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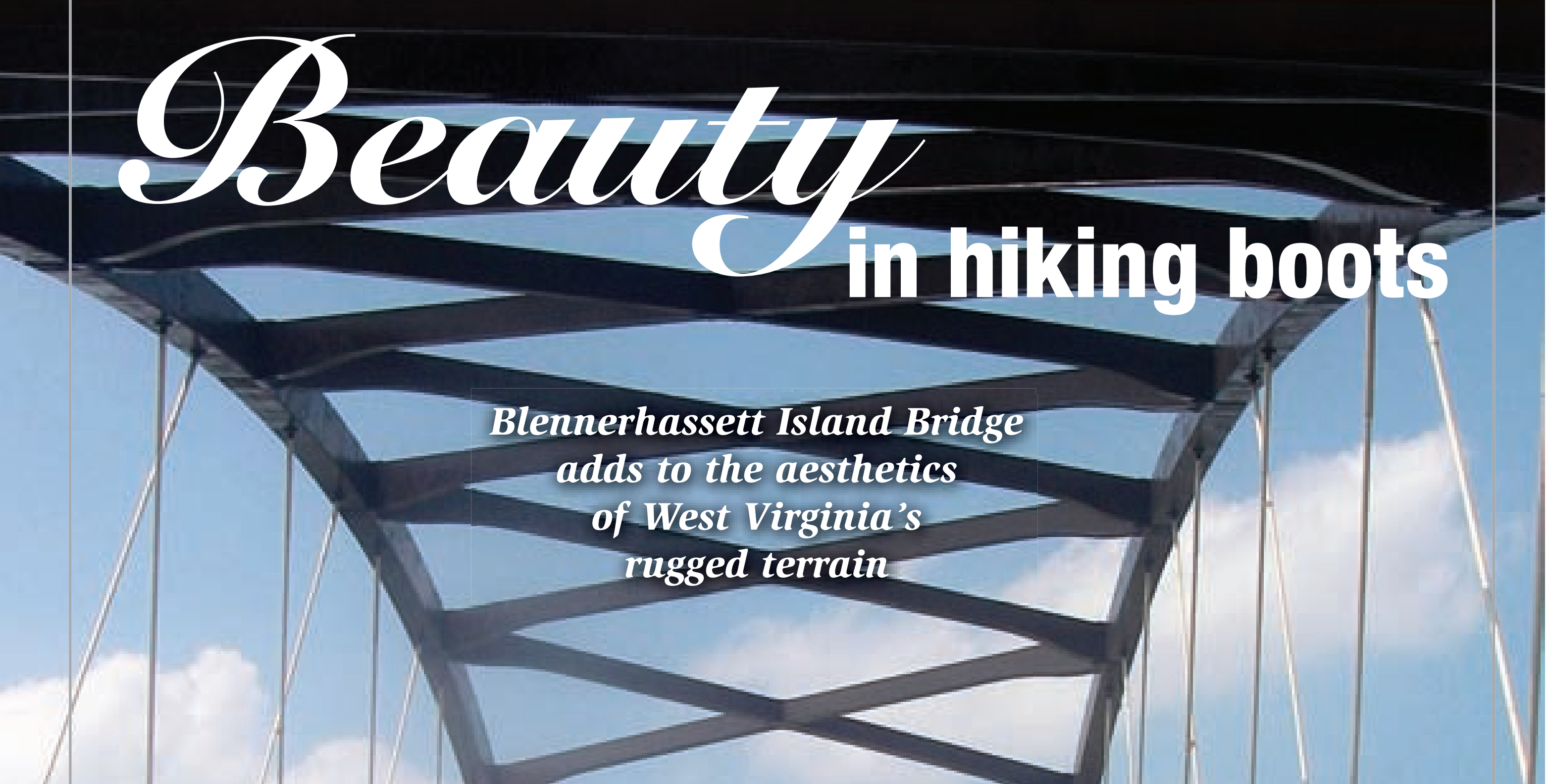
CONTRIBUTING AUTHORS



Beauty in hiking boots

Blennerhassett Island Bridge adds to the aesthetics of West Virginia's rugged terrain

Singer John Denver's 1971 hit single "Take Me Home, Country Roads" pays tribute to the rugged beauty of West Virginia's mountains and rivers.

But neither Denver nor the residents of the state could have envisioned the breathtaking entryway to West Virginia that exists today: the Blennerhassett Island Bridge over the Ohio River.

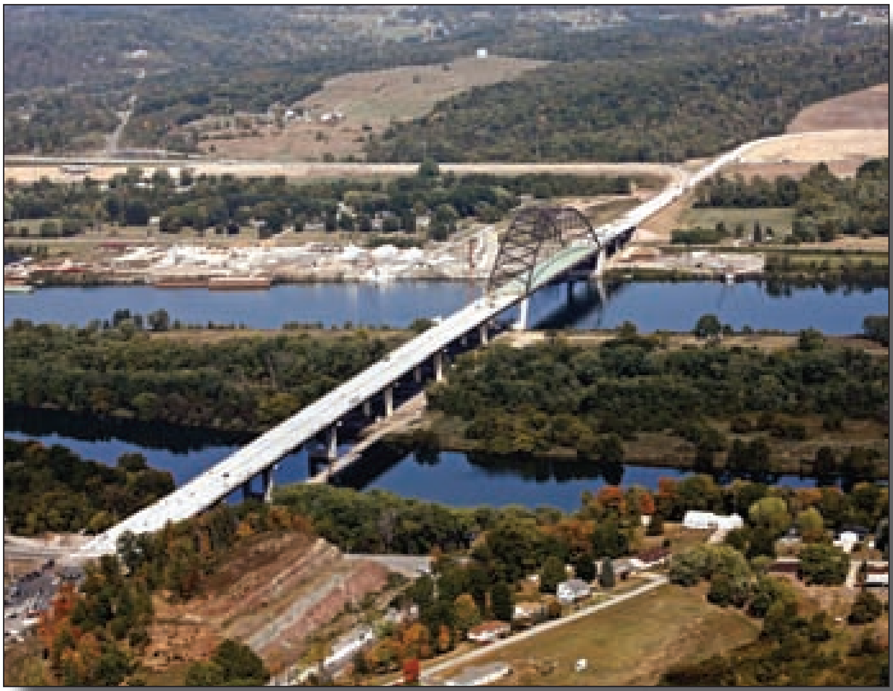
The structure arches high above the horizon, yet its slender lines, which make it appear almost transparent, preserve the scenic vistas of the Ohio River and historic Blennerhassett Island. With integrated arch and truss elements that promote safety and cost efficiency, the bridge embodies the innovative application of design technology.

"The Blennerhassett Island Bridge is a signature structure designed by engineers who were willing to test the limits of traditional engineering methodology. They realized that the unique setting of this structure demanded a special approach," said James Shook, P.E., project manager for the West Virginia Department of Transportation (WVDOT), Division of Highways, owner of the structure. "The bridge also exemplifies the benefits of the strong partnership forged between the West Virginia and Ohio departments of transportation to improve mobility and promote economic vitality in the region."

The Blennerhassett Island Bridge spans Blennerhassett Island—an environmentally sensitive area and historic district, as well as a prime tourist attraction—and the main and back channels of the Ohio River. Located at the border between Ohio and West Virginia, the structure was identified as the critical remaining "missing link" of the final segment of Appalachian Highway Corridor D, a major economic development highway that traverses approximately 240 miles along U.S. 50 from Cincinnati, Ohio, to Clarksburg, W.Va. The corridor represents a longstanding commitment among federal, state and local agencies to enhance the east-west highway system and promote access to major urban centers and western markets.

The total length of the Blennerhassett Island Bridge is 4,008 ft from abutment to abutment. The structure includes an 878-ft-long tied-arch main span whose apex towers 245 ft above the Ohio River. The bridge approach spans consist of steel-plate girders with spans up to 401 ft in length. The bridge's tied arch ranks as the longest networked tied-arch structure in the U.S.; it also is among the longest in the Western Hemisphere.

The WVDOT selected the Michael Baker Jr. Inc. team to undertake the design of this long-span river crossing. Baker served as the prime consultant and provided project management, preliminary and final bridge design, post-design, environmental permitting and visualization and public involvement services. HNTB performed an independent design of the arch and provided construction inspection services. E.L. Robinson was responsible for the Ohio approach span design and the hydraulic design. H.C. Nutting, a Terracon Co., performed geotechnical reconnaissance and engineering and established foundation capacities. Walsh Construction Inc. constructed the bridge.



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The best of both types

From the earliest planning stages, accommodating the massive size of the Blennerhassett Island Bridge posed a significant design challenge. Engineers sought to develop a design that would optimize structural integrity and user safety, but that also would control costs by minimizing the size and weight of the approach-span superstructure. It was a complex problem that demanded an innovative solution.

Engineers departed from traditional bridge design methodology by designing a tied-arch structure that integrated a key truss-type element: post-tensioned steel networked cables that improve structural strength and flexibility and enhance safety. This hybrid arch-truss design approach made it possible to leverage the benefits of both bridge types.

In addition, post-tensioned pier caps provide support for the main tied-arch span and helped to reduce project construction cost.

The design included hybrid steel members utilizing high-strength, high-performance 70-ksi weathering steel for maximum durability and improved ductility. The high-strength steel also reduced material quantities, which lowered costs.

Networked tied-arch span

Ensuring structural integrity and durability were critically important. The bridge's arch span is strengthened by post-tensioned, seven-wire-strand steel cables configured in a unique X-shaped network, which enhances stiffness and redundancy in the bridge's superstructure. The post-tensioned, networked cables allow the structure to redistribute some of the arch rib's horizontal load, so that the members function similarly to those in a truss structure.

To evaluate stress distribution within the structure under normal conditions as well as during catastrophic events, such as cable loss, a 3-D finite-element model of the bridge was created. The 3-D model was used to refine the construction sequence. Each time survey points on the arch were measured, the 3-D model was updated to obtain data on the actual stresses to the members. The networked cables were carefully adjusted to optimize deck elevations and stress distribution for the structure based on the results of the 3-D model.

Use of the networked cables also enabled engineers to reduce the size of the arch rib by approximately half and thereby significantly reduce overall construction cost.

The arch-tie itself, normally a fracture-critical member, is a box-shaped tension tie specially designed to withstand cracking and not collapse. The tension tie was mechanically fastened together with bolts for redundancy, rather than welded together, which enables it to withstand loads even if one of the four plates that make up the box fractures. Mill-to-bear connections were established on the arch rib to reduce the number of bolts required at the connection and redirect the load to load-bearing members.

The bridge deck is longitudinally post-tensioned to prevent cracking caused by the lengthening of the tied arch under load. The piers also are post-tensioned to resist cracking.

Providing adequate corrosion protection also was a primary concern. To protect the cables from corrosion, significantly increase design life and reduce maintenance costs, engineers

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proposed an unusual three-tier cable protection system. The multiple seven-wire monostrands that make up each cable bundle are individually encased by a polyethylene sheath to prevent moisture infiltration. Each covered monostrand is then individually greased, and the cable bundle is encased in an HDPE pipe.

Engineers reduced the potential for expansion joint-related substructure corrosion by incorporating only two large deck expansion joints within the bridge's 4,008 ft length. The deck joints are located at each end of the 878-ft-long arch span. In addition, an expansion joint is located at the end of the Ohio and West Virginia approach slabs. To accommodate temperature-induced movement at the West Virginia approach, an open-cell chamber was constructed beneath the approach slab. A large steel toothdam was installed between the West Virginia approach slab and the approach roadway pavement to accommodate temperature-induced movement.

West Virginia approach

The 2,629-ft-long West Virginia approach consists of one eight-span continuous girder segment. The spans range in length from 195 to 401 ft. Hybrid steel girders 10 ft deep carry the load of the long-span segment. Seventy-ksi high-performance weathering steel was used in the high-stress areas of the segment to maximize strength and to minimize girder weight. The last two spans near the West Virginia abutment utilize flared girders to accommodate a turning lane at the end of the bridge. The two river piers were skewed 20° so that they would align with the shoreline.

A 3-D finite-element model also was created to analyze the West Virginia approach spans. The analysis was performed to account for the complex geometry and to accurately calculate girder stresses and dead-load deflections for the deck concrete-pouring operation.

The in-span deflection was tremendous—the bridge exhibited a 22-in. total dead-load deflection under concrete and steel loading and a 10-in. total dead-load deflection under concrete loading. Additionally, there was a 3-in. deflection among girders within the same span because of the complex bridge geometry. The cross frames that connect girders also were specially designed to account for variable deflection among girders.

The long-span girders were extensively stiffened both transversely and longitudinally, which helped to dramatically reduce both their weight and the thickness of the web plate (to ½ in.) and ultimately reduced construction cost. The design of the slender web plate challenged engineers by requiring them to develop a design that approached the limits of the AASHTO design code.

Putting pretty in its place

The construction phase presented many complexities that easily could have delayed completion of the bridge. Critical elements ranged from the steel fabrication method chosen for the arch rib to the construction of the girders and arch to the erection of huge cofferdams in the river to the need to maintain river traffic. Janssen & Spaans Engineering Inc. served as the contractor's engineer for construction design and collaborated with the contractor to tailor construction solutions to project needs.

Special steel fabrication

Design plans specified the use of the stringent mill-to-bear method for fabrication of the steel required to construct the arch rib. The intent was to use the most precise fabrication process available and thereby help reduce construction cost. However, the mill-to-bear method also presented its challenges for the steel fabricator and the design team. Although the shop measurements were precise, they did not always correspond to field measurements, and the differences had to be reconciled. Nonetheless, use of the mill-to-bear fabrication method succeeded in reducing the number of bolts required at the arch-rib splices by 50%.

Girder and arch erection

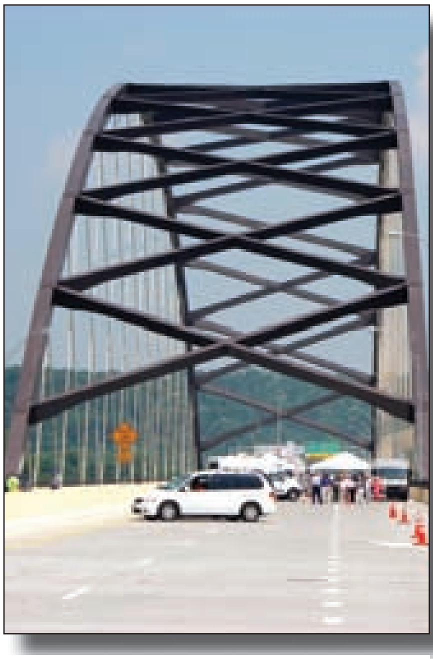
In preparation for construction of the tie girder and arch, the contractor constructed eight temporary drilled caissons in the river. The tie girder and arch were constructed in segments, from each abutment, halfway across the channel. The most efficient method was to construct a significant portion of the tie girder and use it as a base for building out the arch rib until the cantilevers reached the center of the span. The construction of the arch was the most complicated task of the entire project because of its overwhelming size and the need to ensure that the arch segments fit together perfectly. Temporary adjustable stays were used to brace the arch segments during erection prior to installation of the cable hangers. As each cable hanger was installed, the supporting temporary stay was removed.

The position of the arch was monitored very closely. Elevations were taken after every segment was erected, and the position of the structure was adjusted through the use of the temporary falsework stays provided by the contractor.

The Ohio side of the arch was constructed 6 in. out of position longitudinally, and then jacked into place during installation of the arch's "keystone" section. The ends of the arch were temporarily post-tensioned to the pier caps to ensure the stability of the cantilevered sections during jacking. Sand jacks with steel shims and polytetrafluorethylene sliders were mounted on top of the river caissons and served as temporary supports. The jacks and sliders also could be quickly and easily removed after the arch was constructed.

Large, barge-mounted cranes were necessary to install the heavy steel segments (which weighed up to 60 tons) for the arch and the West Virginia approach. The parabolic arch-rib segments had to be precisely balanced during lifting to enable in-situ connection to the erected segments.

The contractor designed a temporary bridge and used a "barge bridge" to cross the back channel of



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the Ohio River in order to access the island from the West Virginia shore. On the island, the contractor erected 70-ft-high falsework towers, designed to withstand a 75-mph wind load, to support the girder segments. The towers were anchored by guy wires connected to concrete deadmen embedded in the island soil.

Cofferdam construction

Staging and performing construction tasks within the constraints imposed by the swiftly moving currents of the Ohio River presented its own special concerns. Because four of the bridge's piers had to be located in the river, it was necessary to construct cofferdams up to 50 ft long × 110 ft wide × 50 ft deep.

The contractor took special safety precautions by designing the cofferdams to withstand barge impacts. Designing for this contingency proved to be very prudent: During a summer storm in 2006, a barge broke free from its moorings and struck the cofferdam at Pier 8 of the West Virginia approach, causing minor damage. If the cofferdam had been unable to withstand the impact, the results could have been catastrophic.

River traffic maintenance

Construction activities could not impede or interrupt river traffic, since the Ohio River is a major commercial shipping channel. The U.S. Coast Guard required that the contractor maintain a 410-ft-wide × 69-ft-high temporary navigable channel under the arch span during construction.

The construction schedule was closely coordinated with the U.S. Coast Guard and also with the U.S. Army Corps of Engineers.

Standardizing the uncommon

By pursuing a hybrid design for the Blennerhassett Island Bridge, engineers succeeded in maximizing structural integrity and safety while achieving efficiencies in material quantities and reducing project costs—an uncommon solution to a common problem, and one that will deliver long-term benefits by reducing maintenance cost and extending service life.

Innovative construction methods and techniques were employed to conquer the challenges presented by the extraordinary weight and size of the structural members, the mountainous terrain and the riverine environment. This approach may have implications for future similar engineering applications.

Derechin and Bertone are with Michael Baker Corp.

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