New life for a 60-year-old Canada–U.S. crossing

Rehabilitation of the Thousand Islands Bridges

by Randy Pickle

Completed in the 1930s, the landmark Thousand Island Bridge system spans the St. Lawrence River from Ivy Lea in Ontario to Collins Landing in New York. The region has long been a major summer vacation area of northern New York state and eastern Ontario. Crossing of either the Canadian or American spans affords spectacular vistas of the islands as the bridges arch over the main channels of the river.


Suspension spans with work platforms and portal frame gantry.

The bridge system was built not as a tourist attraction but as a crossing for traffic over the St. Lawrence River. It provides a direct link between Highway 401, a major expressway from Windsor, Ontario, to Quebec City, Quebec, and Interstate I-81 in New York state. At the time of its opening, the annual number of vehicle crossings was approximately 150,000. By 1995, that number exceeded 2 million. A daily average of 1000 trucks and 4000 passenger cars cross the Thousand Islands Bridge. The peak traffic demand during the summer period can be as great as three times that of winter.

The Thousand Islands Bridge system consists of two separate crossings of the St. Lawrence River. The American Crossing, a suspension bridge with viaduct approach spans, traverses the south shipping channel from the American mainland to Wellesley Island. The Canadian Crossing spans the north channel from the Canadian mainland to Hill Island.

The Canadian Crossing consists of four distinctive bridge structures. Spanning the north channel from the Canadian mainland to Georgina Island is the signature structure of the crossing, a 412 m (1350 ft) long suspension span with a vertical shipping clearance of 36 m (120 ft) above the St. Lawrence River. From Georgina Island to Constance Island is a 106 m (348 ft) long rib arch structure, and from Constance Island to the south abutment on Hill Island is a 183 m (600 ft) long Warren-truss structure. Viaduct spans form the north and south approaches as well as the span for the islands between the suspension, arch, and Warren-truss structures. The total length from abutment to abutment is 1014 m (3330 ft).

Over the life of the structures, numerous improvements have been made to accommodate the increases in traffic volumes and truck loads. After the 1940 collapse of the Tacoma Narrows suspension bridge in Washington state, a system of cable stays and torsion framing was installed on the suspension spans. Stiffening plates have been added to a number of the original structural members to meet increased capacity demands. There have been many localized repair projects to replace cracked clip angles and loose rivets. The Thousand Islands Bridge Authority carries out an extensive annual maintenance program that includes cleaning, painting, and bearing lubrication.

In 1991, a project was undertaken to replace the deck panels on the north viaduct span from Pier 19 to the north abutment. Replacement of the structurally deteriorated deck panels also allowed for widening of the roadway surface from 6.7 m (22 ft) to 7.3 m (24 ft).

Structural inspection

In 1994, a detailed structural inspection of the Canadian Crossing was completed for the St. Lawrence Seaway Authority, the bridge owners, and the Thousand Islands Bridge Authority. The field inspectors found the substructure, abutments, and piers of all of the structures to be in good condition.

The deck systems of the suspension spans and the Warren-truss spans were found to be in poor condition. On the Warren-truss spans, the deck was cracked and separated from the stringers. A number of the floor beams had become warped along the axis of the web. Longitudinal expansion of the concrete deck had occurred as a result of corrosion of the main bars of the steel-grid deck panels. There was also severe spalling of the concrete deck surface as well as cupping of the concrete in the deck panel cells. The deck system of the suspension spans was found to be in a similar condition as that of the Warren-truss spans.


Original deck surface condition on the suspension spans.

This inspection made it apparent that the decks of the suspension and Warren-truss spans were nearing the end of their service life and that total replacement would be necessary by the year 2000. The recommended deck replacement would address the structural concerns as well as provide for the continued widening of the roadway, which had already begun north of Pier 19.

The deck system of the viaduct and arch spans was in good condition with some deterioration of the structural steel. The concrete in the deck exhibited areas of random spalling and delamination.

The recommendation was made to replace the deck on the viaduct and arch spans concurrently with the replacement of the deck on the Warren-truss and suspension spans. The deck replacement operations on the viaduct and arch spans would be a continuation of the replacement operation on the suspension spans and Warren-truss spans, employing the same lane closures. As well, the need to provide temporary, but possibly long term, transitioning from a new 7.3 m (24 ft) wide deck to the existing 6.7 m (22 ft) deck width, at three locations, would be avoided.

Canadian Crossing rehabilitation

The original deck on the Thousand Islands Bridge was a system of steel-grid panels with the grid cells filled with concrete. The main bars of the grid panels were aligned to transfer loads to the first level of support of the substructure. On the suspension spans and Warren-truss spans, longitudinal stringers provided the support and on the viaduct and arch spans the deck panels were supported on lateral crossbeams. The cells of the grid panels were filled with concrete to minimize ice accretion in the winter.

In 1995, a detailed design for the necessary rehabilitation work was completed. Designers considered a number of different deck-system types. In the final analysis, the existing system of concrete-filled steel-grid deck panels, as originally designed and installed in 1938, proved that it was still the most appropriate system for use on the structures.

On the suspension and Warren-truss spans, the original-plan depth of the deck was 4¼ in. (108 mm). For the rehabilitation project, the new steel-grid deck panels were specified to have 108 mm high main bars with cross bars 16 mm (0.63 in.) in height, positioned through the main bars to create cells 102 mm (4 in.) wide and 150 mm (6 in.) long in the top of the panel. A secondary bar was positioned in the bottom of the panel for reinforcement of the concrete.

Because the designers wanted great resistance to permeability, they specified microsilica concrete with air entrainment of 1 to 3 percent in the steel-grid deck panels of the suspension and Warren-truss spans. Tests indicate that the presence of silica fume in concrete can reduce chloride ion permeability by as much as 80 percent over a normal concrete mix with a Type 10* portland cement.

The low-permeability, high-density characteristics of this concrete provided two benefits for the new steel-grid deck panels. Low permeability meant resistance to capillary movement of moisture through the concrete, thereby reducing the potential for corrosion of the steel bars of the panels and the supporting stringers and floor beams. The higher density of the concrete provided for improved wear resistance of the surface to minimize the potential of cupping of the concrete in the grid cells. The microsilica concrete was to be struck off and finished flush with the top of the bars of the panel.

On the viaduct and arch spans, the original deck was an 8 in. (200 mm) deep reinforced concrete slab, supported on crossbeams typically spaced at 6'-5" (1.96 m) on center. For rehabilitation of these spans, a 132 mm (5.2 in.) deep steel-grid panel was specified. The main bars were to be oriented parallel to the centerline of the structures with 16 mm (0.63 in.) cross bars installed to create cells 150 mm (6 in.) wide and 100 mm (4 in.) long, with a secondary bar in the bottom of the panel for reinforcement of the concrete.

A 50 mm (2 in.) concrete overfill of the deck panels was proposed to provide a total depth of 182 mm (7.2 in.) for the new deck. This overfill would provide cover on the steel bars of the grid panels and a wearing surface for traffic. AASHTO Class C air-entrained concrete was selected for the viaduct and arch spans. The specified air entrainment was 4 to 6 percent.

The rehabilitation of the deck of the Canadian Crossing would serve two purposes. The primary one was to address

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* Type 10 normal portland cement as provided in Canadian Standards Association (CSA) Standard A5, generally equivalent to ASTM Type I cement.

Table 1 — Concrete mix designs

	Microsilica concrete		AASHTO Class C concrete	
w/c		0.36		0.39
Water		154 kg/m^3		151 kg/m^3
Air entrainment		3.0 percent		6.0 percent
Cement	Type SF 390 kg/m^3	426 kg/m^3	Type 10	390 kg/m^3
	Silica fume 36 kg/m^3			
Fine aggregate		885 kg/m^3		745 kg/m^3
Coarse aggregate	13 mm	972 kg/m^3	19 mm	1085 kg/m^3
Superplasticizer		5325 ml/m^3		1463 ml/m^3

	AASHTO Class B concrete		Rapid-setting concrete	
w/c		0.48		0.14
Water		148 kg/m^3		160 kg/m^3
Air entrainment		6.0 percent		--
Cement	Type III	307 kg/m^3	Patchroc	1170 kg/m^3
Fine aggregate		820 kg/m^3		
Coarse aggregate	19 mm	1090 kg/m^3	9.5 mm	875 kg/m^3
Superplasticizer		1151 ml/m^3		

the deteriorated conditions of the suspension and Warren-truss spans. In addition, removal of the old deck would allow for the widening of the roadway portion of the deck to a safer width for traffic of 7.3 m (24 ft). To create this widened deck, the new panels for the east and west side of the deck were manufactured to a width of 4.0 m (13 ft). With a need to maintain the walkway conditions on the west side of the structure, all widening was to be accommodated on the east side of the structure. Installation of the new wider deck panels offset the centerline of the roadway 280 mm (11 in.) east of the centerline of the structures and moved the east edge of the travelled portion of the roadway 600 mm (24 in.).

Concrete mixes and placement

The contract specified that the existing deck panels would be removed and replaced during overnight lane closures, when traffic volumes would be minimal. Peter Kiewit Sons Construction, the contractor for the project, set up a casting yard near the site. There, the new panels were precast to ensure that the existing deck panels could be immediately replaced as they were removed from the bridge. The elements of the casting yard were situated to provide a production-line approach to the operation.

On the left side of the casting yard, timber racks were constructed for storage of the new skeleton steel-grid deck panels as they were shipped from the supplier. In the center of the yard, a casting table was constructed on which the new panels could be secured for the placement of the concrete. On the right side of the yard, more timber racks were built for the storage and final curing of the panels before their shipment to the bridge site.

One immediate issue that the contractor had to address was how to supply the different concretes to the casting yard. The nearest ready-mix plants were a considerable distance from the casting site, and space did not permit the establishment of a temporary batch plant and storage area on site. To solve this problem, concrete supplier Thousand Islands Concrete Limited provided concrete by mobile mixers. They also provided the necessary concrete mix designs (Table 1).

With a casting table structure equivalent to the supporting structure of the bridge, the contractor prepared the panels for concrete placement by setting adjacent panels together on the table and temporarily connecting them at their perimeters. The panels were bolted down to the casting table to ensure that the longitudinal grade of the panels, as well as the crossfall from the centerline to the outside edge, was constant. This procedure corrected any minor distortions in the panel bars. The concrete fill shaped the panels to fit the bridge deck supports — floor beams, stringers, and crossbeams — and to mate with the adjacent panels on the structure.

The skeleton panels were placed on the casting table in blocks of six. The length of the casting table permitted the placement of two such blocks on the table. One block of six panels would be prepared and concrete placed. While the concrete in the first set of panels was curing, a second block of panels would then be secured to the table and prepared for concrete placement. After the initial curing of the concrete in

Placing the steel-grid deck panels on the casting table.

Placing, finishing, and wet-burlap curing of concrete in the deck panels for the Warren-truss spans.

the first block of panels, those panels would be replaced and the process would continue.

With the new panels secured to the casting table and blockouts and bulkheads installed as required, delivery of the concrete components into the hoppers and tanks of the mobile mixers proceeded. For the suspension and Warren-truss spans, each new panel required approximately 3.3 m³ (4.3 yd³) of microsilica concrete, or 20 m³ (26 yd³) to fill six panels. For the deeper panels on the viaduct and arch spans, which were also longer to fit the crossbeam spacing, each panel required 7.7 m³ (10.1 yd³) of concrete. Placement of 20 m³ of concrete into the six panels, including finishing, was generally one day's production. For the viaduct and arch spans, three panels per day were poured and finished.

The production-line approach allowed the contractor to efficently produce 142 panels for the suspension and Warren-truss spans in 55 working days, using approximately 475 m³ (620 yd³) of microsilica concrete. Similarly, about 600 m³ (780 yd³) of air-entrained concrete was placed in 78 new panels for the viaduct and arch spans during 40 working days.

Finishing

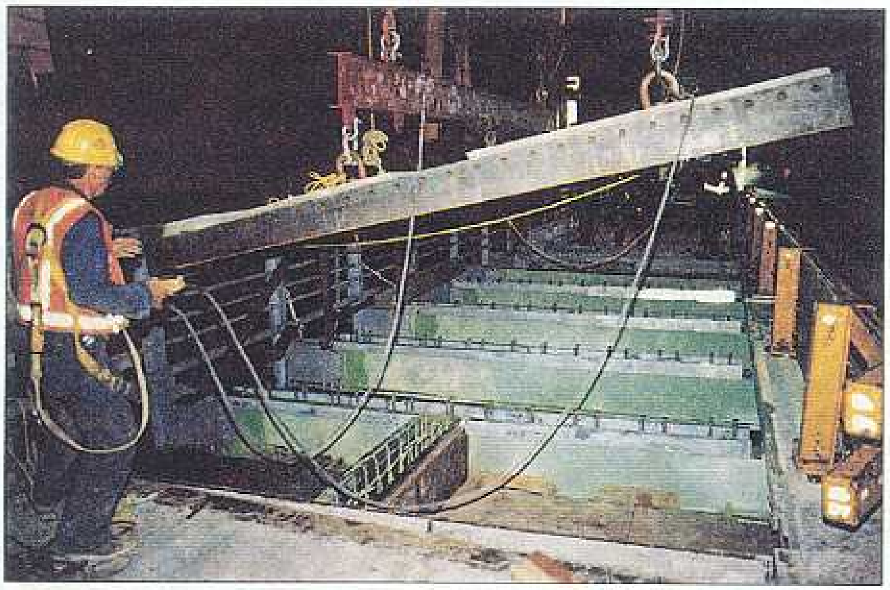
For the suspension and Warren-truss spans, the contract specifications required the panel concrete to be screeded flush with the top of the grid bars and steel-tine finished in a direction perpendicular traffic. Representatives from the Thousand Islands Bridge Authority and project managers Totten Sims Hubicki Associates observed the concrete finishers' initial attempts to screed and finish the concrete as specified. When a finisher attempted to screed the concrete flush with the tops of the grid bars, the trowel would fall off of the bars or pull concrete out of the cells. This operation appeared to cause unwanted cupping of the concrete in the cells of the panel. This was a condition in the existing deck panels that was to be prevented with the new deck panels. Cupping of the concrete had previously caused increased maintenance requirements on the deck.

When the concrete was screeded flush with the top of the grid bars, an effective rough finish could not be applied uniformly across the panel. In pulling a stiff broom across the concrete, the broom would either fall off the top of the bars or bounce over the bars. In some cells the rough finish would be deep whereas in other cells the concrete surface would not be rough at all.

To overcome this problem, the contractor screeded the concrete to a level 2 to 3 mm (1/16 to 1/8 in.) above the grid bars. In doing so, finishing could be completed in a timely manner, certainly a consideration when working with microsilica concrete. The representatives were then able to observe that a very uniform screeding of the entire concrete surface could be attained. Further, the workers were able to pull a stiff broom completely across the deck panel in a single pass, thereby producing an acceptable, uniformly striated concrete surface on the panel.

Placing the 50 mm (2 in.) overfill of concrete on the deck panels for the viaduct and arch spans posed no problem for finishing. Making the bulkheads rise above the top of the grid bars allowed workers to readily strike off the concrete over a large area of the deck panel. Similarly, these areas were easily raked across the width of the deck panel to produce the required striated concrete surface.

Positioning the polyethylene canopy over the freshly-poured concrete.



Placement of a new concrete-filled steel-grid deck panel on a viaduct span.

Curing

Concrete was placed in the steel panels over a period of 95 working days in the spring and summer of 1997. During this time, variations in ambient temperatures were experienced, thus necessitating the use of several methods for the curing of the concrete.

During the initial placement period in April and May, the 24-hour temperatures were such that cold-weather concreting measures were not required. However, the contractor did have an interest in ensuring that the microsilica concrete in the panels for the suspension spans was sufficiently cured for transportation to the bridge and subsequent placement. For that reason, some cold weather protection for the concrete during curing was provided by heating the water and aggregates. Heat was applied passively by the solar heating of the tanks and hoppers of the mobile mixers used for the placing the concrete.

For extended curing, workers installed a piping network beneath the casting table. At the east end of the casting table, the piping was connected to a water storage tank. Over the casting table, workers erected an aluminum framework with a heavy polyethylene covering and on wheels to permit mobility.

With cool overnight air temperatures, workers would position the frame over the finished panels and drape the sheeting around the panels to create a full enclosure. Water would then be pumped through the network of piping beneath the casting table and released, as a mist, into the enclosure. This system provided a high-moisture environment for the initial 24-hour curing of the microsilica concrete. The water was not heated to create a steam cure but simply allowed to heat up in the storage tank by solar radiation through the walls of the tank.

As the operation continued into July and August, the contractor needed to deal with the curing of the concrete under hot-weather conditions. To control the temperature of the concrete, it became necessary to add ice to the mixing water.

For the initial curing of the panels on the casting table, workers covered the surface with burlap. Then they placed soaker hoses on top of the burlap to keep it in a moist condition for curing. The final curing occurred on storage racks in the casting yard. Upon moving a deck panel from the casting table to the storage rack, the panel was covered by polyethylene sheeting before the next panel was stacked on top.

The advanced schedule for placing concrete in the deck panels and the curing methods employed ensured that the all panels could be handled and transported when required.

Other aspects of the project

The design of the replacement deck required new concrete haunches to be constructed monolithically with the deck panel to provide load transfer from the deck to the floor beams and crossbeams. For this purpose, blockouts and bulkheads were installed at the relative location of these supporting members within the limits of the panel.

Upon setting the new deck panel into position on the bridge, workers formed the haunches with galvanized forms. Because the bridge had to be reopened to traffic at the end of the night, the contract specified a rapid-setting concrete — with a minimum compressive strength of 24 MPa (3500 psi) within 3 hours — for the haunches. The maximum size of the coarse aggregate was limited to 13 mm (½ in.) to ensure that the mix flowed freely into the cells of the deck panels and around the new Nelson studs welded to the flanges of the floor beams or crossbeams.

As was done at the casting yard, the contractor used mobile mixers to supply and place the rapid-setting concrete. In determining the final mix design for the rapid-setting concrete, several blends of aggregate and cement were tested. The mobile mixer made the task of metering the aggregate-cement ratio effortless. In the end, a final proportioning of 4 parts aggregate to 3 parts cement was chosen because it was economical yet still produced a workable concrete that met the compressive strength requirement. (Table 1 provides details of the mix design.)

The workability of the rapid-setting concrete became a concern once placement of the material began for the first haunch. The finishing crews found that there could be no delay between the placing and finishing of the grout. On nights when the air temperature was lower than 10 C (50 F), the concrete crew could place and finish the concrete with the usual effort. However, on nights when the air temperature was over 15 C (59 F), finishing had to take place immediately upon the placement of the concrete into the haunch.

The rapid-setting concrete was very sensitive to the ambient temperatures. Low ambient temperatures and low material temperatures produced concrete that required a long time, sometimes more than 3 hours, to attain the minimum strength. Conversely, high ambient temperatures and component materials, subjected to heat from being in the hoppers and tanks of the mobile mixer during the day, produced concrete that reached high strengths quickly but made finishing difficult.

Curing of the rapid-setting concrete was never a concern

Table 2 — Concrete cylinder compression testing

Mix	No. cylinders	Minimum strength	Maximum strength	Average
Deck panels				
Microsilica	133	48.5 MPa	67.1 MPa	58.9 ± 4.4 MPa
AASHTO Class C (AE)	102	37.9 MPa	48.8 MPa	41.4 ± 1.8MPa
Rapid-setting concrete	104	20.7 MPa	40.6 MPa	27.5 ± 3.8 MPa
Maintenance walkway				
AASHTO Class B (AE) High early strength	23	30.5 MPa	38.4 MPa	35.1 ± 2.8 MPa
South abutment				
AASHTO Class B (AE)	2	37.1 MPa	37.9 MPa	37.5 ± 0.56 MPa

given the short time period from start of placement to the end of the plastic state of the material. On occasion, when the water tanks had been filled early in the day, the resultant concrete mix would have a high temperature and cause the concrete to set before the surface could be finished. On the Warren-truss bridge deck, winds blowing underneath the spans would cool the concrete, resulting in longer times for the material to achieve the required strength for the reopening of the bridge. When high temperatures occurred in the concrete mix, bagfuls of ice cubes were added to the water tanks on site. To prevent the concrete from cooling too fast, plastic sheets were draped over the side of the bridge deck and secured to work platforms below to provide housing that would moderate the air temperature at the underside of the deck.

On the west side of the structure from Pier 19 to the south abutment, a maintenance walkway was to be constructed of concrete-filled steel-grid panels. Since there was no urgency for completing the new walkway, construction could proceed in stages by first installing the walkway grid and then placing the concrete. The only concern was that the placed concrete should have an opportunity to attain significant compressive strength before being subjected to traffic vibrations. For this reason, a high-early-strength, air-entrained concrete was specified (Table 1).

To give the high-early-strength concrete an opportunity to set, the contractor placed the concrete early during the night shift. A minimum of five hours was required from completion of the placement to the reopening of the bridge to two-way traffic.

Modifications to the parapet walls of the south abutment were also required to accommodate the new deck and walkway. The contractor utilized the same concrete mix for this work as was used in the walkway.

Quality assurance and control testing

The project managers established a comprehensive quality assurance and testing program for the placed concretes. This included field measurements of air content, slump, and concrete temperatures. In addition, technicians prepared concrete cylinders for compressive strength testing (Table 2).

For the concretes delivered by mobile mixer, delivery trucks were calibrated for each of the concrete mixes to ensure that components were properly mixed on the conveyor belt. The gate settings of each concrete load were confirmed prior to placement.

For the microsilica concrete, a standard air meter was employed to confirm that the entrapped air was less than 3 percent. The air content in the AASHTO Class C concrete was confirmed to be between 4 and 6 percent as required. The slump of the microsilica concrete was designed to be 150 mm (6 in.). Slumps measured in the field ranged from 110 to 170 mm (4¼ to 6¾ in.). For the AASHTO Class C concrete the specified slump was 90 mm (3½ in.); field measurements ranged from 50 to 110 mm (2 to 4¼ in.).

Considerations for quality assurance of the rapid-setting concrete differed from those of the other types of concrete. This material was placed every night that a new steel-grid deck panel was placed. Since it was necessary to ascertain that the rapid-setting concrete had reached the minimum compressive strength for reopening the bridge, compressive-strength test cylinders were prepared. From the pattern of strengths obtained from extensive nightly testing, the engineers were able to predict cylinder strengths based on the air temperature, concrete temperature, and workability. For that reason, the engineers decided that continuous nightly testing of compression test cylinders was not needed and that, eventually, only random testing of the rapid-setting concrete would be carried out.

Concluding remarks

When designed and constructed in the late 1930s, the Thousand Islands Bridges represented the state of the art in bridge design. Over the life of these structures, a number of improvements have been made to upgrade the spans to meet user demands. In 1994, deck sections on the Canadian Crossing had reached the end of their life cycle and were replaced. In 1997, new construction materials and methods rehabilitated the structure using 1930's-style bridge deck construction.

References

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Selected for reader interest by the editors.

ACI member **Randy Pickle** is a professional engineer and senior project manager with Totten Sims Hubicki Associates Ltd. in Whitby, Ontario, Canada. He has over 20 years experience as a construction manager and resident engineer on large bridge and civil projects. He has supervised the work on bridge deck restoration projects, structural steel bridge structures, highway construction, and airport runways. He specializes in quality assurance, project management, contract administration, and claims management.