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Bridges of Charleston

Henry Petroski

THE MOST TALKED-ABOUT cable-stayed bridge in North America these days is one that provides a modern crossing of the Cooper River at Charleston, South Carolina. With a record-setting span of 1,546 feet between its diamond-shaped towers, the new bridge has replaced an obsolete pair of cantilever trusses that were considered by many to be dangerous and ugly. But the aging bridges themselves were landmarks dear to the hearts of many a sentimental Charlestonian, who viewed their demise with mixed feelings. This should not have been a surprise in a city so steeped in history and tradition.

The Cooper River has repeatedly challenged engineers' resourcefulness

Access for Commerce and Recreation

Charleston is located at the tip of a long peninsula that is bounded on the west by the Ashley River and on the east by the Cooper River, the former being about a half-mile wide and the latter more than a mile wide in the vicinity of the city. Not surprisingly, it was the narrower Ashley that was bridged first, in 1808, thus providing an alternative to ferries for bringing such goods as lumber, rice and tobacco from the extensive James and Johns islands to the Charleston Harbor wharves. Over the next century or so, several more wooden bridges were erected over the Ashley, including a toll bridge that was destroyed by a hurricane in 1893. In the 1920s, concrete was still a relatively new bridge-building material, and it was used to construct Memorial Bridge, the "widest and handsomest bridge in the South."

In the meantime, Charleston's eastern boundary remained unbridged. Only ferries or a long road trip up and then down the banks of the Cooper River linked the city to the sparsely populated communities on the mainland across the river and to the summer retreats on Sullivan Island, which lay at the mouth of the harbor and played a strategic role in the Revolutionary War. A long barrier island to its north, where British soldiers were kept at bay by treacherous currents, remained virtually unoccupied throughout the 19th century. It was variously known as Hunting Island and Long Island until acquired in 1899 by Joseph Lawrence, who renamed it Isle of Palms. Lawrence, who had introduced the electric trolley to Charleston, had plans to exploit the island's sandy beaches by building a resort beside them. His desire to make it relatively easy for people to get from the city to the resort led him to develop the Charleston & Seashore Railroad and integrate it into a system of ferries and railroad trestles to accomplish his end.

The Isle of Palms was well established as a recreational destination in 1913, when James Sottile, whose family's cottage had been the first on the island, became president of the business empire that Lawrence had built up and, now in ill health, sold. Sottile looked for ways to make it more convenient for people to get to the island beach, and he sought to secure the exclusive right to build a bridge across the harbor. Rather than going through local channels, he hoped to achieve his objective via federal legislation. His proposed concrete bridge, which was to have vertical lift spans to allow ships to pass into and out of the harbor, met general opposition from shipping interests and the Navy, which operated a shipyard at Charleston. Sottile suffered financial setbacks in the wake of the World War, and his eventual bankruptcy led to the seizure of his ferries. This led in turn to the establishment in 1924 of the government-based Cooper River Ferry Commission to restore service to the harbor.

New owners had big plans for the Isle of Palms, and they included the construction of a privately financed and operated bridge across the harbor. However, with the proliferation of the automobile, which naturally relied greatly on a network of bridges, there was increasing opposition to the government granting exclusive franchises. The owners of the Isle of Palms, headed by the promoters Charles Allen and Harry Barkerding, established the Cooper River Bridge Corporation and sought to secure a charter to build their structure. But at the same time state and local authorities began to consider building a publicly owned bridge. The situation led to a compromise, in which the private corporation would be allowed to build the bridge, but the county would have the option of buying it after some years of operation.

Which Bridge and Where?

But the nature of the bridge remained to be settled. To remove objections to a low-level crossing, Barkerding had proposed a combination tunnel-bridge, with traffic being carried under the shipping lanes, an idea not unlike that which would be realized three decades later in the Chesapeake Bay Bridge-Tunnel. Thus, the language of the enabling legislation for the Cooper River crossing granted the right to build a "tube, tunnel, and bridge." When engi-

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neering feasibility studies showed the concept to be prohibitively expensive with the technology of the 1920s, it was too late to have the legislative language changed. Thus, if the promoters wished to build a low-level bridge, they would have to seek in the courts a favorable interpretation of the enabling legislation. To assist them, they engaged the attorney John P. Grace, who as mayor of Charleston had opposed just such a crossing. Now, as an advocate, he succeeded in getting the state supreme court to rule in favor of a pure bridge.

It still remained to decide exactly what the bridge would look like and where it would be located. Allen and Barkerding had assumed its Charleston approach would be somewhere near the center of the city, but the War Department opposed that. It furthermore demanded that, wherever located, the bridge be a high-level design with an unobstructed horizontal clearance of 1,800 feet. At the time, that was about the greatest span any bridge had achieved. The Benjamin Franklin suspension bridge just completed in Philadelphia had a main span of 1,750 feet, and the 1,800-foot Quebec Bridge, redesigned and rebuilt after a catastrophic collapse during construction, had established the limit for a cantilever truss. But building at the limits of technology was expensive, and it could not be done in Charleston for the $3 million Allen and Barkerding had planned to spend on a bridge with an 850-foot movable span, according to Shortridge Hardesty, the engineer they had engaged. Hardesty was the junior partner in the firm of Waddell & Hardesty, whose experience in movable bridges made it a natural to design a low-level crossing.

Fortunately, Hardesty and Grace were able to negotiate a compromise, but only to a degree. The bridge would be located about a mile upriver, where it would use Drum Island as a stepping-stone to the Charleston suburb of Mount Pleasant. In exchange for this concession, the War Department agreed that a horizontal clearance of 1,000 feet and a vertical of 150 feet would be sufficient for the Navy. But since a movable span of that length was not feasible, the bridge had to be designed as the fourth longest cantilever span in the world. The budget had risen to $6 million, thanks to financial commitments from Chicago investors whom Grace had courted, but to meet that price Hardesty had to come up with a bare-bones design consisting of a 640-foot span over Town Creek, which separated Drum Island from the Charleston peninsula, and a 1,000-foot span over the Cooper River proper.





The John P. Grace Memorial Bridge was the first to span the Cooper River at Charleston, South Carolina. Finished in 1929, its curves and abrupt changes in height soon earned it the nickname Old Roller Coaster. Grace Bridge was followed in 1966 by the Silas N. Pearman Bridge and just last year by the longest cable-stayed bridge in North America, the Arthur J. Ravenel, Jr., Bridge. (Photographs courtesy of Charleston County Public Library.)

Among the ways in which money can be saved on a bridge design are to reduce the number of water foundations, shorten land approaches and lower viaducts. These ends were accomplished by locating part of the crossing over Drum Island, where piers could be built on land rather than in the water, by employing steeper grades up to and down from the 150-foot height of the structure, and by using a low viaduct over Drum Island, thus employing less steel. The bridge was also made with two narrow lanes and virtually no shoulders, which was in keeping with the practice of the day. Surveying for the alignment began early in 1928, and the bridge was opened 18 months later. The pronounced up-and-down, curving roadway earned the structure the nickname Old Roller Coaster.

Taking a Toll

Despite the local affection that developed for the time-saving Cooper River Bridge, it was not a financial success. Its promoters had overestimated the volume of traffic that would pay its tolls, and the Depression further suppressed revenues. By the early 1930s, negotia-

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tions began for the city's purchase of the bridge, but there was considerable debate over its price and the allocation of tax dollars. After a decade of wrangling, the deal was finally consummated in 1941, for a price of $4.4 million.

The bridge, which officially became the John P. Grace Memorial Bridge, served the area well. Its essential role in the infrastructure of the region was emphasized when in 1946 a 12,000-ton freighter struck a low part of the bridge and knocked out a 240-foot section of it. A Bailey bridge—a portable, easily erected temporary structure developed during World War II—provided continuity in the structure so traffic could continue to use it until repairs could be completed. In the 1950s, increased traffic and an attendant increase in accidents fueled talk of a second bridge, and it was opened in 1966. Although the Silas N. Pearman Bridge, named after a longtime state highway-department official, closely resembled the Grace bridge, especially in its cantilever spans, the newer bridge did not dip so low over Drum Island and so had more gentle grades as well as more and wider lanes.

With the luxury of two bridges, Charleston could sponsor the Cooper River Bridge Run, a footrace that began in 1978. At first the Grace Bridge was used, allowing traffic to move unimpeded on the parallel Pearman, but steadily growing participation in the popular event caused it to be switched to the wider bridge in 1995. In the new millennium, official entrants in the 10-kilometer race have numbered more than 16,000, and nearly twice that number participated in various related runs and walks, making the event one of the largest of its kind in the world.



Construction of the Ravenel Bridge proceeded outward from each of its 570-foot-tall diamond-shaped towers. (Photograph courtesy of Rob Thompson/SCDOT.)

In spite of the sentimental attachment so many Charlestonians had for the Cooper River bridges, they were recognized to be getting old and expensive to maintain. Large trucks and buses were banned from using the Grace Bridge. Studies that had begun as early as 1988 led to the conclusion that the two old bridges would not last much longer and, besides, were not up to modern traffic standards. In 2001, it was announced that the two bridges would be replaced by a single one, of a cable-stayed design. The South Carolina Department of Transportation advertised the availability of the Grace Bridge for purchase, removal and relocation. The ad noted that the bridge was eligible for listing on the National Register of Historic Places and suggested that it might be re-erected elsewhere, perhaps the way London Bridge was in Lake Havasu City, Arizona.

A Signature Bridge

But before the old bridges could be dismantled and carted away, a new one had to be in place. Bridge engineering is always advancing, with new theories, materials, erection techniques, standards and styles displacing the old. Whereas the cantilever truss may have been in vogue when the original Cooper River crossing was designed, in the late 20th century it was the cable-stayed bridge that had become the type of choice. Not only is it an efficient structure to design and construct, but also it is a style that lends itself to distinctive aesthetic features. This made it ideal for Charleston, which wanted a signature bridge to replace both the old Grace and Pearman bridges that had come to be so closely associated with the city.

Since the South Carolina Department of Transportation was the owner of the bridges, it took the lead in laying out where the bridge would be located and what it would look like. The choice in location was rooted in the 1920s, when to satisfy the Navy the first Cooper River bridge was built upriver from downtown. This naturally had promoted development in the area, on both sides of the river. The road network that had developed to accommodate the growth was inadequate for the projected traffic demands imposed by more traffic lanes, and so a more rational and modern system of approaches was to be developed.

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However, since the old bridges were to be torn down, they themselves imposed no aesthetic constraint on their successor. The new bridge could be designed starting with a blank computer screen.

The normal process would have been for the transportation department to prepare a preliminary design—laying out in rough terms the kind of bridge it desired—and then have a consulting firm that specialized in such bridges carry out the detailed design. When that was finished, the project would be let out for bids in order to select a construction company. The traditional process was time consuming, separated designer and builder, and often led to delaying disputes over whose fault it was that something could not be built as designed. To avoid such a situation in Charleston, a design-build contract was sought, in which the same company performs both functions and is thus motivated to resolve any problems quickly, since otherwise they will eat into profits. The preliminary design served as the basis of a competition to select a designer-builder, and in 2001 a fixed-price contract for $531 million was signed with Palmetto Bridge Constructors (a joint venture of the construction companies Tidewater Skanska, of Virginia, and Flatiron, of Colorado) for an eight-lane bridge with a pedestrian walkway and bicycle path cantilevered off one side of the deck and outside the supporting cables.



The Ravenel Bridge's 1,546-foot main span makes it the longest cable-stayed structure in North America. The bridge also dwarfs its predecessors, commanding the most prominent sight in the Charleston area. Its eight traffic lanes have greatly eased travel between Charleston, Mount Pleasant and the beach resorts at Sullivan's Island and Isle of Palms beyond. (Photographs here and on page 118 courtesy of C. Frank Starmer, http://oldcooperriverbridge.org)

Although Palmetto was the general contractor, the engineering design was subcontracted to the firm of Parsons Brinckerhoff Quade & Douglas, which is noted for its bridge work. Still, designing a major bridge for Charleston is far from a routine assignment. The basic loads on a bridge structure, consisting of its own weight and that of the traffic that will cross it, may be well defined, but these are not the only ways the structure will be tested throughout its lifetime. Charleston's location makes any structure built there susceptible to both earthquakes and hurricanes. A bridge across the Cooper River must also be designed to withstand ship impact. And these sources of extreme loads are not mere theoretical constructs. In 1886, an earthquake of a magnitude (7.3) more commonly associated with the West Coast hit the region, and the trauma it caused is memorialized in the many exposed bolt plates associated with the iron rods that hold together some of the older buildings in Charleston. The reality and effects of hurricane-force winds on coastal areas need no documentation after the events of the 2005 season. And senior Charlestonians still recall the 1946 ship collision that left them without a fixed crossing of the Cooper River.

Contemporary structural designers employ computer-based models to test their hypotheses about the suitability of specified quantities of steel and concrete in the form of columns, beams, girders, plates, cables, towers and the details that hold them together into a geometrical configuration that we call a building, bridge or other kind of structure. These models are very sophisticated and capable of representing a wide range of combinations of loads and resistances, and they can be used to identify weak links that can be beefed up before another computer-based simulation is run. By a process of iteration tempered with judgment, designers converge on an arrangement of parts that, taken together, constitute *the* design for the structure.

As powerful as computer models may be, they do have the limitation that they are still models of the bridge and not the bridge itself. Any invalid assumptions or oversimplifications about the structure or its loading can lead to conclusions that differ from the reality that will be. If, for example, a computer model of a bridge is excited only by a computational earthquake dominated by horizontal ground motion, there can

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Once the Ravenel Bridge *(in background)* was opened in July of 2005, the Grace Memorial *(shown here)* and the Pearman bridges were removed.

be no assurance that it will stand up to one with strong vertical movement. Similarly, subjecting a computer model to a computerized wind raises all sorts of questions about the completeness and reasonableness of the response. As a result, it has become commonplace to use physical scale models in wind tunnels to test important structural designs. In the case of the Charleston cable-stayed bridge, there were also questions about how the presence of the existing Grace and Pearman bridges would influence the wind patterns to which the new bridge would be subjected during and after construction, and so models of the old bridges were also placed in the wind tunnel.

Among the most vexing design problems associated with cable-stayed bridges is eliminating cable and deck vibrations. The causes of these phenomena are still not completely understood, and computer models appear to be incapable of predicting the occurrence of severe cable vibration problems with any certainty. As a result, many bridges have had to be retrofitted with motion checking and damping devices when problems have arisen with the finished structure. Increasingly, from the outset damping devices are being incorporated into bridge designs, in anticipation that there will be some vibration problems that can be dealt with as they arise. Not surprisingly, the new Charleston bridge is fitted with such devices.

Two dominant physical features distinguish one cable-stayed bridge from another: the shape and number of the towers (often called pylons) and the pattern of the cables emanating from them. The Charleston bridge has two elongated diamond-shaped towers, each rising 570 feet above the water. Such tall towers were expected to be the most prominent structures in the region, being visible from as far as 30 miles away. This fact, coupled with the importance of the historic architectural environment into which they would be placed, made it imperative that they be designed with a strong sensitivity to aesthetics. The choice of diamond-shaped towers was made during the process of selecting a design-build team, which included a series of public hearings. The diamond shape appears to have been a wise choice. Although it evokes and echoes some prominent church steeples, it does not compete with the other historic structures of the city, and it gives a feeling of lightness and transparency, both above and below the roadway, to an enormous structural form.

The inclination of the sides of the towers imposes an inclination on the plane of the cables that support the bridge's main span in a way that is at the same time cradling and open. As in all cable-stayed bridges, the appearance of the cables changes as one drives or walks across the structure, and it also changes as one views it from different distant vantage points. Since the tops of the towers do not come to a true diamond point but rather are truncated above a short horizontal strut, thus separating the cables and leaving an unobstructed opening to the sky, drivers and passengers experience their full height. When viewed from roadways off the bridge, its towers and cables interplay in a geometric dance of seemingly endless combinations of lines and planes. The most common view of the new bridge can be expected to be from downtown Charleston, and that will likely become the signature postcard image of the structure. Still, for all the variations, its distinctive tower and cable geometry render the bridge recognizable from a variety of perspectives.

The Arthur J. Ravenel, Jr., Bridge, named after the former South Carolina congressman, was opened in July 2005, just four years after groundbreaking and a full year ahead of schedule. A week of celebratory festivities included displays of fireworks, a performance on the bridge by the Charleston Symphony Orchestra and a bridge walk in which overall as many as 100,000 people are said to have participated. Soon afterwards, the old bridges began to be demolished. The Ravenel Bridge now stands alone across the Cooper River—the proud new symbol of Charleston. And it has been designed to last for at least 100 years.

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