The Brooklyn Bridge: tragedy overcome (part 1)

This month, to mark International Women's Day, Sean Brady presents the first of a two-part article exploring the construction of the Brooklyn Bridge and the crucial role Emily Warren Roebling played in making it a reality.

Figure 1
Brooklyn Bridge under construction

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Introduction

The winter of 1852 was particularly bitter in New York City[1]. For days, the frozen East River paralysed ferry traffic between Manhattan and Brooklyn. On one ferry – stranded for hours in the freezing, foggy haze – John Roebling, a bridge engineer, stood beside his 15-year-old son, Washington. Staring at the silhouetted hulks, Roebling would conceive of a bridge to cross the river, a river that many simply believed un-crossable. The realisation of his vision would culminate in one of the most iconic structural engineering achievements in history, would test the physical and mental resolve of the Roebling family, and would result in Emily Warren Roebling, through her intellect and courage, making an historic contribution to the structural engineering profession, with her name becoming forever synonymous with what would become known as the Brooklyn Bridge.

John Roebling

John Augustus Roebling was born in Mühlhausen in Germany in 1806, graduated with a degree in civil engineering in 1826, and, in 1831, emigrated to the New World[2]. By that day on the East River he had completed a number of bridges in the USA, including a suspension bridge in Pittsburgh in 1845. Once off the ferry he returned to his family home in Trenton, New Jersey, and developed the concept for a bridge to connect Manhattan and Brooklyn. It would be the longest suspension bridge in the world[2].

The bridge remained a concept for the next 14 years, through the Civil War and the assassination of Abraham Lincoln, before the winter of 1866 again froze the East River. By this time, Brooklyn had swelled to 400 000 inhabitants, and the river remained blocked for weeks, preventing more than 1000 ferry crossings per day[1]. There were calls for action. Roebling was working on his famed Cincinnati Bridge when he heard his East River bridge concept was finally under consideration. The following year the New York Bridge Company was formed to deliver the bridge and its Trustees appointed John Roebling as chief engineer.

Three months later he presented plans for his suspension bridge. It would be truly monumental. The bridge was over 1800m long and its deck would be supported by four cables suspended between two limestone and granite towers. Between the towers, it had a span of 480m – more than twice as long as Thomas Telford's Menai Straits Bridge (176m) completed in Wales and longer than the record-breaking 310m span of the Wheeling Bridge in West Virginia. Many engineers thought Roebling's proposed span impossible.

The bridge's towers would be 84m high, considerably higher than any other structure on the New York skyline – a sight we, no doubt, struggle to visualise today[1]. The New York tower alone would contain an estimated 80 000t of limestone and granite. The towers would be supported on bedrock, which was estimated at 12m below the waterline on the Brooklyn side, but a worrying 22m below the waterline on the New York side. No bridge had ever been constructed at such depths[1].

The bridge's suspension cables would be revolutionary – for the first time, they would be made entirely of steel. The deck would be over 24m wide, and Roebling declared that the structure, "when constructed in accordance with my designs, will not only be the greatest bridge in existence, but it will be the greatest engineering work of the continent and of the age"[2].

Tragedy, however, would intervene. In June 1869, while surveying positions for the Brooklyn tower, Roebling was injured in a freak accident. He was standing on the Fulton slipway when a ferry lost control and crashed into the slipway. His foot was crushed. Doctors wanted to amputate his toes. Roebling refused anaesthetic and the operation was performed without it[2]. Then he dismissed his doctors in order to manage his own treatment, but over the next few days his condition deteriorated. He died on the 22 July 1869. With Roebling's death, the project itself hung in the balance.

Washington Roebling

John Roebling's son, Washington, had come a long way from the 15-year-old boy standing beside his father on the East River ferry. He had become an engineer, graduating from Rensselaer Polytechnic Institute in New York in 1857. He had assisted his father on the design and construction of the Allegheny

Aqueduct and the Cincinnati Bridge, and he had enlisted in the Union Army in 1861. He saw action, fought at Gettysburg, and in 1865 married Emily Warren, the daughter of a well-respected but not particularly wealthy family[3].

When his father was named chief engineer for the bridge, he went back to work for him. One of his first tasks was to spend a year travelling in Europe with Emily to inspect the use of caisson technology in the construction of bridge towers below the waterline – a technique his father planned to utilise in New York. By the time of his father's death in 1869, he had become intimately involved with the bridge. The New York Bridge Company Trustees agreed that he was the man for the job, and in August 1869, Washington Roebling, then 32 years old, was appointed chief engineer.

Brooklyn tower

Roebling's first task was to construct the bridge towers (Figure 1). Work on the Brooklyn tower began in March 1870, when a large caisson was launched and lowered into the East River. The caisson can be visualised as a 50m by 30m upturned wooden box or 'diving bell' that was lowered to the riverbed (Figure 2). Pneumatic pressure was then applied and maintained to drive all water from the caisson, essentially leaving an encapsulated 'dry' space. Inside this space, which was larger than four tennis courts, over 100 men could dig out the riverbed[1]. As material was removed, the caisson moved downwards into the exposed hole, until it finally reached bedrock.

The caisson had a thick timber roof, its walls were 2.7m thick at the top and they tapered to just 200mm thick at the base[1]. This 'sharp' edge allowed the caisson to cut through the mud as the material inside was removed. Driving the caisson downwards was the weight of the limestone and granite tower being simultaneously constructed above. This process continued until the caisson struck rock, at which time the void in the caisson was filled with concrete and it became part of the structure.

It was a hellish workplace, comparable with Dante's inferno[1]. In the humid air, lit by calcium lights, with temperatures of more than 25°C, workers, many naked from the waist up, dug out mud and boulders to be extracted by a scoop to a waiting barge (Figure 3). The size of these boulders was a significant issue – some were as long as 3m – and when the perimeter of the caisson met these boulders they had to be broken up by hand and pulled out of the way. The work was painfully slow and the caisson descended by less than 6in. per week. To speed things up, Roebling would have to resort to the use of dynamite – risky, given the cramped environment – to break open the rock. It worked and progress accelerated to 18in. per week[1].

The workers also had to contend with blowouts, where compressed air would suddenly escape at some point along the caisson permitter, spraying a jet of water and mud 150m high above the river, only to rain down on those working on the construction of the tower above. When this happened the caisson would partially flood, with the real risk that the river would break in completely. On one occasion, a supply shaft door burst open and the pressure in the caisson dropped dramatically, suddenly applying very large loads to the caisson structure, with risk of damage. Roebling himself was in the caisson when this incident occurred. Fire was also a constant threat, with the timber roof of the caisson being particularly vulnerable, but by early 1871 the caisson hit rock and concrete was pumped into the chamber void, forming a permanent base to the partially completed tower. Work now turned to the caisson on the New York side, a much more formidable task due to the expected rock depth of 22m, almost twice that of the Brooklyn side.

New York tower

It was from Europe that Washington Roebling first heard about 'caisson disease'[2]. There were reports of workers experiencing violent pain after completing work shifts in caissons. In some cases, paralysis or death resulted. Little was known about the disease, but it appeared to occur more frequently at greater depths – where the air pressure that the workers were required to labour in was higher. While there had been only a few cases of the disease during the construction of the Brooklyn tower, Roebling was more concerned about the New York tower and its deeper foundations.

Work in the caisson began in September 1871, and at a depth of 15m the first cases of caisson disease became evident. Some men, once leaving the caisson, suffered headaches, violent pain and cramps in limbs. The pain was described by some workers as feeling like having flesh ripped from every bone[1]. They described the headaches as like

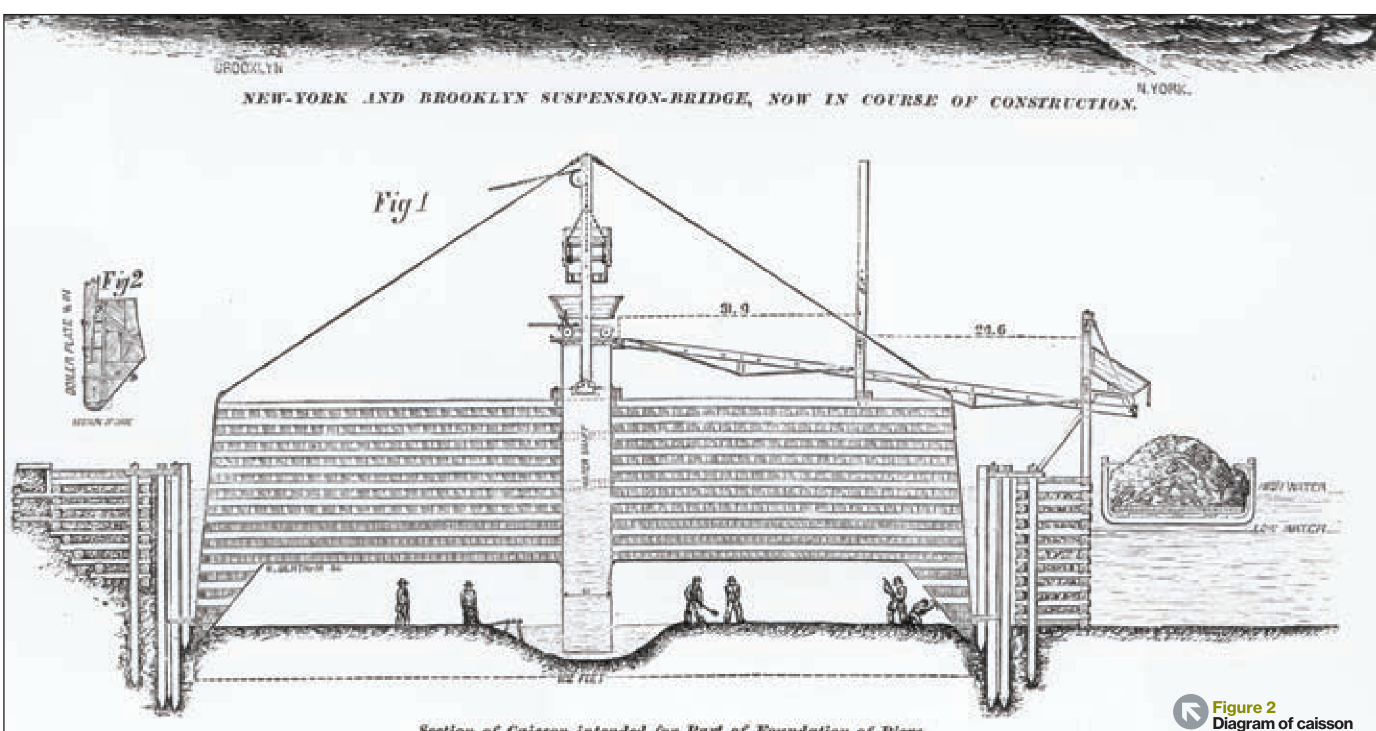

Figure 2 Diagram of caisson

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being shot. The disease was soon nicknamed 'the bends' because those afflicted would suddenly bend over in pain.

Roebling pressed on, the caisson reached 18m deep, and the disease began to afflict more workers and increase in severity: men began suffering paralysis. By 21m deep men were starting to die. Roebling had engaged Dr Andrew Smith to assist and try to understand the disease, but it remained elusive and no management strategy became apparent. His best suggestion was that the men should spend longer 'decompressing' as they left the caisson.

Smith was on the right track. Caisson disease – as we now know – is caused when the nitrogen that is in solution form in our bloodstream is liberated and turns into gaseous form when subject to rapid decreases in atmospheric pressure. This gas forms bubbles that can block the oxygen supply in our bloodstream. When it occurs in the limbs, it results in severe pain; but when it happens in the spinal cord or brain, the consequences are lethal. Allowing more time for decompression gives the body more time to dissipate the nitrogen through the lungs, thus preventing formation of the harmful bubbles. But all of this wasn't known at the time, and as the construction continued, the incidence of injuries, paralysis, and death mounted.

At a depth of 24m, workers hit a layer of compacted sand and gravel that was almost impossible to remove. Roebling faced a tough decision. Did he press on to bedrock as he and his father had originally envisaged? Or did he cease evacuation, leaving this the final resting place for the New York tower? To press on would risk further paralysis and death – Roebling estimated possibly 100 lives – but to stop now required him to evaluate whether the ground was strong enough to support the tower[2]. If it wasn't, subsidence would be a real issue. Roebling chose to stop, and time would bear out the wisdom of his decision. The New York caisson was completed in 1872, two years after the commencement of construction and three years since the death of John Roebling.

Catastrophe

Progress, however, would come at a high cost – not only to the workers but to Washington Roebling himself. While building the first caisson on the Brooklyn side, on the night of 1 December 1870, when the caisson was 13m deep – almost at its final depth – the caisson's timber roof caught fire. Slowly, this small fire, which initially went unnoticed, began to work its way into the roof of the caisson. If the fire spread too far, it would structurally compromise the base of the tower – Roebling estimated that the roof of the caisson was supporting over 25 000t of limestone and granite. Getting the fire out was paramount, but this was an immensely difficult task because at this stage it had wound its way up into the timbers and it was impossible to see or to determine how far into the roof it had progressed.

Roebling threw himself at the problem. He spent almost a straight day and night in the caisson[1]. Holes were drilled in the timber to check the progression of the fire, but they only introduced oxygen and fanned the flames. Water was sprayed continuously at the roof. Finally the fire appeared to be out. Shockingly, with the problem resolved, Roebling collapsed; he had started to notice he had developed some paralysis in his limbs. He was taken home to rest, but after three hours he was called for again. The fire was still burning. Worse, it was now out of control.

He got up and went back to the site, he only had one option available: flood the caisson and hope the rising water could extinguish the fire before it burned through the roof. It was a risky option, there was no guarantee water could be pumped into the caisson at the same rate that air could be released – the caisson itself could collapse or be irreparably damaged. It took seven hours to flood it using fire engines, fire boats and tugs. An exhausted Roebling stayed to watch. They waited. Two and a half days later they pumped the water out and went to inspect. The water had done its job. The fire was out and the caisson was structurally sound.

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Figure 3
Workers descend into caisson and labour in hot, humid conditions

However, after the completion of the second caisson on the New York side, Roebling would again be stricken by the bends, but this time much worse than the attack while fighting the fire. He collapsed, paralysis set in, and he was bedridden and in constant pain. Doctors did not believe he would survive the night[2]. The whole project was now again in jeopardy, with the demise of another chief engineer expected.

It is here, however, that the real human story begins. It is here that Roebling defies the odds and fights on to see through the completion of the bridge. And, importantly, it is here that Emily Warren Roebling really enters our story.

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