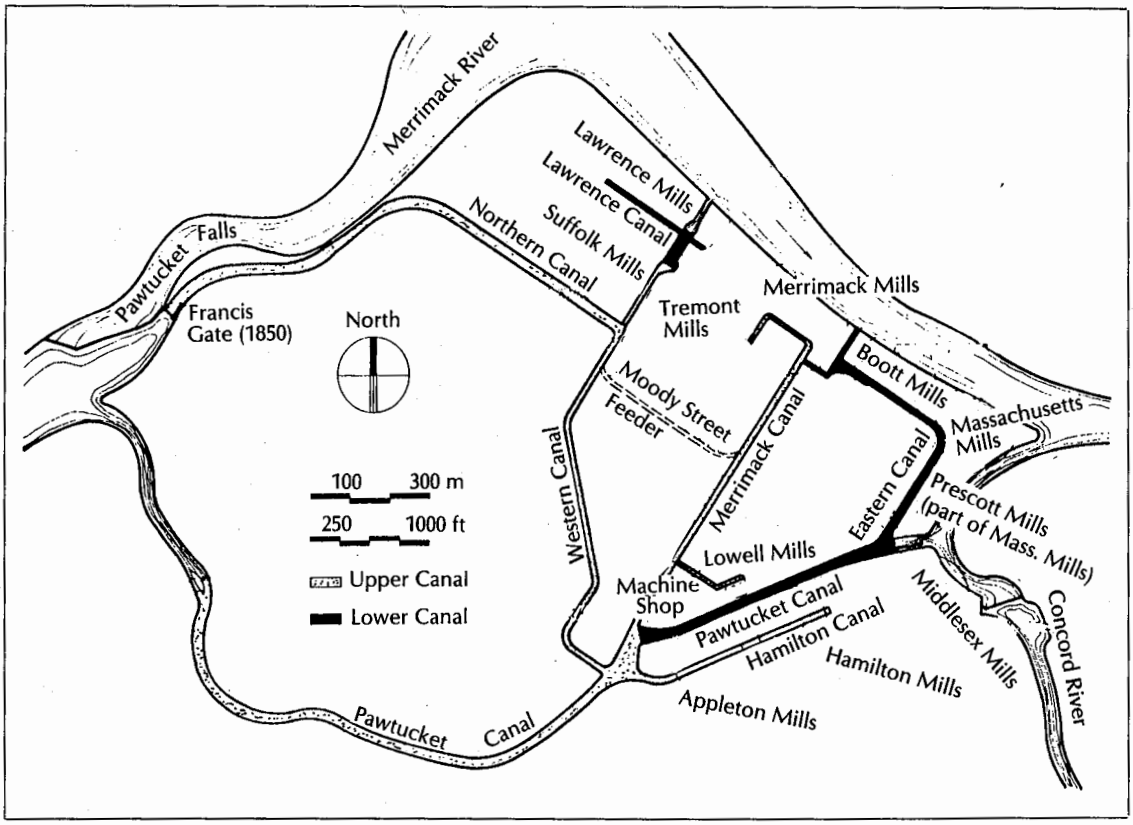

FIGURE 1. The Lowell canal system in 1848.

Lowell waterpower system. The Proprietors of Locks and Canals on the Merrimack River was incorporated in 1792 and it continues in existence today. This company acquired water rights at East Chelmsford, Massachusetts, and built a small transportation canal around the 30-foot Pawtucket Falls on the Merrimack River. This canal was completed in 1796 and a few small mills were built in the area. By 1821, however, the canal's condition had deteriorated and the company was financially pressed.

Meanwhile in 1813 a group of Boston merchants headed by Francis Cabot Lowell (1775-1817) started a textile mill experiment at Waltham, Massachusetts, on the Charles River. The Waltham mill was very successful, but limited waterpower on the Charles restricted mill expansion. In 1821, the group of Boston merchants, now headed by Nathan Appleton, acquired control of the Proprietors of the Locks and Canals, formed the Merrimack Manufacturing Company, and converted the Pawtucket Falls Canal into the main artery of a waterpower canal system. Kirk Boott became the company agent. In 1826, the town of East Chelmsford was renamed Lowell, in honor of Francis Cabot Lowell, and was incorporated as a city in 1836. By that year, under the direction of Kirk Boott and Paul Moody, a carefully planned canal system had been developed with twenty-six mills, two print shops and a number of machine shops operating on Merrimack River power.

Waterpower Engineering Developments

As advanced as the Lowell waterpower system in 1836 was, increasing demands for more power and continued expansion called for improved utilization of the water power resources available. The engineering developments resulting from these demands were:

- More efficient power generators

- Means to measure and control power water flows to assure proper power levels under all conditions to each of the many users
- Canal system improvements based on a more thorough knowledge of the hydraulics involved

In effecting these developments, Uriah Atherton Boyden and James Bicheno Francis made their great contributions to the civil engineering profession and American industry.

Uriah Atherton Boyden (1804-1879), engineer and inventor, originally came from Massachusetts but gained his first technical experience with his brother Seth Boyden, a manufacturer and noted inventor, in New Jersey. Returning to New England, he worked on the first survey for the Boston & Providence Railroad, and with the eminent engineer Loammi Baldwin, Jr., on the naval drydock at Charlestown, Massachusetts. With little formal education, Boyden went on to work on various railroad construction projects before he became engineer for the Amoskeag Manufacturing Company in Manchester, New Hampshire, where he designed the hydraulic works.

In Lowell's early industrial development, breast wheels were used for power generation. High breast wheels measured up to thirty feet in diameter and total bucket lengths measured up to sixty feet. These wheels were an improvement over the old overshot wheels, but the efficiencies were only about 60 percent. About 1840 Boyden started designing horizontal wheels of the Fourneyron turbine type, eventually incorporating so many improvements that they became known as Boyden wheels. His first turbine installed at the Appleton cotton mills at Lowell in 1844 was rated at 75 horsepower and had a power efficiency of 78 percent, a dramatic improvement over breast wheels. In 1846, he designed three 190-horsepower turbines with a power efficiency of 82 percent for the Appleton mills. These turbines included such improvements as a suspended top bearing, and better-designed scroll penstock and diffuser. His turbines were based on the spiral approach, letting water enter the turbine at uniform velocity.

James Bicheno Francis (1815-1892) was born in England and engaged in railroad work there before coming to this country in 1833. He initially worked on railroad construction here under the noted engineer George W. Whistler. Francis was associated in this work with Julius W. Adams and James P. Kirkwood who both later became presidents of the American Society of Civil Engineers (ASCE). It was with Whistler that Francis came to work in Lowell as a draftsman in the machine shop of the Proprietors of Locks and Canals at the age of eighteen. In 1837, Whistler resigned his position with the company and the young Francis was appointed engineer, starting an association with that company that lasted for 55 years. In 1845, he was made agent, or general manager, of the company in addition to engineer. Francis was a founding member of the Boston Society of Civil Engineers in 1848, and served as its president in 1874. He also served as president of ASCE in 1881 and was made an honorary member.

In 1846, Francis ran tests on Boyden's turbines and concluded that the Lowell mills should switch from breast wheels to turbines. The following year he designed his own turbine and installed it in the Pawtucket Gatehouse. He designed the gatehouse with special testing chambers and other features associated with scientific experimentation, making it one of our nation's first industrial research laboratories. The inward-flow type turbine measured almost nine feet in diameter and was installed in a vertical setting within a granite ashlar cylindrical wheel pit. His experiments on that turbine lead to an improved turbine with curved guides and buckets that was installed in the Boott Mills in 1849. This turbine made significant design contributions in the development of the modern, mixed-flow reaction turbine.

With far more potential waterpower in the Merrimack River at Lowell than was then being used for developed mill sites, the challenges were to design a canal system that could deliver adequate water to many sites, develop waterflow controls to assure equal distribution under all conditions, and develop

FIGURE 2. The dedication of the Lowell Waterpower System. From left to right are: Richard W. Karn, President of ASCE; Rodney Plourde, President of BSCES; and the author.

means to monitor flows for control and billing. Francis conducted 92 water flows experiments at the Pawtucket Gatehouse in 1851. Published in 1855 as *The Lowell Hydraulic Experiments*, the book remains an engineering classic for the completeness and accuracy of its test program as well as its landmark achievements in the hydraulics of open channels. Employing the hook-gauge invented by Boyden in his experiments, Francis used weirs as measuring devices and determined the formulas for their use. He also devised improved means of measuring flows in natural streams and channels.

As a result of the water flow data obtained from his experiments and using the means of measurement and control that were developed, far more efficient use could be made of the waterpower resources. Leasing and renting of waterpower became possible on a precise basis, and the distribution of water for power could be formulated on power requirements. The canal system at Lowell was subsequently designed by Francis to operate on a more advanced engineering basis. New canals were constructed and others modified by Francis. The Lowell canal system became a complex machine with many gates and other control and measuring devices. Francis' data, measurement means and design considerations were quickly applied to other locations, permitting the expansion of industrial mill centers. One particular feature of the canal system, Francis Gate, was constructed in 1850 on one of the new canals. After reviewing records of former floods, Francis had erected a gate to shut off flow to the canal. Dubbed "Francis' Folly" at the time, the gate saved Lowell from severe flood damage two years later and again in 1936, a tribute to his engineering genius and foresight.

Landmark Dedications

On July 1, 1985, at the Lowell National Historic Park, the American Society of Civil Engineers (ASCE) dedicated the Lowell Waterpower System as a National Historic Civil Engineering Landmark, and the American Society of Mechanical Engineers (ASME) dedicated the Pawtucket Gatehouse Hydraulic Turbine as a National Historic Mechanical Engineering Landmark.

President Rodney P. Plourde of BSCES presided at the joint ceremony. Brief remarks were given on the historical significance of the two new landmarks. ASCE President Richard W. Karn spoke on the ASCE history and heritage program, noting that Lowell was selected along with the Panama Canal and the Hoover Dam as landmarks the preceding fall. He presented a plaque commemorating the site to James Gutensohn, Commissioner of the Massachusetts Dept. of Environmental Management. The ASME plaque was presented by George Kotnick, past ASME President, to Marshall Field, Chairman of the Proprietors of Locks and Canals, Boott Mills and Boott Hydropower, owners of the system since its inception. Recognizing their historical importance, both sites are included in the Lowell National Historical Park by the National Park Service and the Massachusetts Dept. of Environmental Management.

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