The Legacy of James B. Francis, Engineer

Not relying on "cut and try" methods, Francis brought a scientific mind to bear on a variety of problems in hydraulics and structural engineering.

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A legend in New England's Merrimack River Valley, James B. Francis was a structural engineer, mechanical engineer, hydraulic engineer and a scientific contributor in the fields of hydraulics and hydrology. His contributions of safe, efficient and effective water power and mill structures were vital to the prosperity of the New England textile industry of the 1800s.

Francis the Engineer

Francis was born in 1815 in Oxfordshire, England. At age 14 he apprenticed under his father in Wales in railway and canal construction. The young Francis then immigrated to New York in 1833 with a dream to pursue engineering in the New World. He was hired by Major George Washington Whistler to work on a new rail system linking New York to Boston. When Whistler was appointed a year later as the chief engineer for the Proprietors of Locks and Canals (PLC), a very large company that built and managed the textile industry in Lowell, Massachusetts, he took Francis with him as his assistant.

By that time, Francis had established himself as a skilled surveyor, draftsman and project manager. Also, Whistler appreciated his ability to work with people at all levels to get the job done. In his first job for Whistler, Francis built steam locomotives to provide transport for the textiles produced by the Lowell mills. To engineer the parts, he stripped down a locomotive imported from England and made detailed drawings of all the parts. His staff members created new parts from his drawings, using only chisels and files, and successfully reconstructed the locomotive.

At the time, Lowell's canal system consisted of the Pawtucket Canal and three subsidiary canals that served six textile mills. During Francis' tenure as assistant to Whistler, three more subsidiary canals were built to serve another four mills. Francis also assisted in the layout of building sites, designing foundations, wheel pits, water wheels, belting, shafts and support beams/columns for the mills. When Whistler was hired away in 1837 to supervise a railway project in Russia, Francis replaced him as the chief engineer for the PLC. In 1845, he took on an expanded role as Engineer for the Corporations at Lowell.

As chief engineer, Francis oversaw many large-scale projects in the effort to provide

Courtesy of the Lowell Historical Society

greater water power more consistently to the large mills. He rebuilt the Pawtucket Falls Dam, this time providing an area for the impoundment of river water in times of drought. He also created a new Northern Canal to feed three textile mills and allow two new mills to be built along the existing canals. This new canal had a gate house and guard dam, which served to control the flow and provide safety from flooding to the town and the mills. The canal system as it appeared in 1848 can be seen in Figure 1.

Perhaps Francis' most famous construction was the Francis Gate Complex, built in 1850. Originally dubbed the "Francis Folly" because of its size and cost, the gate is most notable for saving hundreds of lives and potential property damage in Lowell during severe flooding two years after it was constructed, and again in 1936. The gate as it appeared in the 1936 flood (note the sandbags upstream) can be seen in Figure 2. The *Boston Daily Advertiser* published a commentary after the first flood praising Francis' decision to "take measures to guard against what every one considered a useless expenditure of money. Without the Francis Gate, every vestige of the old guard gates would have been carried away, and a mighty and uncontrollable river would have swept through the heart of Lowell, destroying everything in its course."

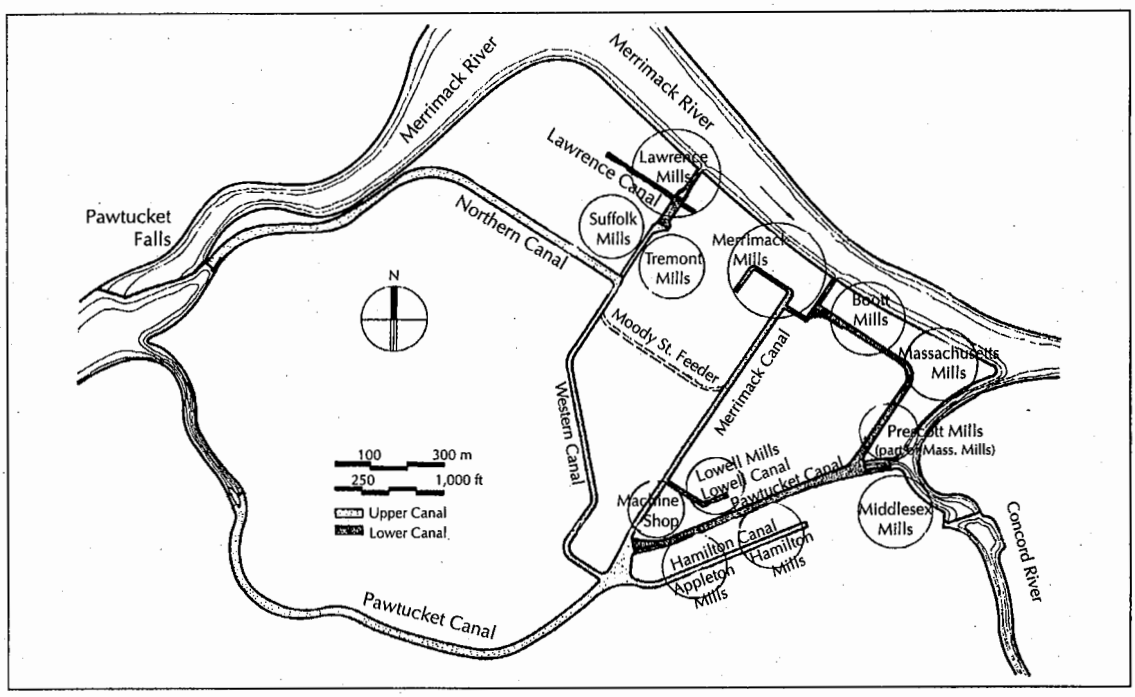
Efficiency, power and safety were important goals of Francis' superintendence of the Lowell mills. With Uriah A. Boyden, he developed what is now known as the Francis turbine. This mixed-flow turbine boosted power efficiency by changing the flow of water to move inward and downward through the turbine, thus minimizing friction and turbulence.

Francis also designed a 2-million gallon reservoir in an elevated section of Lowell, and laid a 6,000-foot, 12-inch main pipe to the city proper to deliver sufficient water to fight up to two mill fires at once. Once this reservoir was operational, Francis further designed and installed a sprinkler system to furnish up to 400 gallons per minute to the roofs of the mills. This innovation was so successful that insurance companies began requiring sprinkler systems in all fire-prone areas of industrial buildings.

Francis the Scientist

Francis continually sought to improve his understanding of engineering and the natural systems in the world around him. Even though he had little formal schooling, he was an avid reader of theoretical texts, among which included J. R. Young's *Mathematics* and Fourneyron's work on outward flow reaction turbines. As a result of this reading and of his own experiments, Francis wrote the *Lowell Hydraulic Experiments* in 1855, which remains an engineering classic on the design and testing of turbines.

The relatively dry New England summers and early falls often forced the mills to shut down due to the lack of water. Collaborating with Charles Storrow (who was Engineer for the canal system in Lawrence, Massachusetts), Francis gained a greater understanding of the hydrologic cycle for the Merrimack River watershed. This watershed of 4,600 square miles includes not only the northeastern Massachusetts area, but also southern New Hampshire and the New Hampshire Lakes Region. Together, the two engineers conducted surveys to determine lake volume, fluctuations in discharge and even impacts from swampy areas. They collected and codified many hydrologic measurements including maximum, minimum and mean discharges, measured rainfall, evaporation and surface runoff at several different sites in the Merrimack River watershed. As a result of their study, the engineers designed and created natural reservoirs in many locations and then installed several control



Courtesy of Mark Howland, *Historic American Engineering Record*

FIGURE 1. The Lowell canal system in 1848.

gates. Power to the Lowell and Lawrence mills during the dry months thus dramatically increased.

Francis conducted exhaustive experiments to create accurate formulas for calculating water flow over weirs. One experiment included measuring gauges, a marine chronometer and electrical signaling devices. This level of instrumentation allowed a number of observers to simultaneously and sequentially record water flow in different locations along the Pawtucket Canal. The results of these experiments led to a better understanding of water flow, not only over weirs and but also as discharged into and out of canals, which served to improve the efficiency of power production.

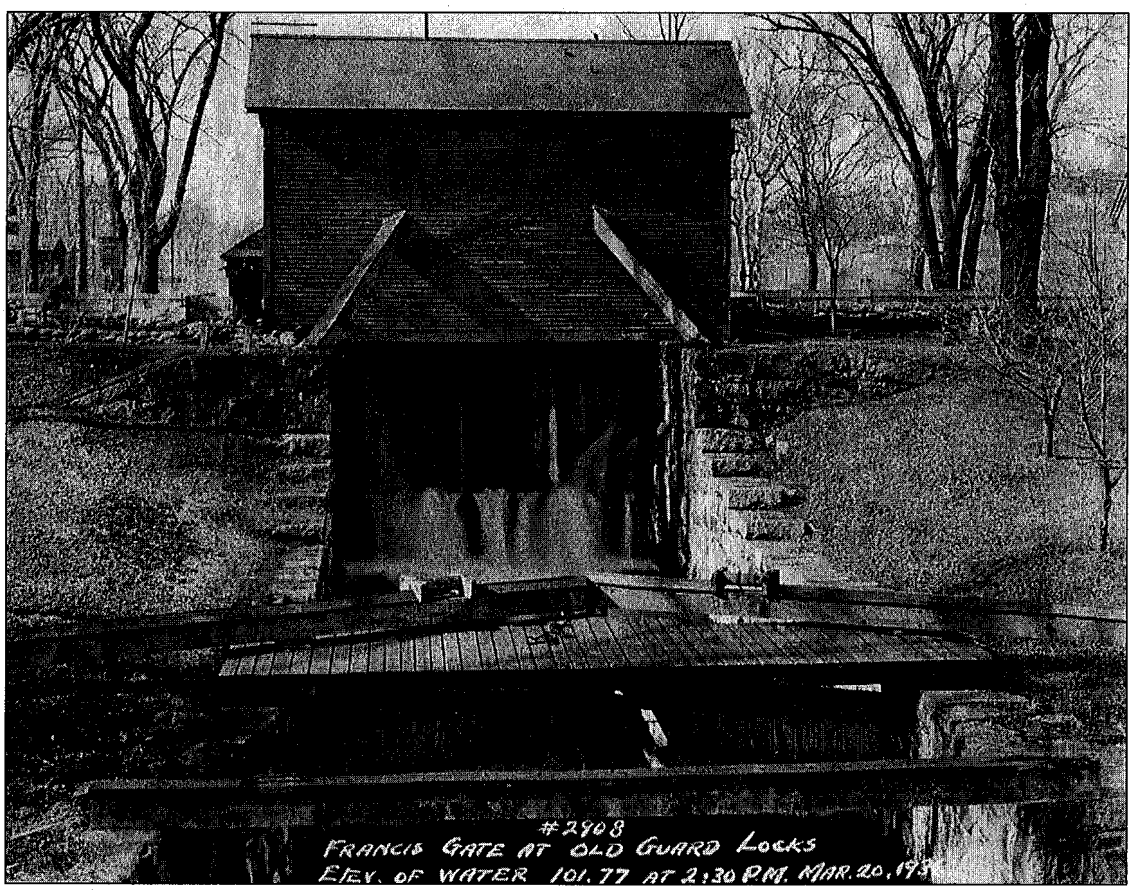
Not limiting himself to hydraulic engineering, Francis built a facility to test the strength of iron and wooden beams and industrial support columns. Based on the results of his tests, he modified construction tables for these materials to include larger safety factors. He then wrote *On the Strength of Cast-Iron Pillars* in 1865 with tables for the use of engineers, architects and builders.

Francis the Visionary

Francis saw that understanding the complete hydrologic system would help engineers create water systems that could feed multiple mill sites in two major cities. Not content to settle for mills with less than full-time production capability, he discovered ways to harness and regulate water sources to control the flow of available water into the mill complex throughout the year.

Francis also knew that it was important to understand all facets of hydraulic systems, from hydrology to hydraulics to mechanical transformation. With this understanding, Francis was able to successfully implement his theories to optimize the water power available for mill operation. This ability to conceptualize, design and build large systems led to his reputation as "America's foremost hydraulic engineer" of his time.

Recognizing that the next generation needed training and mentoring, Francis enlisted many engineers to follow in his footsteps, including Paul Hill (Hoosac Tunnel) and James B. Emerson (Holyoke Testing Flume, a national laboratory for testing turbines). Francis was known far and wide as a team player and a great leader in working on the many projects for the Lowell mills. He knew that working together with other engineers was vital to the successful completion of large-scale projects. This knowledge



Courtesy of Lowell National Historical Park (archives of the PLC)

FIGURE 2. A photo of Francis Gate complex in 1936.

led to his becoming a founding member of both the Boston Society of Civil Engineers (BSCE) in 1848 and the American Society of Civil Engineers (ASCE) in 1852. The acknowledgement by his peers of his engineering and leadership skills was evidenced by his elevation to president of both organizations, in which he remained active until his death in 1892. James B. Francis, a man of leadership, science, and practicality was truly a great engineer.

NOTE — *Francis' leadership in the field of engineering and his dedication to building his community has always inspired the Univ. of Massachusetts at Lowell in the pursuit of its goal to "support and enhance the development of a sustainable, vigorous industrial economic sector" in northeastern Massachusetts. To perpetuate his memory, in 1989 the faculty and staff voted to name the university's College of Engineering after him, recognizing the tradition of engineering excellence associated with his name.*

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