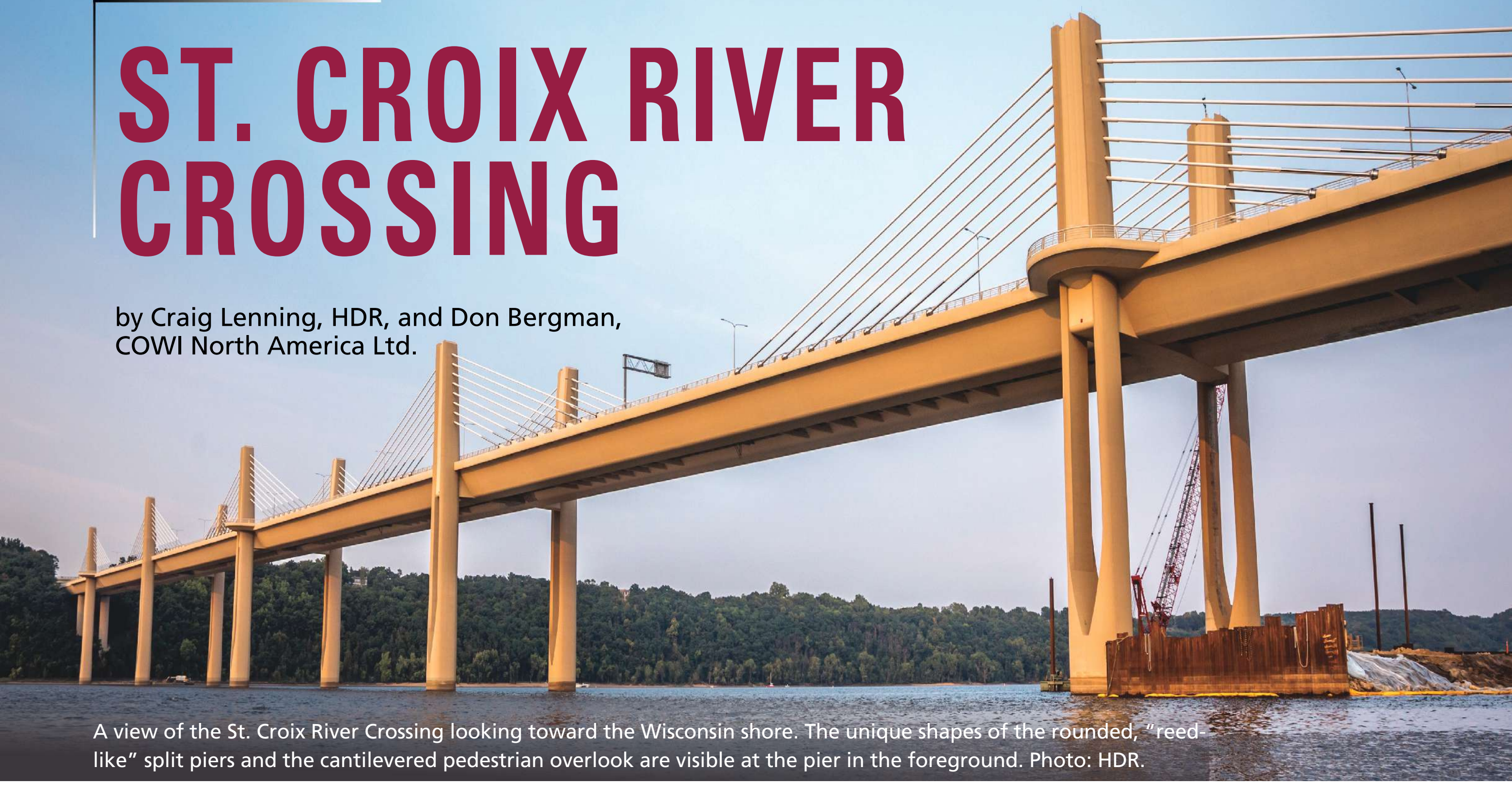
PROJECT

ST. CROIX RIVER CROSSING

by Craig Lenning, HDR, and Don Bergman, COWI North America Ltd.



A view of the St. Croix River Crossing looking toward the Wisconsin shore. The unique shapes of the rounded, "reed-like" split piers and the cantilevered pedestrian overlook are visible at the pier in the foreground. Photo: HDR.

The 6670-ft-long replacement bridge crossing the St. Croix River between Minnesota and Wisconsin includes a seven-span, 3365-ft-long extradosed main unit over the river and a dual seven-span, 1715-ft-long approach bridge with a 960-ft-long off-ramp and a 630-ft-long on-ramp. These structures were constructed with a combination of precast and cast-in-place concrete construction.

The extradosed bridge, which is a hybrid between a concrete segmental box-girder and a cable-stayed bridge, has four 600-ft main spans and a total length of 3365 ft between expansion joints. The out-to-out dimension of the bridge deck is 98 ft 6 in. The approach bridge is located on a 3-degree horizontal curve (1910 ft radius) with a 6% superelevation and includes a 1000-ft vertical curve before the alignment transitions to a tangent 1.74% upward grade from Minnesota to Wisconsin. The distance between the bridge deck and the water line varies from approximately 100 to 150 ft.

The bridge was opened to traffic in 2017, although construction continues. When completed, the St. Croix Crossing will be the second extradosed bridge built in the United States and the longest in North America.

Project Approval Process

The St. Croix Crossing project has a long history. Talk of a new bridge began in 1951, with advocates for new construction arguing that the existing Stillwater Lift Bridge was hindering economic growth and causing traffic delays. However, the St. Croix River is protected by its designation as a National Wild and Scenic River, and, for decades, conservationists and some local community members opposed the construction of a new bridge because of its potential environmental impact and fiscal costs. To address these concerns and comply with federal environmental regulations, a new bridge project would need to include mitigation strategies to protect all of the following:

- Historic properties
- Threatened and endangered species

profile

ST. CROIX RIVER CROSSING / OAK PARK HEIGHTS, MINNESOTA, AND ST. JOSEPH, WISCONSIN

BRIDGE DESIGN ENGINEER: HDR, Minneapolis, Minn., and COWI North America Ltd., North Vancouver, BC

PRIME CONTRACTOR: Lunda Ames Joint Venture (Lunda Construction Company, Black River Falls, Wisc., and Ames Construction Company, Burnsville, Minn.)

OTHER CONSULTANTS: Bridgescape, LLC, Columbia, Md.; Illumination Arts, Bloomfield, N.J.; M-P Consultants, St. Louis Park, Minn.; Prime Engineering, Baltimore, Md.; Rani Engineering, Minneapolis, Minn.; RWDI, Guelph, ON; Weidlinger Associates, New York, N.Y.

- Wooded wetlands on the Minnesota bank
- Highly erodible soils on the Wisconsin bluff
- Water quality in the watershed

The project would also need to relieve traffic congestion, provide safe passage for vehicles and pedestrians, and offer an aesthetically appropriate design for the site.

In 1996, a new design was proposed, and, in the early 2000s, a stakeholder committee was formed while an environmental impact statement (EIS) was prepared to address the many issues that were preventing the bridge project from moving forward. In 2006, the St. Croix River Crossing Supplemental Final EIS (SFEIS)[1] documented the important social, economic, and environmental impacts associated with the crossing and concluded that the preferred alternative structure would be an extradosed bridge. The SFEIS identified the following key attributes of the proposed extradosed form:

- "Minimizes impacts on the Wisconsin and Minnesota bluffs by locating [the structure] in an existing bluff cut in Minnesota and an existing bluff ravine in Wisconsin;
- "Reduces the number of piers and apparent mass of the structural components, decreasing adverse visual impacts on the St. Croix River; and
- "Provides a signature bridge design."[1]

The SFEIS further noted that "The Preferred Alternative extradosed bridge introduces a visually unique bridge type to the river corridor, a type that does not correspond to the nearby Lift Bridge or to other bridge types found along the St. Croix River and presents a visually dramatic form and structural appearance to viewers and users both off and on the bridge."[1]

Also in 2006, the Federal Highway Administration (FHWA) issued a record of decision to allow the project to proceed. However, the project also required approval of the National Park Service (NPS), the federal agency responsible for administering the Wild and Scenic Rivers Act. In 2010, NPS determined that it did not have the legal authority to permit any new construction in the riverway unless federal legislation provided a project-specific exemption.

After more than half a century of legal and political battles, Congress passed and President Barack Obama signed legislation in 2012 that authorized exemptions for the project. Bridge design began in 2012 with an early foundation construction package let in the spring of 2013 and a final construction package let in November 2013. Construction started in the spring of 2014.

Refining the Extradosed Bridge Design

After FHWA issued its 2006 record of decision, MnDOT completed the joint visual quality manual (VQM) in 2007 to define the aesthetic aspects of the proposed extradosed structure.

The 2007 VQM proposed a baseline extradosed structure with maximum 480-ft-long main spans and six piers in the river. The main extradosed bridge would have a total length of 3460 ft.

To align with the visual theme identified in the VQM, the proposed structure would use twin concrete box girders, 19 ft 8 in. in depth, with rounded girder webs and soffit. The 98-ft 6-in.–wide deck carried two lanes of traffic in each direction with shying strips (also known as a shy distance) at the median and wide outside shoulders. The overall width included a 12-ft-wide lane for pedestrians and bikes cantilevered from one side of the deck as well as cantilevered pedestrian outlooks at the main piers. The extradosed cable stays would be anchored to the outside of the twin box girders, and the box girders were connected transversely by solid diaphragms.

The proposed piers were rounded and "reed-like" in form, with three legs to carry the superstructure loads down to the drilled-shaft foundations in the river bed. To achieve continuity of the extradosed superstructure without deck joints or sliding bearings at pier locations, flexible twin legs were used beneath the crossbeam to allow longitudinal thermal and time-dependent length effects. This permitted the ends of the twin box girders to frame into the piers, thereby minimizing the visual impact of the pier crossbeams, which were kept largely within the depth of the deck section. The pile caps were located at the mudline to ensure that the piers rising out of the river were as visually clean as possible.

In 2010, an addendum to the VQM was issued to further refine the visual aspects of the structure. Most importantly, this addendum, which is quoted in the following bullets, described how the revised structure fit the "organic" theme for the structure:

- "The parts of the bridge look as if they were found in nature, or shaped by natural forces.
- The vertical pier forms are reed-like;

MINNESOTA DEPARTMENT OF TRANSPORTATION AND WISCONSIN DEPARTMENT OF TRANSPORTATION, OWNERS

BRIDGE DESCRIPTION: A 3365-ft-long, post-tensioned, precast concrete segmental box-girder extradosed bridge spanning the St. Croix River with 1715-ft-long approaches, a 960-ft-long off-ramp, and a 630-ft-long on-ramp for a total length of 6670 ft

STRUCTURAL COMPONENTS: Cast-in-place and precast concrete segmental box-girders, cast-in-place concrete cross-beam and towers, drilled shafts (river foundations), and pile footings (approach foundations)

BRIDGE CONSTRUCTION COST: $341,600,000 + $40,000,000 early foundation contract = $381,600,000 total

AWARDS: Finance & Commerce: Top Projects of 2017; American Council of Engineering Companies (ACEC) Minnesota Engineering Excellence Awards: Grand Award, Grand Conceptor Award, and People's Choice Award; ACEC National Engineering Excellence Honor Award; American Public Works Association Public Works Project of the Year—Transportation Category, More than $75 Million; Slag Cement Association Project of the Year—Innovative Applications Category

the girders are rounded and tapered like bones or tree branches; and walls, barriers and railings are curved and blended into the larger forms.
- Transitions are gradual and smooth; edges are soft and curved; and colors are unified and natural expressions of their materials."[2]

By using a slightly deeper crossbeam at the piers, the middle leg of the three-legged piers could be removed, providing a lighter, cleaner, and more aesthetically pleasing pier arrangement with a smaller footprint in the environmentally sensitive river.

In the 2010 design concept, the lane for pedestrians and bikes was moved to the inside of the extradosed stay cables, eliminating the cantilevered sidewalk. The change provides visually consistent leading edges on both sides of the deck, ensuring that the curved "organic" nature of the girder webs would be clearly exposed from both viewing directions.

The cantilevered pedestrian outlooks at the main piers remained in the 2010 update, but they were given a rounded soffit to further enhance the visual theme for the structure. The cable anchorages, which were exposed on the outer edge of the deck in the 2007 arrangement, were now covered by a continuous shroud to give the deck edge a cleaner continuous line.

The 2010 design reduced the depth of the deck section from 19 ft 8 in. to 18 ft. Both single and twin box-girder sections were assessed for the deck section, and both were considered to be structurally viable. It was noted that both deck sections could be constructed by cast-in-place methods, but the twin box-girder arrangement would be better suited to precast concrete segmental-type construction. Strutted diaphragms between the twin box girders replaced the solid diaphragms in the 2007 arrangement, giving the 2010 design a more interesting and lighter appearance from the underside, which would be visible from the nearby Stillwater, Minn., community. Internal ribs were used to adequately transfer the vertical cable forces across the wide deck section.

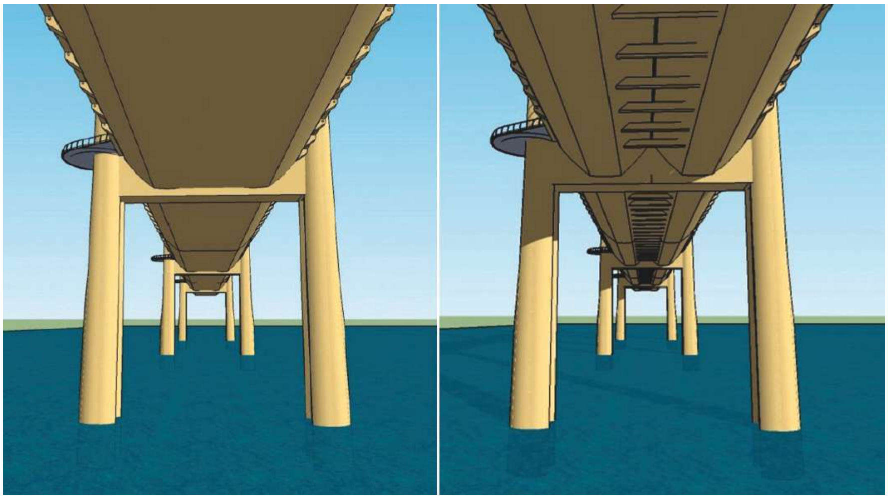
Final Design of the Extradosed Bridge

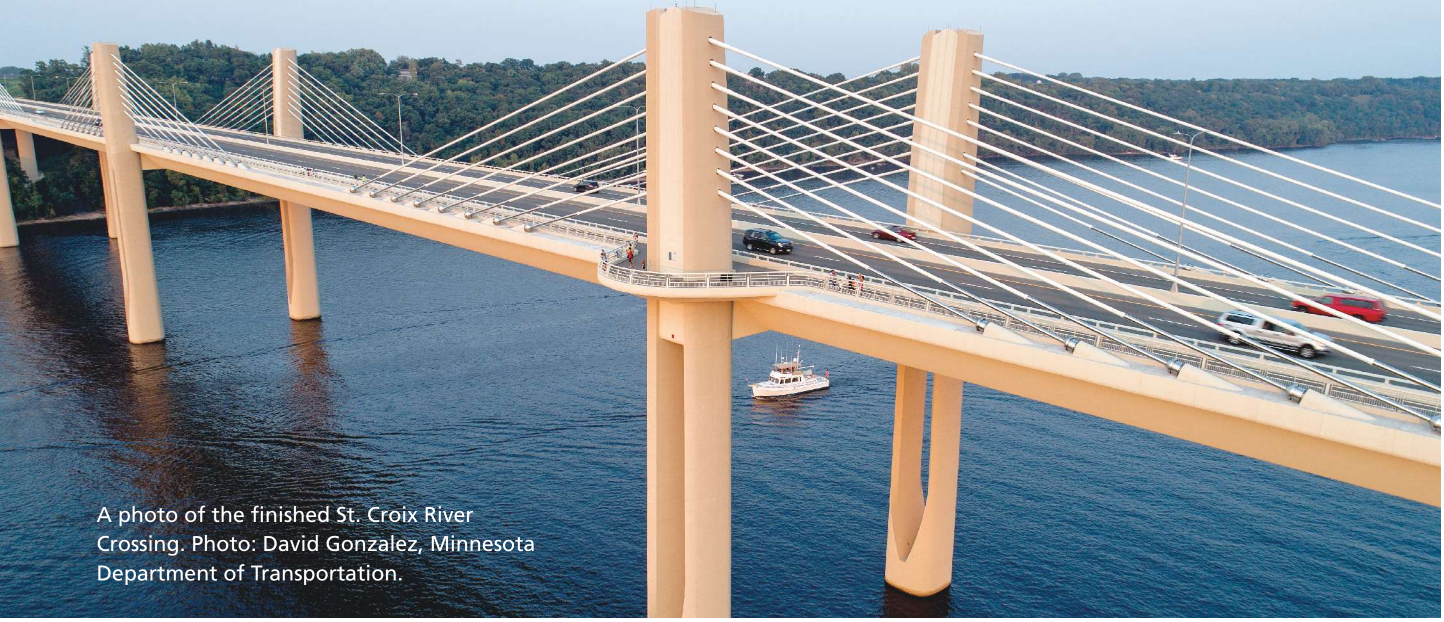
Once the exemption from the Wild and Scenic Rivers Act became law, work on the final detailed design of the structure started in late 2012. Further assessment of the span lengths resulted in the decision to lengthen the main spans to 600 ft, for a 3365-ft-long extradosed structure. The final structure has five piers in the river (one less than the 2010 arrangement), which further reduces the bridge's footprint in the river. The final arrangement also eliminates the earlier proposed extradosed pier on the sensitive Wisconsin bluff slope, and the extradosed piers now are clearly visually associated with the main river crossing.

Due to the lengthening of the spans, the depth of the deck section was increased from 16 ft proposed in the amended 2010 VQM concept to 18 ft. Selection of the deck section was an important consideration for the final design. Schedule and constructability were paramount considerations. Precast concrete segmental construction was selected over cast-in-place construction to minimize the construction schedule and project costs. To match the precast concrete segmental schedule, cast-in-place construction would have required several large form travelers working in difficult weather conditions. The selection of the precast concrete segmental option led to a twin box-girder arrangement instead of a single box-girder design because the former would minimize weight for segment handling. Additionally, the twin box-girder arrangement allowed deck drain pipes to travel down the middle of the bridge external to the box girders, a feature that was important to MnDOT, which had encountered problems with drain pipes leaking inside box girders on previous projects.

Three twin box-girder concepts were studied during the development of the final design: twin three-cell boxes, twin strutted boxes, and twin two-cell boxes. All three deck sections have a cast-in-place closure joint between the box girders and a strutted connection at the bottom flange level. The limited width of the bottom flange of the two-cell box was ultimately not viable because of the large hogging demands at the piers and the large quantity of post-tensioning tendons in the bottom flange required at midspan. The heavier three-cell box section was considered more constructable and resilient and was therefore selected.

The extradosed cable-stays largely provide longitudinal post-tensioning to the deck section; however, they also provide some vertical support to the outside edge of the wide deck section. The twin box girders with their central cells behave essentially as Vierendeel frames in the transverse direction. To distribute the vertical support from the extradosed stay-cables effectively across the deck section, external transverse post-tensioning tendons are located at each stay-cable anchorage. The tendons are deviated at the inner web of the three-cell box to transfer vertical load to the inner girder web, which would otherwise rely on transverse Vierendeel effects to take up vertical load from the


Single box-girder and twin box-girder design concepts for bridge as considered in 2010. Figure: Minnesota Department of Transportation.



A photo of the finished St. Croix River Crossing. Photo: David Gonzalez, Minnesota Department of Transportation.

stays. The transverse tendons also act to post-tension the struts connecting the bottom flange of the twin box girders and to deviate the horizontal cable force into the deck section.

Considerable effort was put into refinement of the pier and pylon shapes in the final design stage. The efforts were focused on both the visual aspects of the pylons and structural efficiency. The twin legs beneath the pier crossbeam were widened and thinned to obtain the necessary cross-sectional area to carry the vertical loads while at the same time reducing the moment of inertia of the legs to minimize force effects generated from longitudinal thermal and time-dependent length effects in the deck. This design modification was particularly critical for pier 8, which, as a result of the grade on the bridge, is the shortest and stiffest of the piers and therefore attracts the largest forces.

To maintain constructability as well as the visual theme for the piers, the vertical edges were curved with dimensional variations made only to the tangents connecting the curves. Texture given to the outside face of the upper pylon eliminates what would otherwise be a large, flat surface, thereby adding visual interest—particularly when the bridge is lit at night.

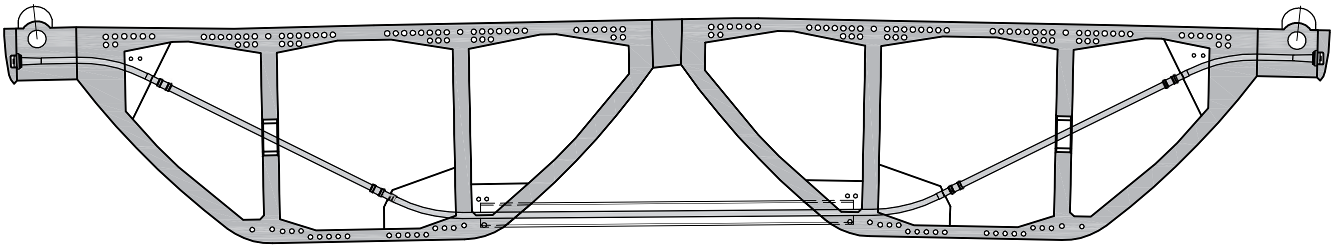
Internal steel anchor boxes are used in the upper pylons to anchor the stays and resist the large tensile splitting force generated by opposing pairs of extradosed cable stays. In the 2007 and 2010 design concepts, the pylons above the deck were visualized as relatively monolithic in form. In the final design, the above-deck pylons are tapered, which gives the structure a pleasingly slender and open appearance from the perspective of the motorists, bicyclists, and pedestrians who cross the bridge.

Design of the Segmental Box-Girder Approaches

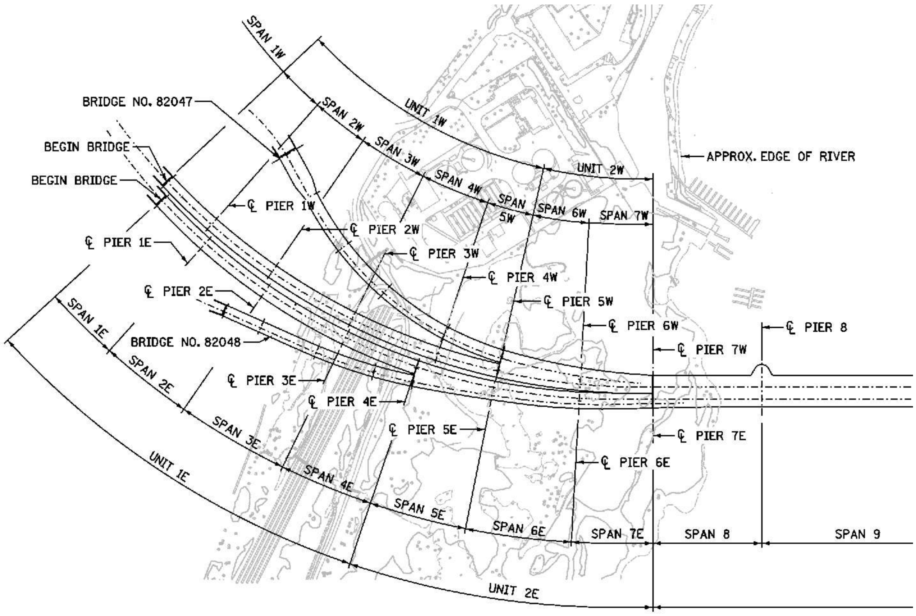
Mainline Approach

In addition to the previously described changes in the extradosed structure, the design team also refined the preliminary design of the mainline, off-ramp, and on-ramp approach structures. The 2007 preliminary plans included a sag curve located approximately halfway down the mainline approach and a horizontal curve with associated superelevation, which extended into the second span of the extradosed structure. The on- and off-ramps originally extended further to the east, with the transition also extending into the second span of the extradosed structure. The mainline approach was composed of twin boxes connected with a longitudinal joint. These features caused a very wide twin box structure, and, with a 6% superelevation, the south side of the bridge would extend upward a significant distance to provide sufficient vertical clearance over Minnesota Trunk Highway (TH) 95. The low point on the bridge for drainage was located at midspan, causing significantly large longitudinal drainage pipes.

The revised 2010 mainline approach design consisted of two units with twin box-girder superstructures. The joint between the two structures was at the confluence with the on- and off-ramps. The box girders were separated with offset horizontal alignment and twin vertical curves to form unit 1. The twin box girders were then brought back together, forming unit 2, with a longitudinal joint before the pier 8 transition to the extradosed unit 3. This allowed the vertical curve to be moved west and the horizontal alignment to be modified, bringing the superelevation transition onto the approach bridge and off the extradosed span. The designers were then able to shift the on- and off-ramps further west, greatly reducing the widening of the extradosed end span. This change also moved the low point of the bridge to pier 1 on the off-ramp, which reduced the size of the



Typical cross section at anchorage locations of main cable showing transverse external post-tensioning and strut between boxes. Figure: Minnesota Department of Transportation.



Plan layout of the extradosed St. Croix River Crossing. Figure: Minnesota Department of Transportation.

trunk line for the drainage system. The end result produced a twin box-girder system for unit 2, which was a significant improvement over the complex framing system envisioned in 2007.

The final design for the mainline approach consists of four separate units: units 1 and 2, east and west. Both units 1 and 2 are composed of continuous spans of post-tensioned box girders, with the unit 1 box girders being precast concrete segments erected using balanced-cantilever method and unit 2 box girders constructed with cast-in-place concrete on falsework. Piers for both units are founded on steel HP piles.

Unit 1E is a 964-ft 3-in.-long, four-span bridge that carries eastbound TH 36. It has two 12-ft-wide traffic lanes, a 6-ft-wide inside shoulder, and a 10-ft-wide outside shoulder. The out-to-out bridge width is 43 ft 4 in. The single box girder varies in depth from 10 ft at pier 1 to 14 ft at the beginning of pier 2. The four-span continuous structure has modular expansion joint devices located at abutment 1 and pier 4E, expansion bearings at abutment 1 and piers 1E and 4E, and fixed-bearing connections at piers 2E and 3E.

Unit 1W is a 1212-ft-long, five-span structure that carries westbound TH 36 using the same roadway cross section as unit 1E. The five-span continuous structure has modular expansion joint devices located at abutment 1 and pier 5W; expansion bearings at abutment 1 and piers 1W, 4W, and 5W; and fixed-bearing connections at piers 2W and 3W.

Unit 2E is a 749-ft 9-in.-long, three-span structure in the gore area where the on-ramp merges with mainline eastbound TH 36. The out-to-out bridge width varies from 82 ft 6 in. to 46 ft 7 in. The box girder varies in depth from 14 ft at pier 5E to 18 ft at the beginning of pier 6E. The three-span continuous structure has modular expansion joint devices located at piers 4E and 7E, expansion bearings at piers 4E and 7E, and fixed-bearing connections at piers 5E and 6E.

Unit 2W is a 488-ft-long, two-span structure in the gore area where the off-ramp departs from mainline westbound TH 36. The out-to-out bridge width varies from 88 ft 3 in. to 55 ft 10 in. The box girder varies in depth from 14 ft at pier 5W to18 ft at the beginning of pier 6W. The two-span continuous structure has modular expansion joint devices located at piers 5W and 7W, expansion bearings at piers 5W and 7W, and a fixed-bearing connection at pier 6W. Additionally, there is one more span with a conventional pier (pier 13) after the last extradosed pier (pier 12). This section is part of the extradosed structure and not a separate approach bridge or span.

Off-Ramp Approach

The off-ramp approach is a five-span bridge composed of a 960-ft 11-in.-long, post-tensioned single box-girder structure. The bridge is the off-ramp from westbound TH 36 and carries one traffic lane, two auxiliary lanes to pier 1, 4-ft-wide shoulders, and a 12-ft-wide, barrier-separated trail. The out-to-out bridge width varies from 60 ft 6 in. to 40 ft 6 in. The box girder varies in depth from 10 ft at pier 3 to 14 ft at the beginning of pier 4. The bridge was constructed with precast concrete segments erected using the balanced-cantilever method. The five-span continuous structure has modular expansion joint devices located at abutment 1 and pier 5; expansion bearings at abutment 1 and piers 1, 2 and 5; and fixed-bearing connections at piers 3 and 4.

On-Ramp Approach

The on-ramp approach is a four-span bridge composed of a 632-ft 11-in.–long, post-tensioned single box-girder structure. The bridge is the on-ramp to eastbound TH 36 and carries one traffic lane and one auxiliary lane with 4-ft-wide shoulders to pier 3. The out-to-out bridge width is 35 ft 4 in. The box girder varies in depth from 10 ft at pier 2 to 14 ft at piers 3 and 4. The bridge was constructed with cast-in-place concrete

A Firsthand Account by Fredrick Gottemoeller

When viewing this bridge from upstream or downstream, you can't help but be impressed by the degree to which the structure seems to disappear into the landscape. The hillsides and sky beyond can be clearly seen through the vertical slots in the piers, and the sides of the piers look like the stalks of aquatic reeds, just as the authors of the visual quality manual envisioned. The curved surfaces of the piers and girders not only seem "organic" but also make it difficult to judge the actual dimensions of the piers and girders, thus minimizing their visual mass.

These curved shapes continue smoothly into the girders and piers of the Minnesota interchange. All transitions in girder depth are accomplished with gradual tapers. The interchange piers borrow shapes and details from the river piers. Whether crossing below the approaches on the highway or proceeding down the St. Croix River on a dinner cruise, onlookers will enjoy the strongly articulated, unified vision of the bridge's integrated design.

on falsework. The four-span continuous structure has modular expansion joint devices located at abutment 1 and pier 4; expansion bearings at abutment 1 and piers 1 and 4; and fixed-bearing connections at piers 2 and 3.

Design Criteria, Materials, and Post-Tensioning

The bridge was designed for a 100-year service life. The following were used to increase the durability and service life of the bridge:

- Stainless steel reinforcement in the top deck of the box girder with a zero-tension limit on the top fibers.
- Epoxy-coated reinforcement in the rest of the box-girder superstructure and in the substructure above the footings.
- Post-tensioning, both longitudinally and transversely, to limit concrete tensile stresses.
- Thixotropic grouts (see the related Concrete Bridge Technology article in this issue).

References

1. Minnesota Deparment of Transportation (MnDOT). 2006. *St. Croix River Crossing Supplemental Final EIS*. http://www.dot.state.mn.us/metro/projects/stcroix/pdfs/sfeis2006/Chapters%20and%20Figures/Ch7/StCroixSFEIS-Ch7.pdf.
2. Parsons Brinckerhoff. 2010. St. Croix River Crossing Project Visual Quality Manual Addendum: Final Submission. Prepared for MnDot and Wisconsin Deparment of Transportation. http://www.dot.state.mn.us/metro/projects/stcroix/pdfs/vqalow-res.pdf.

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EDITOR'S NOTE

For more details on the grouting of post-tensioning tendons for this project, see the Concrete Bridge Technology article on pages 34-36 in this issue. For a time-lapse video of the construction of the St. Croix River Crossing, please see https://www.youtube.com/watch?v=iexen6Csef0. *Video courtesy of EarthCam.*