Arthur Ravenel, Jr. Bridge

Outstanding Project Award Winner

Parsons, Brinckerhoff, Quade & Douglas

Located in a busy port in a highly seismic area subject to frequent storms, the Arthur Ravenel, Jr. Bridge was designed to withstand ship collisions, earthquakes and hurricane-force winds.

Designed to replace two existing outdated truss bridges, the new Arthur Ravenel, Jr. Bridge is one of the largest design-build bridge projects in the United States. This 3.5-mile-long bridge across the Cooper River in Charleston, South Carolina includes an eight-lane main span of 1,546 feet with two 572-foot-high diamond-shaped concrete towers, high-level approaches, 15 ramps and two interchanges.

The South Carolina Department of Transportation (SCDOT) in partnership with the FHWA awarded the contract for the bridge in 2001 to a joint venture of Tidewater Skanska and Flatiron Constructors, known as Palmetto Bridge Constructors (PBC).

Arriving at an appropriate, cost-effective design solution to the demanding site conditions and design criteria in a very competitive design-build environment was a major design challenge. The environmental conditions in Charleston are among the most difficult in the United States, due to the occurrence of both significant earthquakes and severe hurricanes. Ship collision loads were also a major factor. The bridge was completed at a cost of $531.3 million.

Parsons Brinckerhoff served as the lead designer and Donald MacDonald Architects as the project's architect. Other team members included Buckland & Taylor, Ltd., design of high-level approaches and curved steel ramps; Ben C. Gerwick, Inc. foundation design for main span and high-level approaches; Rowan Williams Davies & Irwin, Inc., wind engineering; the LPA Group, Inc., civil and structural design; and SC Solutions, Inc., time history seismic analysis.

The project featured a number of structural engineering innovations:

Offset stay cable anchors to reduce main span tower moments. Due to their slope, the tower legs were subjected to a relatively large lateral bending moment. While it had been initially intended to align the stays with the center of each tower leg, it was found that locating the stay anchors to the inside face of the tower leg introduced a lateral bending moment that offset the dead load lateral bending moment. This not only saved a considerable amount of reinforcing steel, it also simplified the anchorage and provided more space in the tower interior for the elevator and access ladders. Another significant benefit was its impact on the overall esthetics of the bridge. When viewed from the roadway, the stay cables tend to blend into the edge of the tower and provide a smooth plane that is not interrupted by the tower leg. This effect was further enhanced by using light poles that are at the same incline as the stays.

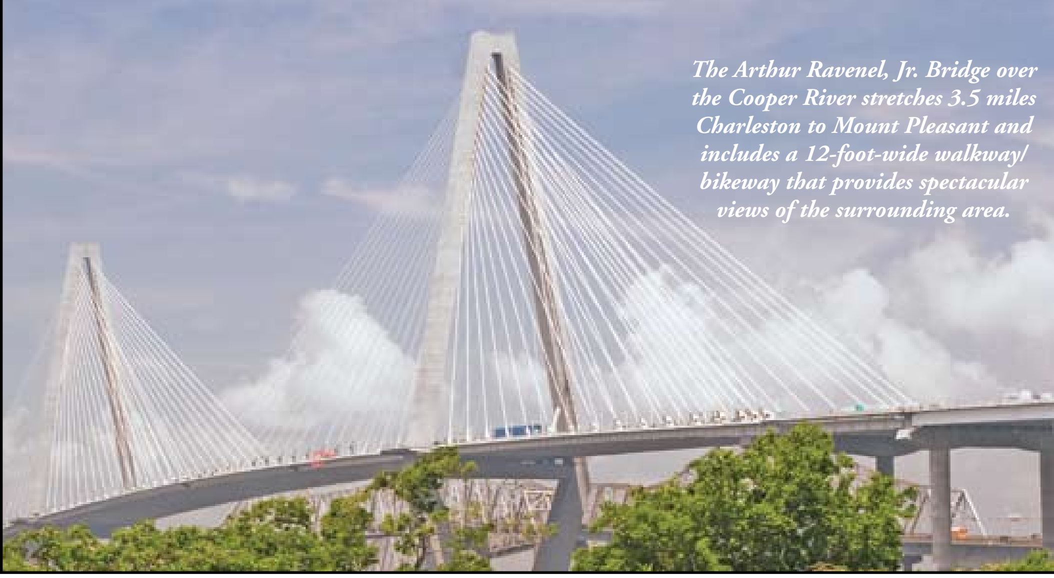
Parsons, Brinckerhoff, Quade & Douglas was presented with an NCSEA 2005 Excellence in Structural Engineering Outstanding Project Award (Bridges & Transportation Structures) for their project, the Arthur Ravenel, Jr. Bridge

Very long continuous approach spans. The very long, continuous high-level approach spans provided a flexible and cost-competitive structure that could meet the project's seismic demands and minimize future maintenance. The height of the piers for the high-level approach spans proved to be too flexible along the axis of the bridge. The solution adopted was to make the approach spans continuous over a significant length, 4350 and 2090 feet, so the shorter piers at the lower portions of the approaches act to brace the taller piers. This solution has the advantage of minimizing expansion joints, although it required considerable analysis to demonstrate its feasibility.

Elimination of almost all pile caps. This was achieved by using large-diameter drilled shafts framed directly into pier columns. The entire site is characterized by a layer of stiff clay known as Cooper Marl at a depth of 50 to 60 feet below Elevation 0. Above the marl, the river has soft alluvial deposits, while the land portions of the project have relatively soft surficial soils, so the bearing stratum throughout the site is the Cooper Marl.

In general, the solution adopted, particularly for the main span and high-level approach spans, was to minimize the structure weight to provide enough flexibility to minimize seismic demands. The use of 10-foot-diameter drilled shafts in the foundations both lessened the number of shafts and provided the required flexibility. For the main span piers, only 11 of the high-capacity drilled shafts were required. On the high-level approaches, typically only two drilled shafts per pier were required.

Simple, hollow rectangular main pier towers. These provided adequate ductility, thereby simplifying the construction. While the AASHTO standard specifications provided specific detail criteria for most of the structure, the behavior of the hollow cross sections of the main span piers was not well covered by existing criteria. As a result, an investigation into recently published reports on the nonlinear behavior of hollow reinforced piers was required to demonstrate that properly detailed hollow rectangular reinforced concrete sections have adequate ductility. This literature search was supplemented by an analysis using ADINA, with a specific subroutine to track the moment curvature behavior of those sections of the structure that would undergo plastic behavior during a seismic event. By comparing the theoretical analysis with published test results by Professor John Breen at the University of Texas, we were able to validate this approach. Considerable guidance on this matter was provided by a seismic resource panel chaired by Professor



The Arthur Ravenel, Jr. Bridge over the Cooper River stretches 3.5 miles Charleston to Mount Pleasant and includes a 12-foot-wide walkway/ bikeway that provides spectacular views of the surrounding area.

The graceful diamond-shaped towers of the Arthur Ravenel, Jr. Bridge soar 572 feet from the water line to the tops of the towers.

Frieder Seible of the University of California at San Diego.

Economical corrosion protection techniques. Elimination of epoxy coated bars, silica fume and corrosion inhibitors was achieved by making use of large amounts of locally available fly ash, a relatively low cost, low-permeability, environmentally friendly concrete.

Computer Programs. A number of computer programs were used on this project. Much of the structural analysis was accomplished using GT STRUDL®, with the time history and pushover analyses being accomplished using ADINA®. These analyses were summarized and combined using EXCEL® spread sheets. Typical concrete cross section analyses were accomplished using PCACOL®. The prestressed girders were designed using CONSPAN®. The main span dead and live load analyses utilized TANGO®. Despite the significant challenges on the Arthur Ravenel Jr. Bridge, the project was completed a year ahead of schedule. This is a tribute to the detailed planning on the part of the designers, as well the careful execution of construction by the entire design-build team.▪

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