Because of longstanding congestion and safety issues in both Minnesota and Wisconsin, a new river crossing to replace the aging lift bridge near Stillwater, Minn., had been discussed for decades.

The area of eastern Minnesota and western Wisconsin served by the bridge is a growing region that is within 25 miles of the Twin Cities of St. Paul and Minneapolis. The initial planning process began back in 1985, but it was not until 1995, when the Federal Highway Administration (FHWA) approved the final environmental impact statement, that final design began. No sooner had final design been completed when the project was stopped due to a determination by the National Park Service that the proposed bridge would have an adverse effect on the St. Croix River, which is a part of the National Wild and Scenic River System.

Formal efforts to revive the river crossing began once again in 2002, with a focus on the project’s context, including the visual appearance of the St. Croix River Crossing and the setting of the bridge within the Wild and Scenic Riverway. During the development of the supplemental final environmental impact statement (SFEIS), the stakeholders, including local, state and federal government agencies, as well as local and national citizen organizations, selected the extradosed bridge type for the main river crossing.

In parallel with the SFEIS process, a Visual Quality Manual (VQM) was developed to outline the aesthetic values for the project. A Visual Quality Review Committee (VQRC), with member participation from the stakeholder groups, was a key part of the visual-quality
process. In addition, the VQM process included a public open house to gather input for the aesthetic development of the bridge. These efforts culminated in the approval of the SFEIS in 2006. With the approved SFEIS in place, and a record of decision by the FHWA, the concept design phase was finally under way. The bridge owner agencies, the Minnesota Department of Transportation (Mn/ DOT) and Wisconsin Department of Transportation (WisDOT), retained the services of Parsons Brinckerhoff (PB) to conduct the concept engineering for the new crossing.

The overall design objective is a new river crossing structure of segmental concrete construction, including 3,460 ft of extradosed spans (six 480-ft spans and two 290-ft end spans). The bridge will provide 40-ft-wide roadways in each direction. The new St. Croix River Crossing is characterized by three key features. The first feature is the extradosed bridge type, which is new to the U.S. In fact, upon completion, the crossing will be only the second extradosed bridge constructed in the U.S. The second feature is the use of only two expansion joints in the long, continuous length of structure to accommodate thermal and long-term creep and shrinkage movements of the superstructure. Finally, the third feature is the emphasis on the bridge aesthetics, with particular attention paid to creating a structure with an “organic” appearance to complement the scenic river setting.

**Something extra**

The extradosed bridge design concept was first proposed in 1988 for the new Arret-Darre Viaduct in France by the French engineer Jacques Mathivat. Mathivat proposed a structure in which shallow external tendons extended above the bridge deck, rather than maintaining their alignment within the superstructure as traditionally done in girder bridges. Mathivat referred to these external tendons as “extradosed” prestressing based on the French phrase “extra dos,” which means “out of the back.” However, Mathivat’s design was not constructed. Officially the first extradosed bridge to be constructed was the Odawara Blueway Bridge in Japan, which was designed and built by Sumitomo Mitsui Construction Co. Ltd. in 1994. Since then, more than 40 extradosed bridges have been built around the world, with the majority of the bridges built in Japan.

In general, the extradosed bridge is a hybrid structure that combines a post-tensioned concrete box-girder bridge with a cable-stayed bridge. An extradosed bridge typically has much shorter towers (height-to-span ratio around 1:8) compared with a traditional cable-stayed bridge (height-to-span ratio around 1:4), resulting in shallower cable angles. These flatter cables result in higher horizontal forces, which act more to compress the superstructure rather than supporting it.
The challenges of the new St. Croix River Crossing, such as its long continuous length and the strong commitment to the bridge’s aesthetics, have been successfully met by careful consideration of the details and effective teamwork.

The extradosed stay cables for the St. Croix River Crossing are arranged in two planes and anchor to individual anchor pods along the exterior edge of each box girder, with typical spacing of 20 ft between cables. There are a total of 252 cables, with 36 cables anchored at each pier. The angle of the cables from the horizontal plane varies from 14° to 22°. The extradosed stay cables were initially sized assuming that they would resist approximately 60% of the dead-load moment. Following this initial sizing, the average cable tension was selected to be applied to each cable upon installation.

According to the Cable Stay Recommendations of the French Interministerial Commission of Pre-stressing, stay cables with a change in stress caused by live load of less than 7.2 ksi are considered extradosed. The standard limits the extradosed cable tension to 60% of the guaranteed ultimate tensile strength (GUTS), that is, 0.6 fPU, under the effects of maximum service loading. When the stress range is above 7.2 ksi, the maximum allowable stress is reduced nonlinearly until a limit of 0.45 fPU is reached, which is the limit for a traditional cable-stayed bridge. It has been determined that the stress variation caused by live load (HL-93 with no pedestrian load) for the St. Croix River Crossing is approximately 4 ksi, which defines the cables as extradosed. Utilizing the maximum allowable tension limit of 0.6 fPU for design, all cables comprise 37 0.6-in.-diam. strands.

The design of a segmental extradosed bridge is dependent on the construction sequence used to build the bridge. For the St. Croix River Crossing, the structural arrangement conforms to a balanced cantilever construction sequence. The substructure, consisting of the foundation and pier, is built first followed by construction of the superstructure girder. Segments of the girder are either cast using a form traveler for cast-in-place construction or erected using a deck-mounted lifting system or land/water-based crane for precast construction. As each segment is cast, or in the case of precast as each pair of segments is erected, cantilever post-tensioning tendons in the top flange are installed and stressed. In addition, for the extradosed structure, the cables are installed and stressed as cantilever construction progresses.

After balanced cantilever construction is completed, a closure segment is cast between the two sections of girder, and continuity post-tensioning tendons in the bottom flange are installed and stressed to make the span continuous. The time-dependent effects due to increasing concrete strength, concrete creep and shrinkage, and post-tensioning steel relaxation are considered in the design of the segmental structure.

**Double jointed**

To reduce future maintenance and improve long-term performance on the bridge, it is best to minimize the number of expansion joints and bearings required for the structure. The new St. Croix River Crossing extradosed spans have been designed with only two expansion joints: one at the Wisconsin abutment and one at the Minnesota transition pier. The extradosed portion of the bridge has been made continuous over all eight spans, which results in 3,460 ft between expansion joints. And since the superstructure has been made integral with the piers, the only bearings required on the bridge are located at the two expansion joints.

The key component to accommodate the deformations caused by temperature variation, long-term creep and shrinkage is providing adequate flexibility in the substructure. Fortunately, the topography at the proposed bridge location requires relatively tall piers. Of the seven bridge piers, six are located in the river with one pier located on the Wisconsin...
The towers extend a constant height of 60 ft above the deck to provide an anchorage for the extradosed stay cables and vary in height above the water line from 170 ft at the pier closest to the Minnesota shore to 212 ft at the pier on the Wisconsin bluff. To further increase flexibility, the columns are split into two stems from the top of the pier to 104 ft below the roadway level. A stay-cable anchor housing extends from just below the top of the column to 17 ft above the girder. The column stems connect only at the upstream and downstream face of the column, creating a C-shaped column in cross section. Near the high water line, the open side of the column is closed off to avoid trapping ice and debris from the river. The columns are connected by a rectangular-shaped cross girder at the roadway level. The expected movement at each joint due to thermal effects, creep and shrinkage of the extradosed bridge is approximately 25 in. With a design temperature range of ±75°F, the majority of the movement is from temperature variations throughout the year, but girder shortening caused by creep and shrinkage is estimated to be approximately 6 in. The expansion joint at the east abutment will have a movement rating of 25 in., while the expansion joint at the transition pier will have a movement rating of 37 in. to accommodate the movement of the approach spans in addition to the main spans.

Since the actual effects of the long-term creep and shrinkage can be difficult to accurately predict, a concrete-testing program will be implemented during construction. The testing program will monitor the creep and shrinkage behavior of the concrete, which will then be compared to predicted values. If the actual creep behavior of the concrete during construction is determined to be greater than predicted, a jacking scheme can be employed to compensate for the differences. Prior to casting the closure pour between superstructure cantilevers, jacks are utilized to induce forces in the piers that are opposite of the creep and shrinkage forces.

Building organic

The St. Croix River Crossing’s organic concept, which is well suited to its natural setting, is a critical factor in the design development of the bridge. Since the bridge is in a scenic environment, the challenge of designing and detailing the bridge to meet structural demands while maintaining aesthetic quality and adhering to the criteria in the VQM is a priority.

To maintain an organic appearance, nearly every surface on the bridge is curved. The bridge piers have the added complexity of tapering and transitioning these curved surfaces. When developing the various cross sections, careful consideration was given to defining working points and reference lines to describe the geometry. All curved surfaces, with the exception of the V-shaped portion of the pier columns, have constant circular curvature. Transitioning of curved surfaces, while maintaining a constant radius, is accomplished by utilizing variable-width tangent surfaces between the curves. Defining the curved section geometry in this fashion results in relatively smooth transitions without the complications of warped surfaces.

To enhance the experience for the pedestrians on the bridge, scenic overlooks have been added to three of the river piers. The overlooks are integrally framed to the piers, and the geometry of the overlook complements the curved surfaces on the rest of the structure.

For the norm, and the wild

The challenges of the new St. Croix River Crossing, such as its long continuous length and the strong commitment to the bridge's aesthetics, have been successfully met by careful consideration of the details and effective teamwork between the engineering and architectural teams. Once completed, the St. Croix River Crossing will not only serve the community as a functional crossing of the river, but also will fit into the Wild and Scenic Riverway as a complementary asset to the area.

St. Croix River Crossing Project details including drive-through animations can be found at: www.dot.state.mn.us/metro/projects/stcroix/.

Vineyard is with Parsons Brinckerhoff, New York, N.Y. Towell is with Parsons Brinckerhoff, Minneapolis.