2022 Canadian Consulting Engineering Awards

HIGHWAY 69 FOUR LANE CROSSING OF THE FRENCH RIVER, ONTARIO

Submission Category B: Transportation

ABOUT THE PROJECT

The Ministry of Transportation of Ontario awarded WSP the detailed design assignment for the four-laning of Highway 69 from 3.8km north of Highway 522 to 4.5km north of Highway 64. As part of this project a new major crossing of the French River was required. The resulting twin bridges carrying two northbound and two southbound lanes of traffic respectively, are the subject of this submission.

The French River Bridge site is located just south of Bigwood, Ontario in Highway 69. The river forms part of a historic canoe route used by early European explorers and traders to access the central portion of the North American continent and has long been considered the dividing line between Northern and Southern Ontario. The river crossing is immediately adjacent to the French River Provincial Park which is the center of the region's scenic tourist area.

The river is located in a relatively shallow, 180m wide gorge cut into bedrock. The top of the gorge rises 20m above the water and the water depth is approximately 10m. The wall of the gorge on the south side of the river is exposed bedrock and talus (broken and fractured rock) covered the north wall of the gorge.

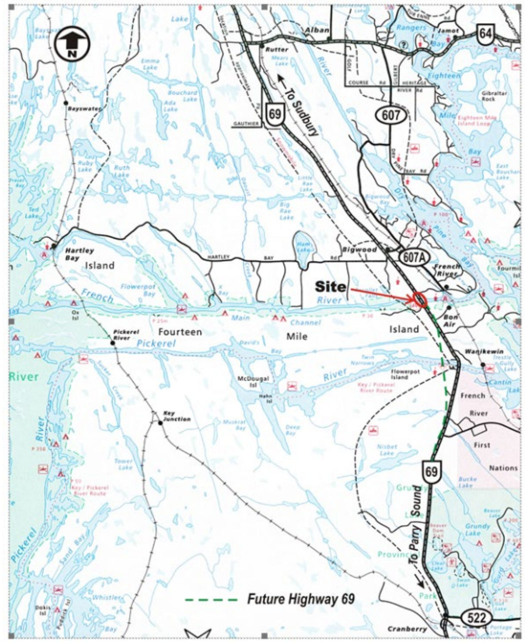

Figure 1: Site Plan

Figure 2 below provides an aerial view of the site before the construction of the new bridges and a plan showing the relative location of the new bridges to the existing highway. A 98m through truss carries the existing 2-lane Highway 69 over the French River. Both the bridge and old highway have been retained as a service road for the local community. A cable stayed pedestrian bridge west of the existing highway provides snowmobilers and hikers access across the river. The new crossing carries two lanes of traffic in each direction on separate northbound and southbound bridges over the river and gorge. The new bridges are located approximately 80m east of the existing highway as shown in the plan below and cross the river at a skew of 46 degrees.

Figure 2: Site Photo and Plan

Given the natural beauty of the site, the recognition of the French River as the Gateway to Northern Ontario, and the historic importance and heritage designation of the French River, the Ministry desired the construction of an iconic bridge for the new crossing. The development and construction of an innovative design for the bridges at this site are the subject of this submission.

INNOVATION

As noted in the preceding section, the natural beauty of the site, the recognition of the French River as the Gateway to Northern Ontario, and the historic importance and heritage designation of the French River, warranted the construction of an iconic bridge crossing. Accordingly, extensive effort was put into the development and evaluation of suitable bridge alternatives and the selection of an innovative design as the optimum structure type for this site.

PLANNING REPORT

The preliminary design of a new bridge for the Ministry of Transportation, Ontario typically involves the assessment of 3 or 4 relatively standard bridge alternatives in a Structural Design Report. Although aesthetics and innovation may be a consideration, they are typically incidental to meeting the operational requirements of the road and providing an economical and durable structure. Given the importance assigned to this site, an additional phase was added requiring the development of Planning Report for the Crossing that would consider a more extensive list of non-standard, long-span bridges that would not only be functionally compliant but also fit the environment and result in an aesthetically pleasing crossing.

Ten structural alternatives in four different bridge categories were developed. These are listed below and are further represented in the adjacent Key Plan taken from the Planning Report.

- Category 1: Superstructure below the Bridge Deck
  - Alternative 1 - Steel Plate Girder (Twin Structures)
  - Alternative 2 - Inclined Leg Rigid Frame Box Girder (Twin Structures)
  - Alternative 3 - Deck Arch (Twin Structures)
- Category 2: True Arches
  - Alternative 4 - Half Through Arch (Twin Structures)
  - Alternative 5 - Half Through Arch (Single Structure)
- Category 3: Tied Arches
  - Alternative 6 - Basket Tied Arch (Twin Structures)
  - Alternative 7 - Tied Arch (Twin Structures)
  - Alternative 8 - Tied Arch (Single Structure)
- Category 4: Cable Stayed Bridges
  - Alternative 9 - Single Tower Cable-Stayed Bridge (Twin Structures)
  - Alternative 10 - Single Tower Cable-Stayed Bridge (Single Structure)

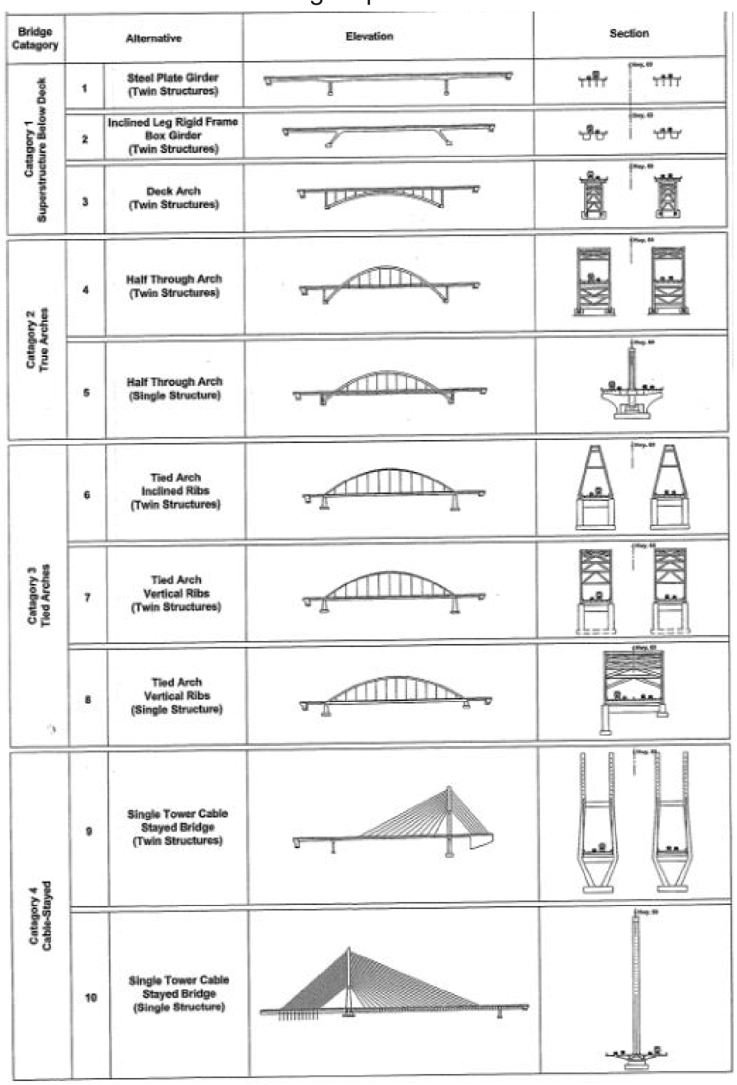

Figure 3: Ten Structural Alternatives

The alternatives were evaluated for a series of criteria grouped under the headings: Structural Characteristics; Construction Issues; Long-term Maintenance; Aesthetics; and Cost. The technically preferred Structure was determined to be Alternative 2 (Twin, Inclined Leg Rigid Frame Steel Box Girder Bridges). This alternative was carried forward for further refinement during Preliminary Design.

PRELIMINARY DESIGN

Further refinement of the preferred planning option was undertaken during Preliminary Design. This included refinement of the structure spans for the Southbound structure to better conform to the geometry of the valley; and, refinement of the overall structure geometry by haunching the steel girders over the inclined legs to meet the structural demands of this heavily loaded area of the structure while also enhancing the appearance of the bridges. The final revised spans and structure geometries taken to detail design are shown in **Figures 4** & **5** below.

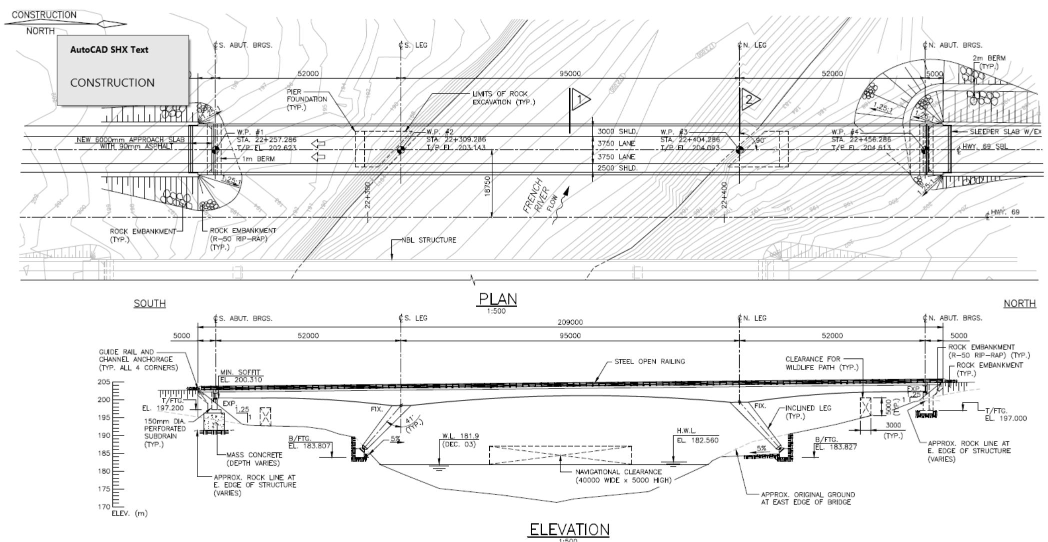

Figure 4: French River Bridge SBL - Final Plan and Elevation

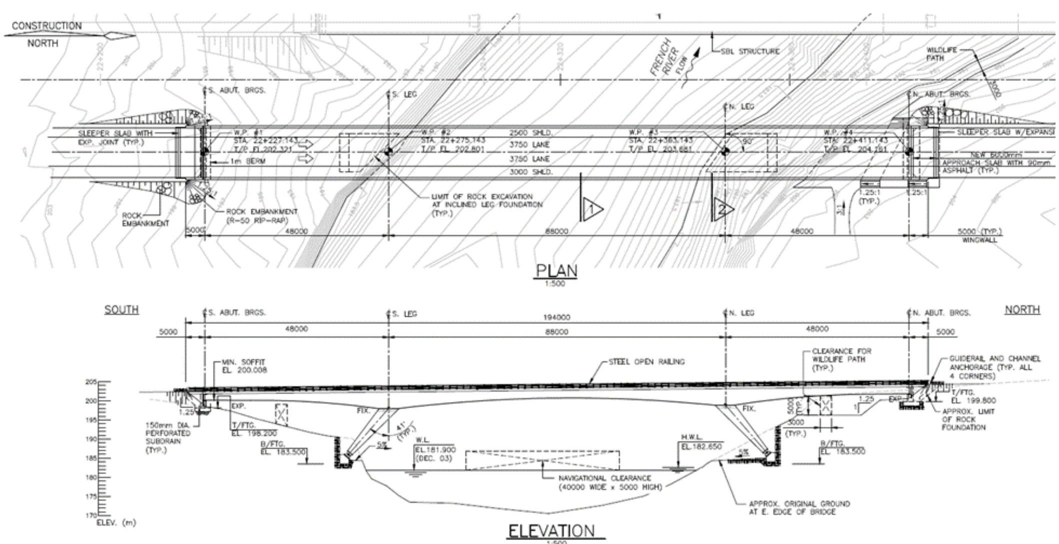

Figure 5: French River Bridge NBL - Final Plan and Elevation

INCLINED LEG DESIGN VERSUS CONVENTIONAL STEEL GIRDER BRIDGE SUPPORTED ON CONVENTIONAL VERTICAL PIERS

The valley spans approximately 200m and the river is approximately 80m wide along the new highway alignment. The depth of the river and its identification as an historically important river precluded the construction of piers within the waterway.

The construction of a conventional 3-span slab on girder bridge would have resulted in a main span of 130m to locate the wide footings required to support the tall vertical piers on a solid foundation each side of the river. The end spans of a three-span bridge must be at least 55% the length of the main span to avoid lift up of the ends of the bridge. This would result in an overall bridge length in excess of 270m, well in excess of the width of the valley.

By inclining the piers (i.e., the inclined legs) over the river, the main span is dramatically reduced. Additionally, the rigid connection of the inclined legs to the deck provides stability to the inclined legs, which in turn, allows for a much smaller the foundation required to support the legs than would be required for conventional vertical piers. The combination of these two factors permitted a reduction in the main span to 95m for the NBL structure and 88m for the SBL structure. The 55% rule for the end spans also applies to an inclined leg bridge resulting in bridge lengths for the inclined leg bridges of 209 m for the SBL structure and 194 m for the NBL structure, both of which closely match the valley width.

As a result, although the inclined leg bridge alternative is a more complex structure with a higher unit construction cost per square metre of deck area, the cost premium for an iconic design as compared to a conventional design was significantly reduced by its smaller size. The reduction in the bridge length also reduced the impact of the structure on the natural environment and provided a bridge that was in scale with the width and depth of the gorge.

EXTENSION OF AN INNOVATIVE DESIGN CONCEPT TO A MAJOR BRIDGE CROSSING

Prior to the construction of the new French River Bridges, there were only two or three examples of bridges with inclined legs in Ontario. These are modest bridges with short spans and include both pedestrian and short road bridges. While there are several examples in Europe and the United States with spans of up to 200m (**Figure 6**), they still remain a relatively uncommon bridge type and pose numerous interesting design and construction challenges.

Figure 6: Grand Duchess Bridge, Luxembourg (L), Boone Ave Overpass, Pennsylvania (R)

The detail design of the bridges was largely complete by the end of 2010. The bridges were tendered as part of the Hwy 69 Four Laning project in 2015 and construction was completed in late 2021. A photo of the completed crossing is provided on the following page (**Figure 7**).

Figure 7: Complete Hwy 69 French River Bridge (NBL Structure only)

COMPLEXITY

The size and geometry of these bridges presented numerous design and construction issues that are not part of a standard bridge design. A sample issue for each is provided below.

DESIGN OF THE HAUNCHED GIRDER TO INCLINED LEG CONNECTION

The rigid connection of the haunched girder to the inclined legs is a highly stressed area of the bridge. Numerous internal diaphragms and stiffeners are required in the girder to prevent buckling of the steel plates in the member. Determining the optimum configuration (number, size, location etc.) for the diaphragms and stiffeners required sophisticated structure modelling techniques.

Two different 3-dimensional models were used in the analysis and design of the bridge using commercial Finite Element Analysis software. The first consisted of a frame model comprised of two-dimensional beam elements. This model provided the design forces for members where the stresses in the bridge components are uniform and readily designed using standard code equations – i.e., for members away from the girder to leg connection. As such, this model was used to determine the initial girder and leg member plate sizes.

A more complex second model was required for the design of the girder to leg connection, where the distribution of stresses is not uniform, nor obvious. In this model the simple beam connection between the girder and leg in the first model was locally replaced by a highly detailed 3-dimensional finite element shell model that accurately modelled the diaphragms and stiffeners in the haunched box girder and the inclined leg. This component of the refined model extended 6m either side of the girder/leg connection and 5m down the leg to capture the transition zone between uniform stresses in the girder and leg to the non-uniform stress distribution at the girder/leg connection. This model was used finalize plate sizes, diaphragms, and stiffener details in the vicinity of the girder/leg connection. Details of the respective models are shown in the following figures.

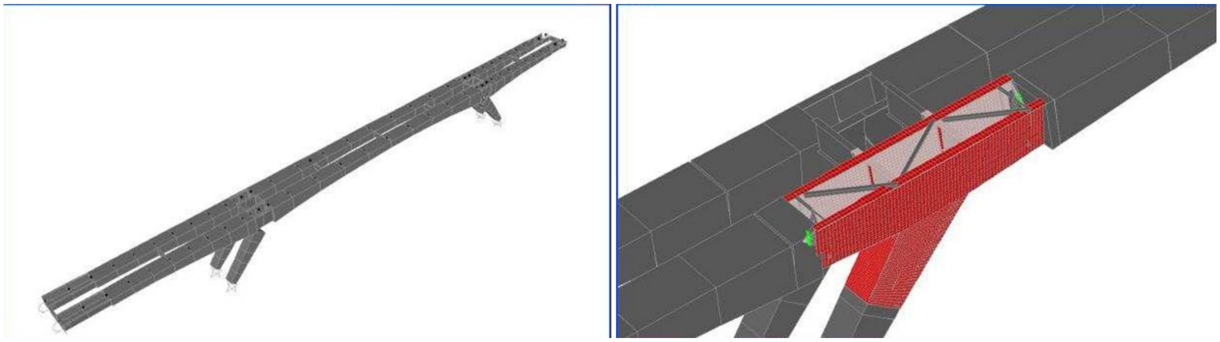

Figure 8: Model 1 (Frame model) - extruded view (L), Model 2 Combined shell/frame model (R)

Figure 9:, Model 2 Cutaway view of the shell model (L), Leg to Girder connection (R)

Creating two different models to design a complex structure requires verification of the results of each. Accordingly, a detailed comparison of the stresses produced by the two models was completed. Overall, the results from the two models were very close and provided strong confirmation of the results provided by the two models.

STAGED ERECTION OF THE STRUCTURAL STEEL

The size and weight of the steel components and site constraints on crane locations to make the lifts required a detailed assessment of the method of erection of the bridge. Accordingly, the conceptual erection procedure provided in Figure 10 was included in the contract drawings.

The weights of the haunched girder segment and the inclined leg component precluded assembling these before erection. As a result, tiebacks were required in Stage 1 to restrain the tops of the inclined legs prior to erecting the haunched girder on top in Stage 2.

The centre span, erected in Stage 3, consisted of 3 girder segments bolted together on a barge in the water prior to hoisting and completing of the span. To ensure fit of this closure section of the main span, the contractor would require the ability to adjust the opening between the ends of the previously erected haunched girder sections.

Conceptually this was provided by adjustable tie-back systems at the abutments that could be used to draw the girders back to increase the opening or allow the structure to “lean” towards the river to reduce the opening. The control of this gap turned out to be a challenging component during construction. However, the connection was ultimately completed successfully.

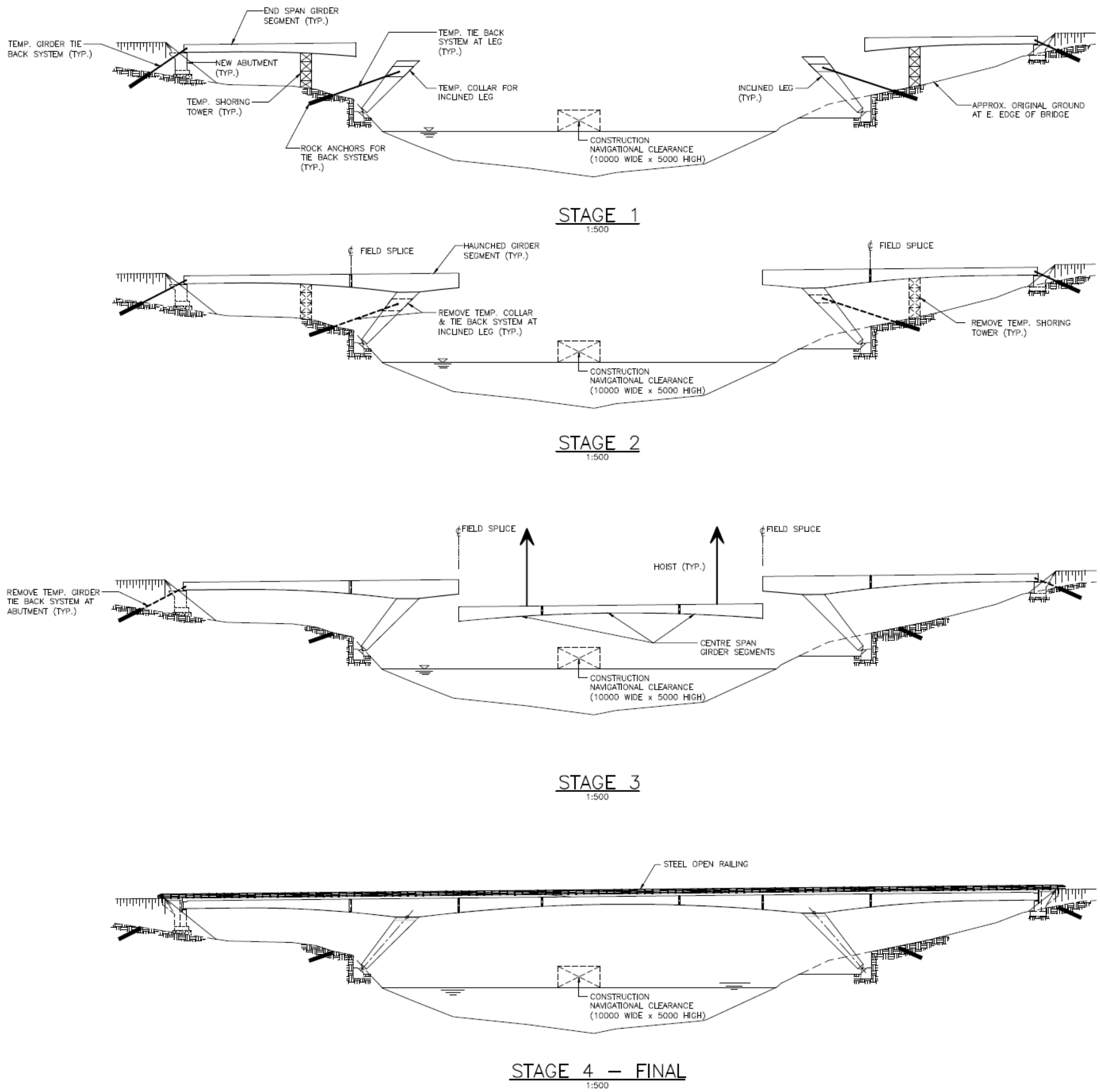

Figure 10: Staged Construction of the bridge

SOCIAL AND/OR ECONOMIC BENEFITS

Economic Link: Highway 69 forms part of the Trans-Canada Highway providing an important link for goods and services between Toronto and Southern Ontario, and Parry Sound and the East-West portion of the Trans-Canada in Northern Ontario. The French River is the largest natural feature that must be traversed to complete this link. As such, the new bridges over this river are critical to economic development in the north.

Enhanced Safety: The new French River Bridges form a major component of the four-laning of Highway 69. Separate bridges improve the safety for the travelling public by accommodating northbound and southbound traffic on separate structures, eliminating the possibility for collisions between opposing traffic. Additionally, each bridge has wide freeway shoulders – 2.5m on the left and 3m on the right - that will accommodate any disabled vehicles that might need to stop on these long bridges. The new bridges also double the number of lanes previously available to the travelling public, permitting passing of slower trucks by cars without the need to use an opposing traffic lane.

Cultural Heritage: The local First Nation community expressed concern regarding potential cultural heritage remains that could be disturbed by construction of the new highway and French River bridges. Although an earlier 2004 assessment had not identified any artifacts at this site, a Stage 2 Archaeological investigation of the site was undertaken as part of the four-laning assignment in 2010 to confirm these findings. This work included both visual assessments and test pits within the highway right of way in the vicinity of the French River. The work did not uncover any archaeological materials within the highway right of way, however, further investigations were undertaken of pictographs identified in 2004 on the French River rock face approximately 220 metres east of the right-of-way. In order to protect the pictographs from potential construction activities beyond the right of way, such as tying off of barges used in construction of the bridge, the contract required the Contractor take all such measures required to protect them during all stages of construction, including blasting operations.

ENVIRONMENTAL BENEFITS

Wildlife Passage: The four laning of Highway 69 included numerous design features to mitigate the destruction of natural habitat caused by the new alignment. These included 2.4m high wildlife fencing to keep small and large animals as well as amphibians/reptiles from attempting to cross the highway. The fencing serves to funnel wildlife to structures that will provide safe passage under the roadway. In that regard, the French River Bridges provide two large dry crossings for large animals such as deer and moose (as well as for smaller species) under the end spans of the bridge. These crossings provide a minimum height of 4m and a passage width of 3m and are provided on both sides of the river. These passages will dramatically reduce the number of vehicle/animal collisions that occur, leading to greater safety for both wildlife and the travelling public.

Fish Communities: The French River also supports diverse fish communities for several species of warmwater and coldwater sportfish including Bass, Suckers, Walleye, Northern Pike, Muskellunge, Cisco, Lake Whitefish and Lake Sturgeon. Given the new bridges span the river, the greatest risk to the fish was posed by blasting of the bedrock forming the valley walls required to construct the foundations for the inclined piers and the abutments. This was achieved through the inclusion of stringent blasting requirements specific to the French River to prevent blast rock from entering the waterway. This included limiting of the size of individual detonations; not permitting the use of diesel fuel and fertilizer types of explosives; and, the requirement for a Blasting Plan/Program incorporating all available best management practices (including but not limited to the use of blast mats, reduced/controlled blast charges, staged blasting techniques, use of mechanical rock excavation equipment etc.) necessary to prevent rock debris from entering the river.

Minimizing Climate Impacts: The bridges are a major element of the four laning of Highway 69. The free-flow conditions offered by the four-lane freeway allows for safer and more efficient travel thereby reducing the number and severity of collisions while at the same time reducing harmful tailpipe emissions. The grades of the freeway are generally flatter than the existing Highway 69 which will further result in more efficient travel. Wherever possible, the recycled asphalt pavement from existing Highway 69 is being incorporated into the new works.

MEETING THE NEEDS OF THE OWNER

The Ministry of Transportation's requirements for the new crossing of the French River extend well beyond the need to carry a major highway over a wide and deep river.

The introduction of a four-lane controlled access highway through Central Ontario had the potential to cut off wildlife access across the entirety of their natural habitat. The detrimental effects of this unavoidable impact of the highway have been mitigated by the construction of multiple wildlife crossing structures along the length of the highway. These structures vary in opening size as required by the species each crossing is expected to serve. The new French River Bridges provides the largest and most natural passage of these structures through the introduction of wide wildlife pathways on both sides of the river. This is particularly important on the north side of the river, where the original steep and rocky slopes of the valley did not encourage passage. Through careful collaboration between WSP's Terrestrial Specialists and Bridge Engineers, a new level pathway was constructed on the north side that introduced passage that did not exist previously. As a result, the new structure will play a major role in protecting the health and safety of these large animals.

As noted elsewhere in this submission, the French River is a designated heritage river for its historic role as a water highway for Indigenous people, French Explorers, fur traders and Voyageurs. The river remains a canoe route for adventurous paddlers through the many interconnected lakes and gorges from Lake Nipissing to Georgian Bay. The new bridges maintain unfettered access along the river and compliment the natural surroundings with their unique shape and wide gateway opening over the water.

Notwithstanding the aesthetic requirements of the crossing, the bridges also needed to meet the functional requirements of the new highway and travelling public. This was optimally achieved through the construction of wide structures with generous shoulders adjacent the travelled lanes. The bridges use atmospheric weathering steel that protects the girders from corrosion without the need to paint the steel girder, the maintenance of which is a costly and environmentally sensitive activity. The bridges have also been provided with open railing barriers that provide an unobstructed view of the river valley below. This was all achieved through the innovative application of a structure shape that was more commonly limited to much smaller structures in Ontario.

Finally, the new bridges met the above requirements using a structure that took full advantage of the geometry of the valley. The depth and width of the valley and river were ideally suited for the inclined leg configuration, which significantly reduced the bridge span over the river and the overall length of the bridge compared to a more conventional bridge design. This ensured the new bridges were cost competitive with a more conventional and less attractive bridge design.

PROJECT SUCCESS

A three-span steel frame bridge with inclined legs was chosen for the French River Crossing for its economical cost, largely conventional fabrication and erection, and its iconic and attractive appearance. The use of inclined legs was a significant and highly successful extension of an existing, if seldom used, structural configuration to a major crossing. The resulting structure met or exceeded the needs of the owner, the travelling public, the local community, and the environment. WSP thanks the Ministry of Transportation, Ontario for the opportunity to provide the planning and design services to make this crossing a critical success.