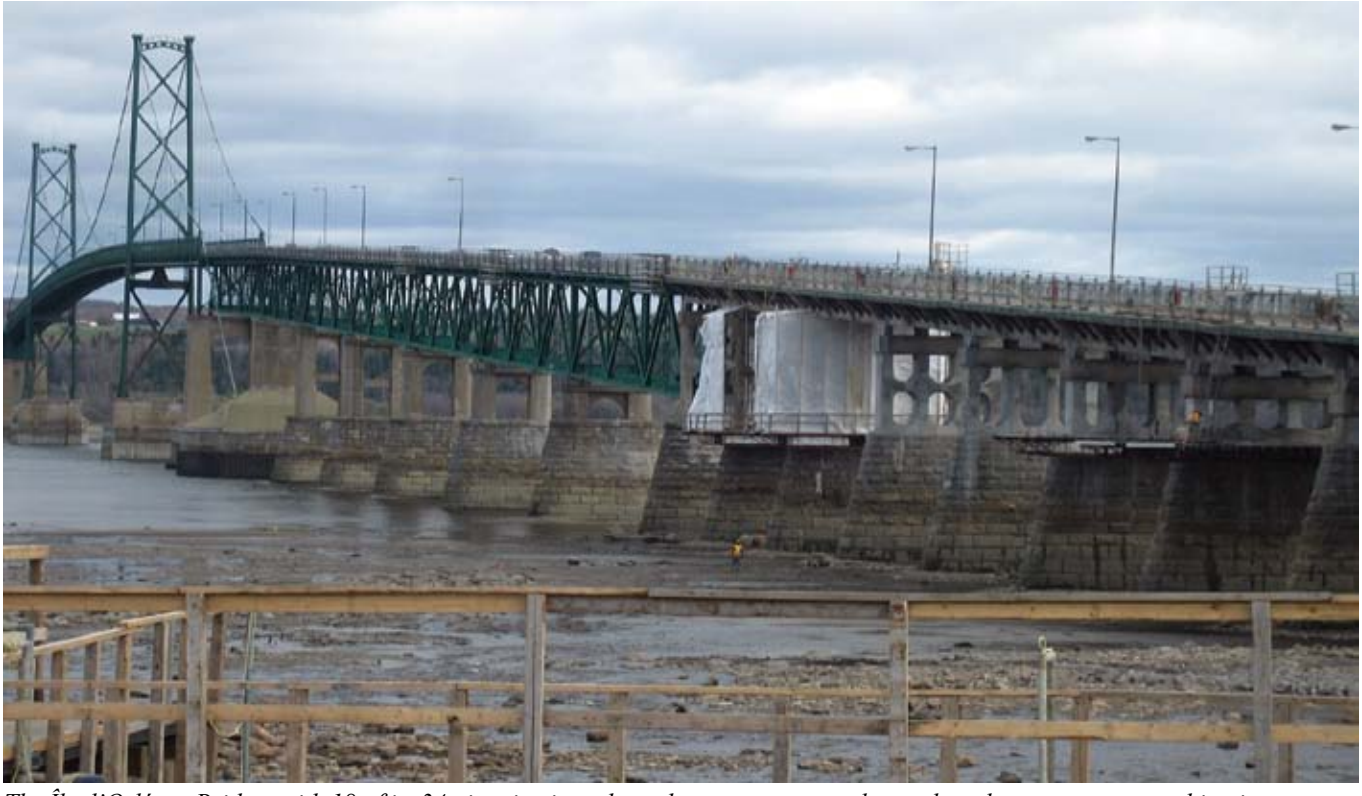
The Rehabilitation of the Île d'Orléans Bridge

By Philip Sawoszczuk and Daniel Bordeleau

The Île d'Orléans Bridge was built between 1931 and 1935. It was inaugurated on July 6, 1935.[1,2] The bridge crosses the mighty St. Lawrence River between the Beauport borough of Québec City and the Island of Orléans. The Island of Orléans, with its six villages, has a population of roughly 7000, with over 600 historical buildings and plentiful agricultural land, making it a prime tourist attraction for locals and travelers alike.[3] Presently, the bridge is owned, operated, and maintained by Transport Québec, Québec's Department of Transportation.[2,4] It is not the intent of this article to cover all the aspects of the concrete/shotcrete rehabilitation specifications of Transport Québec, as this was covered by Dufour et al.[5] in 2006 and the Ministère des Transports du Québec (MTQ) dry-mix shotcrete specification has not changed since.

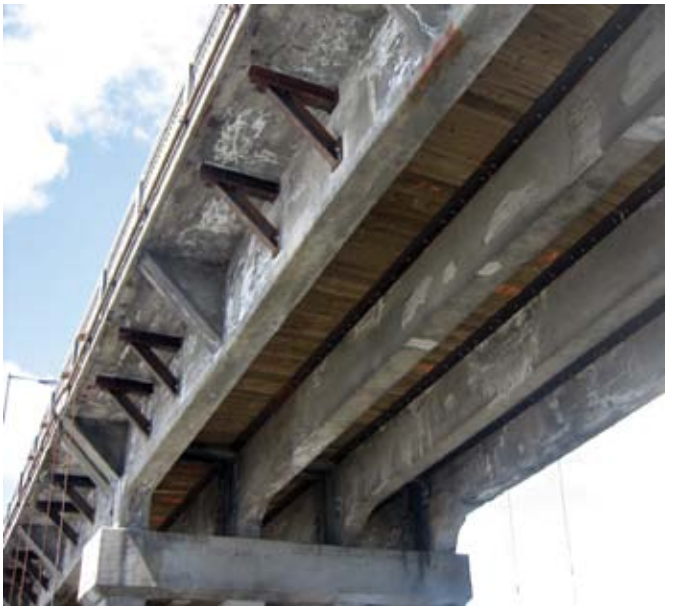
This 2.8 mile (4.5 km) long, 215 ft (66 m) tall, two-lane structure can be divided into five sections: two concrete beam spans, two steel truss spans, and a steel-suspension span in the center. The bridge pier foundations are all limestone masonry units with mortar. The concrete beam section is supported by nine sets of four concrete columns, which are braced at midheight on either side of the bridge. There are five sets of two concrete columns, with sets braced at the center heights, supporting the steel truss section on either side of the bridge. There are two monolithic piers with large sharply profiled pier foundations to break ice flows and serve as anchor points for the suspension wire. There are two more piers with small steel columns at either end of the suspended span and two steel truss towers holding the suspension wires on two more piers in the center of the bridge. In total, 34 piers with columns of either concrete or steel support the bridge. The deck is made of timber beams placed laterally with asphalt paving. The suspended section is 2370 ft (722 m) long,



The Île d'Orléans Bridge, with 18 of its 34 piers in view, shows how masonry, steel, wood, and concrete can combine into an elegant engineering solution

"The project was complicated, but working with dry-mix shotcrete allowed us to overcome all our obstacles and complete the project on schedule."

–Daniel Bordeleau, Eng, MSc, Groupe Diamantex



The concrete beams and timber deck are clearly visible, showing how various materials can work together. Some salt stains, corrosion, and freezing-and-thawing damages show how materials age

The shotcrete workspace was protected from wind, while also preventing dust and debris from falling into the river

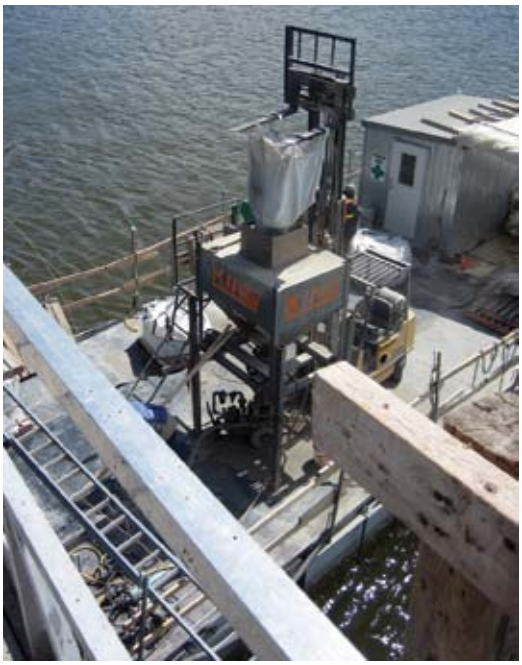
with the center sub-span at 1060 ft (323 m), and the two adjacent sub-spans are 420 ft (127 m) each. The steel suspension cables are a total of 5040 ft (1535 m) and are composed of 37 galvanized steel tendons.[2,4] Although various items in the bridge have been inspected and repaired over the years, the concrete repairs were the focus of the work in 2009 through 2010.

After 75 years, concrete deterioration was significant. Site inspections revealed corrosion of reinforcement, spalling, efflorescence, and freezing-and-thawing damage on many of the concrete columns and beams. Corrosion was likely initiated by deicing salts, but it could also have been aggravated by carbonation. Some map cracking was also present, potentially caused by alkali-aggregate reactivity. The amount of rehabilitation was valued by Transport Québec[6] at 14.9 million (CAD). Stellaire Construction, the general contractor, was faced with some unique challenges. The bridge has only two lanes, which had to remain open during rush-hour periods. Due to high winds and the sensitive fluvial ecosystem below, the work area had to be enclosed in tarps. Another constraint was the rectangular cross section of many of the concrete steel reinforcements, which complicated the application. With limited space and a tight schedule, the contractor turned to the dry-mix shotcrete process, which is allowed by Transport Québec for concrete repair.[7] One subcontractor, Groupe Diamantex of Québec City, had the experience and the tools to overcome many of the site's challenges. It is worth noting that self-consolidating concrete with a form-and-pump or gravity-fed approach could also have been used. Additional challenges regarding formwork, site mixing, and quality assurance, however, would have to have been resolved.

The work began in 2009 at the Island of Orléans side of the bridge. The majority of the work surrounded the columns of the bridge piers, so scaffolding, catwalks, staircases, platforms, and ladders were erected to improve accessibility. The work was limited to the period between the spring and fall; it started in 2010 on the Québec City side of the bridge. Groupe Diamantex elected to use a barge to move the shotcrete equipment and some of the dry-mix shotcrete materials from shore because lane restrictions made it impossible to locate the equipment on the deck. Material was supplied in 2200 lb (1000 kg) bulk bags and fed through a bulk silo to improve efficiency of the material supply.

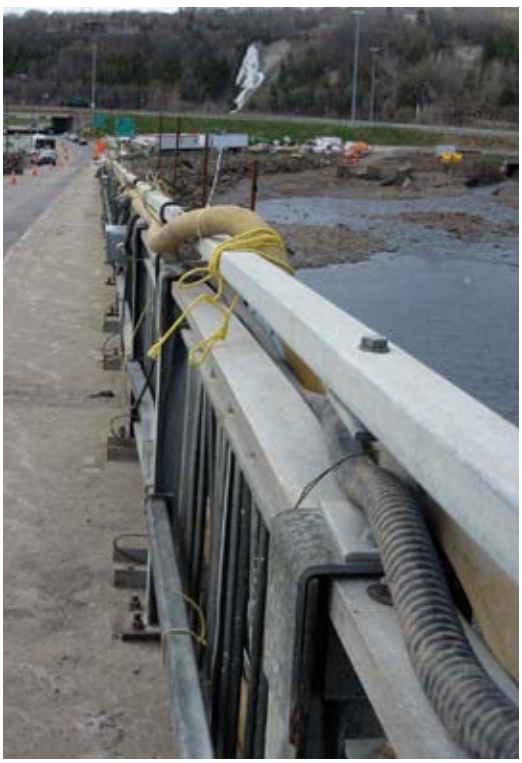
Groupe Diamantex elected to use a dry-mix shotcrete material (MS-D1 Shotcrete, supplied by King Packaged Materials Company). The mix is specially formulated with microfibers and an air-entraining admixture and enhanced with silica fume to meet Transport Québec's standards[7] (Table 1). As a silica fume shotcrete, it provided excellent adhesive and cohesive properties and low permeability in its hardened state.[8] The low permeability greatly retards ingress of deleterious agents such as chlorides and water, preventing further corrosion and alkali-aggregate reaction. The aggregate gradation met the requirements of ACI 506R Gradation 2.[8] Some

Scaffolding before chipping has begun. The limestone masonry and map-cracking on the existing concrete is also visible



Silos are loaded with shotcrete material by a forklift on the barge for continuous and efficient material flow. The shotcrete material was lifted to the barge by crane

The column was chipped to 1 in. (50 mm) behind the corroded rectangular steel reinforcements, cleaned, and covered in a welded-wire steel mesh



The air hoses had to travel over 985 ft (300 m) to reach the barge at this point in the project

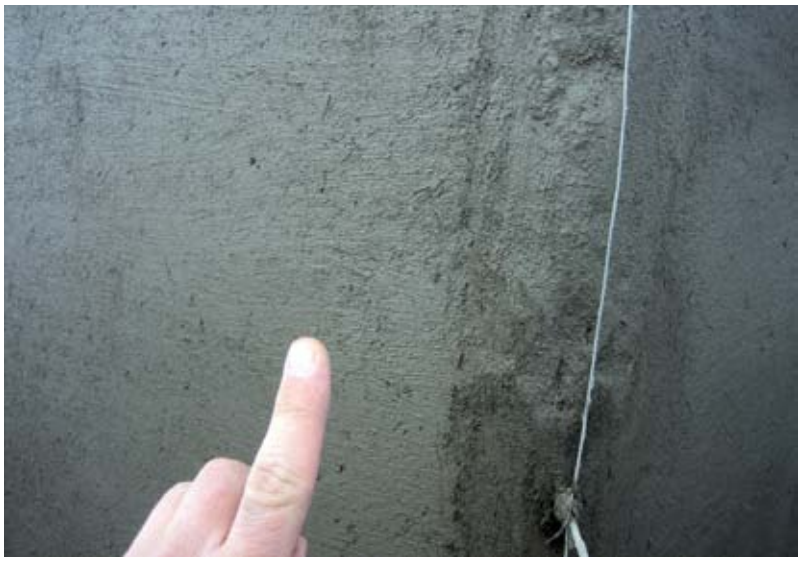
Table 1: Dry-Mix Shotcrete Performance Requirements

28-day compressive strength, MPa (psi)	Minimal weight of cement, kg/m³ (lb/yd³)		Maximum water-cementitious material ratio (*w*/*cm*)*	Minimum proportion by weight of 10 mm (3/8 in.) aggregate, %	Air content (plastic and hardened states), %	Minimal weight of synthetic fiber, kg/m³ (lb/yd³)
	Type GUb-SF (Type 1 with silica fume)	Type HE (Type 3)				
35 (5000)	450 (760)	460 (775)	Based on consistency (~0.40)	10	3.5 to 7.0	0.9 (1.5)

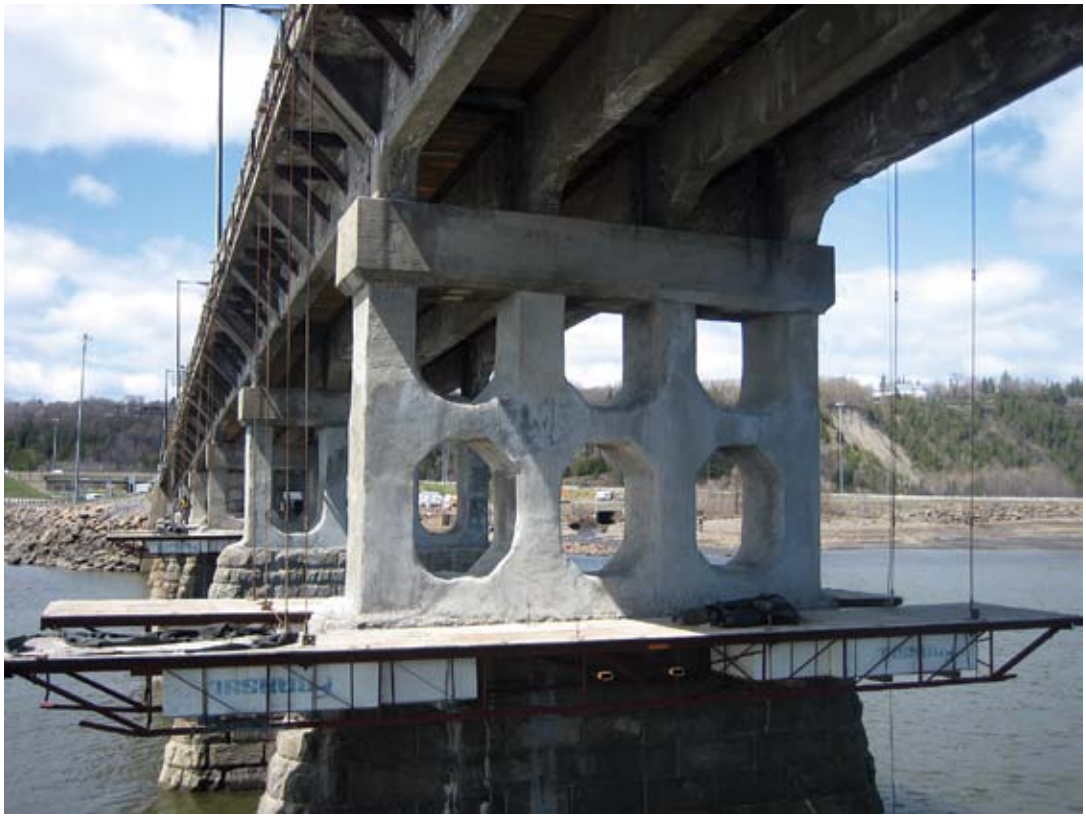
*(*w*/*cm*) is not verified

benefits of coarse aggregates, up to 3/8 in. (10 mm) in size, are optimal compaction and packing density, reduced shrinkage, and cleaner equipment and hoses.[9]

Temporary shoring was necessary during demolition work, as the cross section removed a significant amount of concrete. The surface preparation began by chipping the concrete columns with pneumatic hammers to 1 in. (25 mm) behind the reinforcing steel. Transport Québec specifications limit the pneumatic hammer weights to 35 lb (16 kg) to reduce the possibility of inducing microcracks in the substrate.[6] The corroded reinforcing steel was sand-blasted to remove corrosion and the columns were then cleaned with high-pressure water to remove rust stains, laitance, loose concrete, dust, and any other substances that could potentially weaken



Shotcrete was trowel-finished for aesthetics and also to increase durability



A finished repair is visible, with a support platform in place for final touches and inspection

the bond. A welded-wire steel mesh was then fastened tightly to anchors to prevent vibration during shotcrete placement. The substrate was soaked a few hours prior to application to obtain a saturated surface-dry (SSD) condition of the substrate.

ACI-certified nozzlemen were used to place the shotcrete. Working in the tight confines of the enclosed platform and encapsulating the rectangular reinforcements with the welded-wire mesh was a challenge, but the shotcrete crew was able to complete the job with excellent results. The shotcrete was float-finished to create an aesthetic and durable finish and wet-cured using burlap, water, and plastic sheets for a minimum of 7 days, ensuring complete hydration from surface to core of the repair.

The total area repaired was approximately 8000 ft² (750 m²), and the thickness varied from 4 to 8 in. (100 to 200 mm). All repaired areas were sounded after the shotcrete gained sufficient strength. Cores were extracted from test panels daily as a quality control measure.

Using a high-performance dry-mix shotcrete repair material to rehabilitate the pier columns allowed the service life of the bridge to be extended by a couple of decades. The ease of use and flexibility of the dry-mix shotcrete method enabled Stellaire Construction, along with the expertise of Groupe Diamantex, to deliver the rehabilitated bridge on time and on budget to Transport Québec.

References

1. Île d'Orléans Tourism, "The Region," 2003, http://www.tourismeiledorleans.com/introang.html. (last accessed Oct. 22, 2011)

2. Laflamme, J.-F.; Talbot, M.; and Lacoste, M., "Instrumentation des Ouvrages d'Arts au Ministère des Transports du Québec," Association Québecoise du Transport et des Routes, Apr. 26, 2011, http://www.aqtr.qc.ca/congres/pdf/LaflammeJF_MTQ_InstrumentationOuvrages.pdf. (last accessed Oct. 22, 2011)

3. Statistics Canada, "2006 Community Profiles," 2006, http://www12.statcan.ca/census-recensement/2006/dp-pd/prof/92-591/search-recherche/lst/Page.cfm?Lang=E&GeoCode=24&Letter=S. (last accessed Oct. 22, 2011)

4. Talbot, M., "Méthodes Expérimentales et Numériques Utilisées pour l'Evaluation du Pont Suspendu de l'Île d'Orléans," June 8, 2002, Cegep Outaouais: http://pedago.cegepoutaouais.qc.ca/media/0260309/0378334/SCGC BON/Documents/ST031-Talbot.pdf. (last accessed Oct. 22, 2011)

5. Dufour, J.-F.; Reny, S.; and Vézina, D., "State-of-the-Art Specification for Shotcrete Rehabilitation Projects," *Shotcrete*, V. 3, No. 4, Fall 2006, pp. 4-11.

6. Transport Québec, (2008, February 8), "Investissements Routiers 2008-2009," Feb. 8, 2008, http://www.mtq.gouv.qc.ca/portal/page/portal/Librairie/Publications/fr/salle_presse/2008/20080211_investissements2008_2009/investissements_cap_nat.pdf. (last accessed Oct. 22, 2011)

7. "Normes Ouvrages Routiers," Tome VII, Sections 3.2., Éditions 2005—Matériaux, Publications du Québec, Quebec City, QC, Canada.

8. ACI Committee 506, "Guide to Shotcrete (ACI 506R-05)," American Concrete Institute, Farmington Hills, MI, 2005, 40 pp.

9. Reny, S., and Jolin, M., "Technical Tip: Improve Your Shotcrete: Use Coarse Aggregates!" *Shotcrete*, V. 13, No. 1, Winter 2011, pp. 26-28.

Île d'Orléans Bridge

Project Location
Québec City, QC, Canada

Shotcrete Contractor
Groupe Diamantex

General Contractor
Stellaire Construction

Project Owner
Transport Québec

Engineer
Cima +

Material Supplier
King Packaged Materials Company*

*Corporate Member of the American Shotcrete Association

***Philip Sawoszczuk**, Jr. Eng., is a Technical Services Representative for King Packaged Materials Company. His areas of expertise include rehabilitation and preservation of infrastructure, structural engineering, and durability of concrete. He received his degree in civil engineering from McGill University, Montreal, QC, Canada.*

***Daniel Bordeleau**, Eng, MSc, is Owner and President of Groupe Diamantex, a contractor specializing in the rehabilitation of concrete structures, based in St. Augustin, QC, Canada. Bordeleau received his master's degree in applied science from Laval University, Québec City, QC, Canada, in 1988 and has completed articles on polymer-modified concrete that have been published in the* ACI Materials Journal *and the* ACI Structural Journal. *Bordeleau is a member of Québec Association of Transport and Roads and the Association of Québec Engineers. He has served as President of the Canadian Society of Civil Engineers between 1994 and 1999 and of The 1995 Annual Congress of the Association of Concrete Products; he was Regional Director of the American Concrete Institute from 1997 to 1998.*