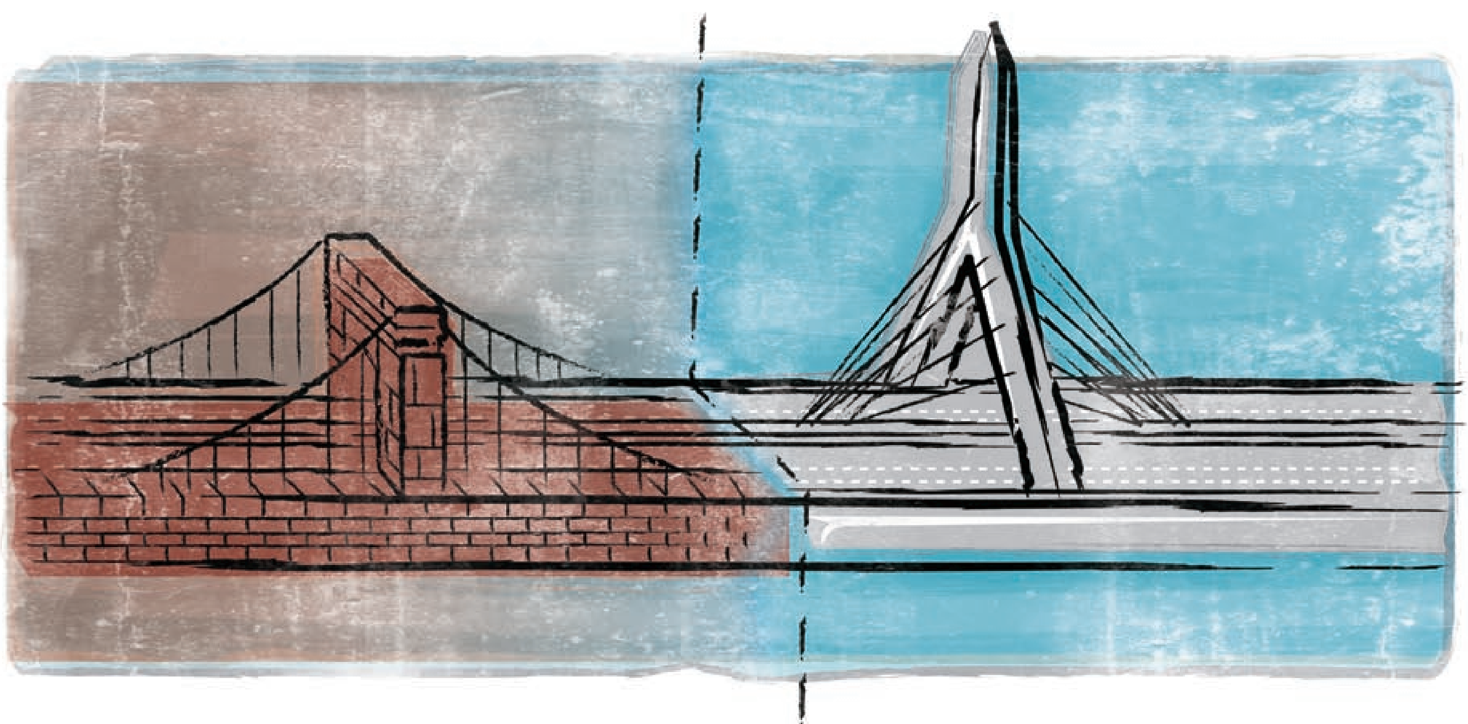
Success Through Failure

BY HENRY PETROSKI

"Nothing succeeds like success" is an old saw with many different teeth—some still sharp and incising, some worn down from overuse, some entirely broken off from abuse. In fact, the saying borders on tautology, for who would deny that a success is a success is a success? We know success when we see it, and nothing is quite like it. Successful products, people, and business models are the stuff of best sellers and motivational speeches, but success is, in fact, a dangerous guide to follow too closely.



Imagine what would have happened if the *Titanic* had not struck an iceberg and sunk on her maiden voyage. Her reputation as an "unsinkable" ship would have been reinforced. Imagine further that she had returned to England and continued to cross and recross the North Atlantic without incident. Her success would have been evident to everyone, and competing steamship companies would have wanted to model their new ships after her.

Indeed, they would have wanted to build even larger ships—and they would have wanted to build them more cheaply and sleekly. There would have been a natural trend toward lighter and lighter hulls, and fewer and fewer lifeboats. Of course, the latent weakness of the *Titanic*'s design would have remained, in her and her imitators. It would have been only a matter of time before the position of one of them coincided with an iceberg and the theretofore unimaginable occurred.

The tragedy of the *Titanic* prevented all that from happening. It was her failure that revealed the weakness of her design. The tragic failure also made clear what should have been obvious—that a ship should carry enough lifeboats to save all the lives on board. *Titanic*'s sinking also pointed out the foolishness of turning off radios overnight, for had that not been common practice with the new technology, nearby ships may have sped to the rescue.

A success is just that—a success. It is something that works well for a variety of reasons, not the least of which may be luck. But a true success often works precisely because its designers thought first about failure. Indeed, one simple definition of success might be the obviation of failure.

Engineers are often called upon to design and build something that has never been tried before. Because of its novelty, the structure cannot simply be modeled after a successful example, for there is none. This was certainly the case in the mid-nineteenth century when the railroads were still relatively new and there were no bridges capable of carrying them over great waterways and gorges. Existing bridges had been designed for much lighter traffic, like pedestrians and carriages.

The suspension bridge seemed to be the logical choice for the railroads, but suspension-bridge roadways were light and flexible, and many had been blown down in the wind. British engineers took this lack of successful models as the reason to come up with radically new bridge designs, which were often prohibitively expensive to build and technologically obsolete almost before they were completed.

The German-born American engineer John Roebling, the bicentennial of whose birth is being celebrated this year, looked at the history of suspension-bridge failures in a different way. He studied them and distilled from them principles for a successful design. He took as his starting point the incontrovertible fact that wind was the greatest enemy of such bridges, and he devised ways to keep the bridge decks from being moved to failure by the wind.

Among his methods were employing heavy decks that did not move easily in the wind, stiffening trusswork to minimize deflections, and steadying cables to check any motions that might develop. He applied these principles to his 1854 bridge across the Niagara Gorge, and it provided a dramatic counterexample to the British hypothesis that a suspension bridge could not carry railroad trains and survive heavy winds. The diagonal cables of Roebling's subsequent masterpiece, the Brooklyn Bridge, symbolize the lessons he learned from studying failures.

Ironically, the Brooklyn Bridge, completed in 1883, served not as a model of how to learn from failure but as one to be emulated as a success. Subsequent suspension bridges, designed by other engineers over the next half century, successively did away with the stay cables, the trusswork, and finally the deck weight that Roebling had so deliberately used to fend off failure.

At first, the size of the main span of the suspended structures increased in small increments. The 1,600-foot inter-tower span of the Williamsburg Bridge, completed in 1903, was only a few feet longer than that of the Brooklyn Bridge, but like all subsequent record-setting suspension bridges it was designed without stays. However, it did have an extremely deep truss, which made it look ungainly.

Over the next two decades, the main span of suspension bridges was increased only gradually. When the Benjamin Franklin Bridge opened in 1926, its world-record 1,750-foot span was less than 10 percent greater than that of the Brooklyn Bridge, which was then more than forty years old. But bridges like the Williamsburg, Manhattan, and Ben Franklin, serving the traffic of large cities and carrying mass transit tracks, were necessarily wide and consequently heavy, and they all had very visible stiffening trusses.

The next dramatic departure from Roebling's recipe for failure-based success was achieved in the George Washington

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Bridge, which was completed in 1931. This enormous structure, with a main span of 3,500 feet, almost doubled the record, representing an amazing 95 percent increase over the previous record holder, the Ambassador Bridge in Detroit.

However, the George Washington Bridge not only represented a great reach beyond the envelope of experience, it also represented a new direction in the design of suspension bridges. In having no stiffening truss at all, it did away with another of Roebling's specifications for dealing with the wind. But the George Washington Bridge was an enormous success, in large part because its cables and deck were so massive that their inertia ensured that the wind would not move them to any appreciable extent.

The success of the George Washington Bridge ushered in a new era of suspension bridge design, one that was characterized by an aesthetic of slenderness. This soon became the goal for virtually all suspension bridges designed and built in the 1930s, including the Golden Gate Bridge, which opened in 1937. At 4,200 feet between towers, that San Francisco bridge represented another 20 percent leap in length. And even though it incorporated a deck truss, it furthered the aesthetic of lightness and slenderness of appearance.

The culmination of this steady paring down of Roebling's design principles was reached in the late 1930s, when bridges were increasingly being built longer, lighter, and more slender. However, unlike the George Washington and the Golden Gate, which were designed to carry a relatively large number of lanes of traffic, many of the newer bridges were designed for remote areas where traffic projections called for as few as two lanes and virtually no sidewalks, which made for spans that were not only long but also exceedingly narrow. And, in keeping with the new aesthetic, the roadways were also very shallow, making for structures that provided little stiffness against bending and twisting.

The deck of the Bronx-Whitestone Bridge, completed in 1939 just in time to carry traffic to the World's Fair in Flushing Meadows, began to undulate in the wind, as did that of the Deer Isle Bridge in Maine, which opened that same year. Other contemporary bridges also proved to be susceptible to the wind and exhibited excessive movement of their roadways. Engineers disagreed on the cause and remedy of the unexpected motion, and also on exactly how to retrofit the bridges with cables to check it. Still, no one appears to have feared that the bridges were in imminent danger of collapse.

The Tacoma Narrows Bridge, completed in 1940, at first behaved in much the same way, with its deck rising and falling in great undulations. The fun of driving over it actually increased beyond all expectations the amount of traffic using the bridge, which had come to be nicknamed Galloping Gertie. The fun lasted for only four months, however, at the end of which the bridge deck began to move in a new way. It started to twist with great amplitude, and after only hours of such motion its deck collapsed into the arm of Puget Sound that it had been designed to cross.

The story of suspension bridges from the Brooklyn to the Tacoma Narrows provides a classic case history in the value of designing against failure and the danger of gaining undue confidence from successful achievements. Today, there is a new type of bridge whose evolution may be following all too closely more recent models of success.

A cable-stayed bridge may be thought of as a Brooklyn Bridge without the swooping suspension cables. The new form lends itself to considerable aesthetic variation in how its cables are arranged, and so it has become the bridge type of choice for signature spans. The cable-stayed Leonard P. Zakim Bunker Hill Bridge crowned Boston's Big Dig, and Charleston's new cable-stayed Ravenel Bridge has already become that city's new symbol.

But as cable-stayed bridges have grown in length and daring, their cables have been stubbornly difficult to control in the wind. Many such bridges have had to be retrofitted with damping devices to check the cable motion. Even though the aerodynamic phenomena involved are not completely understood, longer and sleeker cable-stayed bridges continue to be designed and built around the world. It is as if the history of suspension bridges was being repeated. Let us hope that the precursors to failure become understood before the models of success are pushed too far. ●

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