Use of Synthetic Fiber-Reinforced Dry-Mix Shotcrete for the Rehabilitation of a Wharf in Northeast Quebec, Canada

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This paper presents a description of the repair works carried out in 1998 on the La Romaine Wharf, located in the northeastern part of the Province of Quebec, Canada. The Wharf's concrete transfer slab was deteriorated due to severe ice exposure conditions during winter. A major rehabilitation was needed to reinstate its structural integrity. Difficult access conditions to the job site as well as the location of the repair sections (underneath the transfer slab) led engineers to a dry-mix shotcrete solution as the most appropriate repair method. Furthermore, the dry-mix shotcrete was especially designed to meet the particularly severe environmental conditions (sea currents, tidal cycles, ice movement, and freeze-thaw cycles) of the area. Type 30 cement, silica fume, synthetic fibers, a powdered set-accelerator, and a powdered air-entraining admixture were used in the mixture to provide the required strength and durability requirements. The removal of the deteriorated concrete, the installation of the new reinforcing steel bars, and the shotcreting operations are described in this paper.

Introduction

Located 1000 km (620 miles) northeast of Quebec City along the St. Lawrence River, La Romaine is a village with an approximate population of 1100 (Figure 1). No roads lead to La Romaine; only planes and boats allow the residents to be in contact with other cities. Up until now, the Wharf has been the essential means to exchange merchandise and lay in provisions, particularly those that are too heavy or too bulky to be moved by planes.

La Romaine Wharf is under Transport Canada's jurisdiction and is maintained as part of a major federal program for marine structures located on the Basse Côte-Nord of the Province of Quebec. La Romaine's first commercial wharf dates back to 1950. This old wooden structure was entirely reconstructed in 1982-1983 by Transport Canada (Figure 2). Approaches to the Wharf are made of fractured stone, which protects and supports the access road (Figure 3).

The Wharf's structure is a steel sheet pile type that forms the cofferdams, which are partially filled with rock. Because the design did not allow for the entire filling of the cofferdams, a large void many meters high was kept inside the steel structure. In order to prevent a surcharge of the rock backfill, a transfer platform was built inside the Wharf at high-tide level. This platform consists of a concrete slab supported by piers and steel beams.

Description of the Damage

The La Romaine Wharf is part of a series of strategic wharves on the Basse Côte-Nord, and because its existence is considered essential for the population's needs, regular inspections are made and constant maintenance is scheduled.

In 1994, major damage to the Wharf was identified.

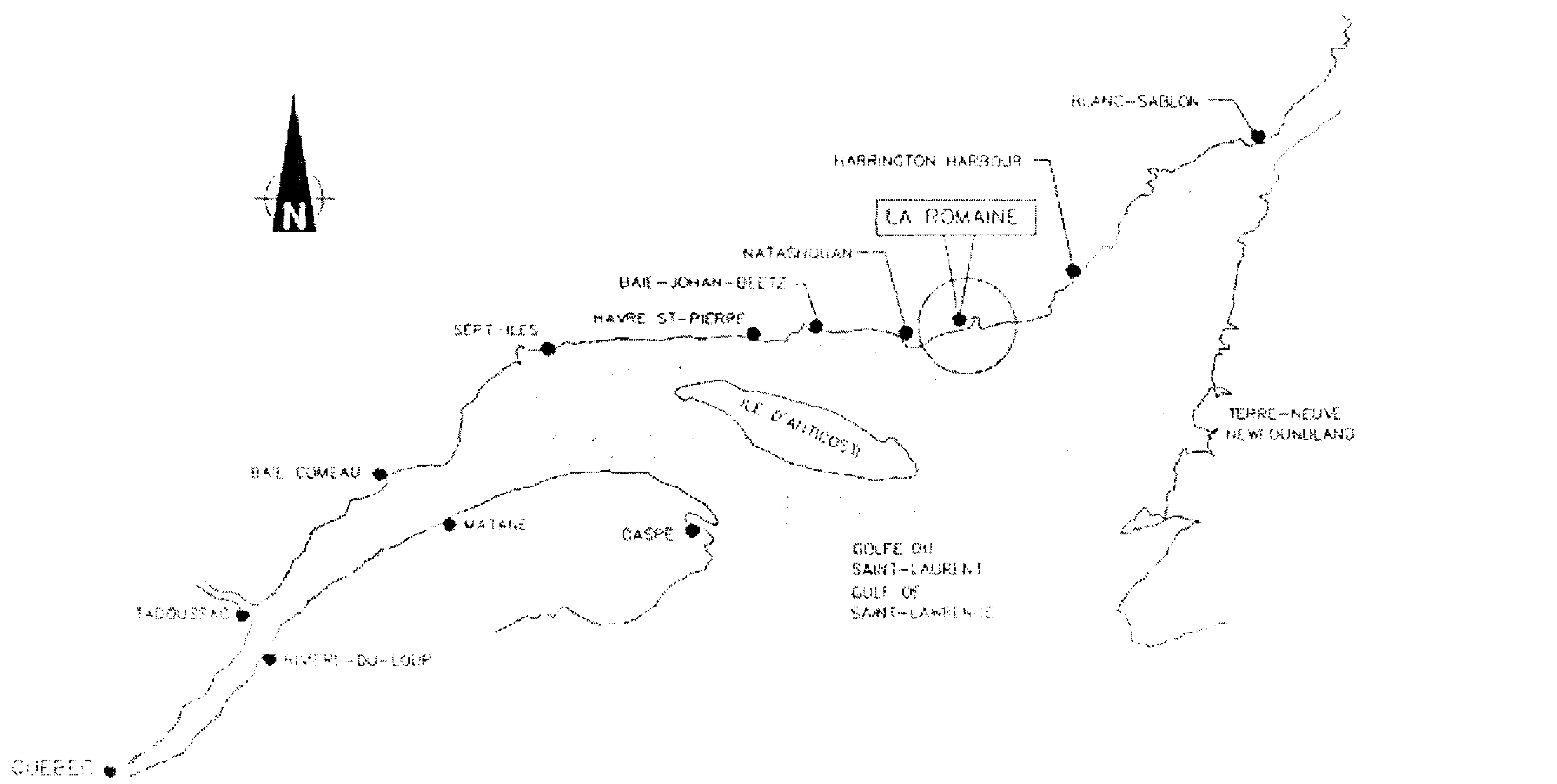

Figure 1. Location map of La Romaine

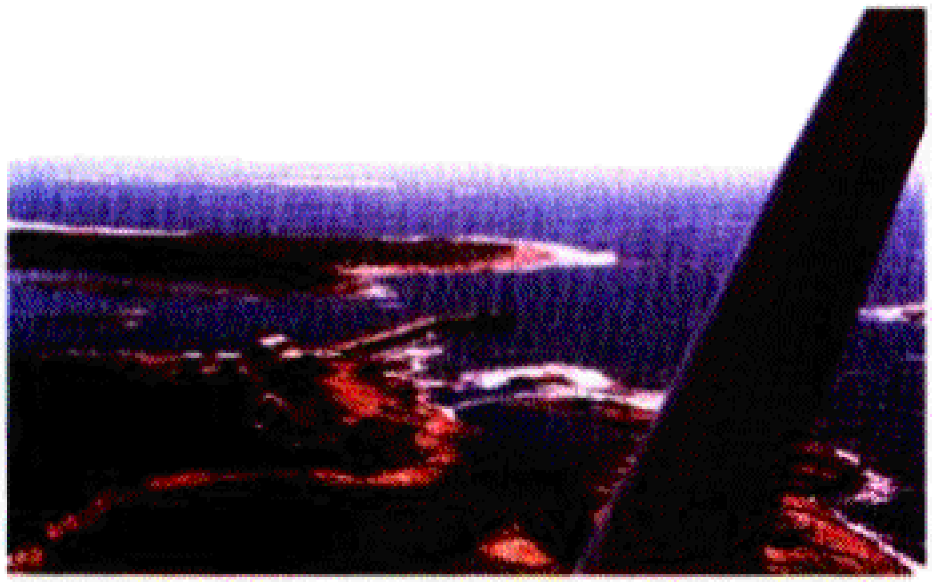

Figure 2. La Romaine Wharf (view from airplane)

Figure 3. La Romaine Wharf

Considering the presence of exposed steel (steel beams) inside the Wharf, it was decided to open the structure. A systematic inspection undertaken in 1996 showed that almost all the precast concrete elements constituting the transfer slab of the structure had deteriorated. The surface of the concrete slab was damaged at the junction with the steel sheet piles, and severe corrosion of the reinforcing steel bars in the precast elements was reported (Figure 4).

Because the transfer slab supports many meters of backfill materials as well as the surface slab of the Wharf, their failure, even partially, may have led to the collapse of the entire structure (or may have impeded repair works if no actions were undertaken within a short time). Thus, study of the entire damage, which was principally located on the concrete transfer slab, was carried out to determine the most appropriate repair method.

Identification of the Causes of the Damage

First, visual inspection pointed out that embedded steel corrosion may not be the cause of the damage observed on the failing concrete because the recently exposed steel did not show any traces of corrosion.

Cores were taken from the transfer slab to assess the quality of the in-place concrete. The analysis revealed no particular problems related to the concrete. In fact, results of tests performed on the in-place concrete showed that the compressive strength, air-void system characteristics, and freezing-and-thawing resistance were adequate. So, the concrete of the transfer slab had all the necessary properties to resist the severe environmental conditions to which the La Romaine Wharf is exposed.

It was determined that the ice action that forms inside the Wharf during winter was the main cause of deterioration. The concrete transfer slab was installed directly on transverse steel beams, which serve as braces for the cofferdams. Because this reinforced concrete slab was not equipped with stirrups to reinforce their edges against lateral stresses, steel plates attached to the slab were welded on the steel beams, which kept the transfer slab in place.

Considering that the transfer slab is located in the high-tide area, the water freezes between the cofferdams and its edges. Furthermore, with the tidal cycles in this part of the St. Lawrence Gulf, the number of freezing-and-thawing cycles is most pronounced during the high-tide season. The water located in the upper part of the Wharf also tends to freeze when it tries to move to the bottom section of the structure, passing through the junction of the steel cofferdams and the concrete slab.

When the water freezes, the steel cofferdams dilate and create a lateral pressure on the reinforced concrete slab. The concrete's reinforcement is not designed to resist such stresses and fails in a horizontal pattern. The damage has expanded over the years toward the center of the slab. This has also been confirmed by observation of the failure of many bolts coupling the cofferdams to the transverse beams.

Considered Solutions

Many repair solutions were considered to reinstate the structural integrity of the concrete transfer slab without risking the loss of backfill materials. The repair solution would have to prevent ice formation between the transfer slab and the cofferdams.

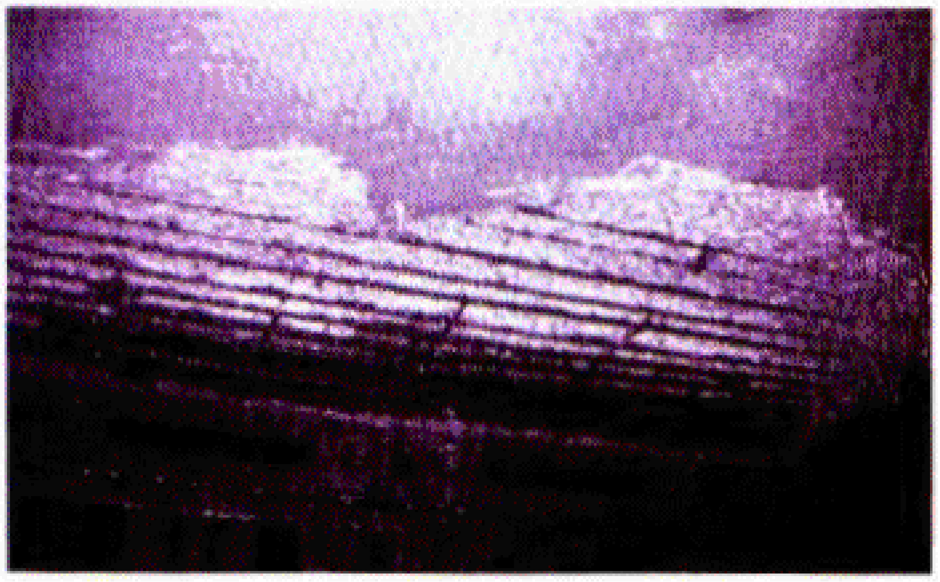

Figure 4. Transfer slab deterioration

Figure 5. Demolition operations

Figure 6. Ongoing demolition operations.

Figure 7. A ready-to-be-shot section.

One of the major concerns of the repair project was difficult access to the job site. Some repair solutions considered were impractical given that the area was only accessible by plane or by boat. The repair zones were located underneath the transfer slab of the Wharf. Furthermore, the Wharf is located in a cold region; the period of the year (mainly during summer or fall) during which the weather is acceptable for performing such work is very short.

Initially, a manhole had been dug for previous inspections carried out several months before the rehabilitation project. The restricted dimensions of this manhole, however, limited the type of intervention possible under the Wharf. In addition, the tide rises every 6 hours and makes access under the Wharf impossible. The installation of a second access was studied and finally performed in the steel cofferdam located on the Wharf's side. The necessity of preserving the cofferdam's structural integrity restricted the dimensions of the second access to about 6 m^2 (65 ft^2).

Numerous repair methods were analyzed, including the injection of the upper-part filling above the transfer slab, the construction of a new transfer slab placed under the existing one, and the repair of the existing slab with either self-leveling concrete or shotcrete.

The filling injection was found too hazardous considering the quality and the capacity of the stone/grout resulting from the injection and the high probability of exceeding the allotted budget. The construction solution of a new transfer slab was also abandoned due to the cost inefficiency and the working complexity related to the installation of such a structure (such as formwork and steel reinforcement) underneath the existing slab, inside the tidal zone, which is submerged every 6 hours. The self-leveling concrete technique was abandoned due to the complex formwork that would have to be put in place.

It was decided to repair the deteriorated sections of the transfer slab using shotcrete. Dry-mix shotcrete was considered the most suitable repair material. The materials (supplied in 30 kg [66 lb] bags) and the equipment were sent on a barge from Montreal to La Romaine.

Due to its location, both delivery time and cost of materials supplied to La Romaine are very high. Consequently, a very precise evaluation of equipment and quantity of dry materials needed to perform the rehabilitation was carried out.

Description of the Repair Work

The rehabilitation of the structure was carried out in three steps. First, the granular backfill located on the transfer concrete slab was consolidated to enable the concrete demolition work. To proceed, the surface preparation included demolition and removal of the unsound concrete, its cleaning, installation of new steel reinforcement, and anchorage to the concrete in place. Formwork was installed at the perimeter of the sections to be repaired to facilitate the construction of a 100 mm (4 in.) thick overlay. Shotcrete operations were then performed, taking into consideration the tidal cycles, starting at the low-tide level.

These repair works were the remedial solution to the structural damage to the concrete. In order to prevent a repeated deterioration pattern from developing, however, rubber plates were installed between the steel cofferdams and the repaired sections. The development of horizontal stresses in the concrete slab during freezing cycles could thus be prevented.

Figure 8. Equipment and materials stored on the Wharf.

Figure 9. Application of dry-mix shotcrete.

Table 1 – Dry-Mix Shotcrete Composition

Component	kg/m³ (lb/yd³)
Type 30 Cement	427 (720)
Silica Fume	48 (81)
Sand (0-5 mm) (0-0.2 in.)	1300 (2190)
Stone (2.5-10 mm) (.1 - .4 in.)	335 (565)
Polypropylene Fibers	2 (3.4)
Air Entraining Admixture	0.6 (1)
Set-Accelerator Admixture	19 (32)

Consolidation of the Granular Backfill

The goal of this operation was to temporarily stabilize the granular backfill to enable the partial demolition of the deteriorated sections without any risk of collapse. The working technique selected by the contractor was first developed on a prototype in Quebec City before starting the repair work. The consolidation was carried out with a cement grout injected at a series of openings made through the steel cofferdams and the transfer slab. This working method led to the achievement of the rehabilitation works without any loss of the granular backfill.

Demolition of the Damaged Concrete

Hydro-demolition was initially considered as the demolition technique. The first field tests, however, did not meet the set targets. The workers' position on the labor bridges located under the Wharf reduced their mobility and the fog that developed during hydro-demolition reduced visibility. The repair profile required partial destruction of sound concrete, and the hydro-demolition equipment used by the contractor did not allow for completion of this work within a reasonable time frame. Further impediments, such as the demolition of a single section of the transfer slab at a time, led the contractor to propose a different demolition method.

The contractor decided to use low-mass chipping hammers that allowed the demolition of many sections of the transfer slab at the same time (Figure 5 and 6). The chipping hammer's maximum mass was restricted to 7 kg (15.4 lbs) to reduce the risk of damaging the existing concrete.

Finally, to remove all loose and microfractured concrete, the demolished sections were cleaned with a water pressure jet. Figure 7 shows a repaired section prior to shotcreting operations.

Shotcreting Operations

Strict placement restrictions and severe exposure conditions for the shotcrete led Service d'Expertise en Matériaux (S.E.M.) Inc. to formulate a dry-mix shotcrete especially adapted for this project.

Because the repair area was located inside the tidal zone, several constraints had to be considered, such as immersion of the shotcrete into salty waters a short period after shotcreting operations, and very brief working periods due to the tide cycles. Due to the restricted access to the repair area, all the equipment and materials needed were installed on the Wharf (Figure 8).

In addition, the hardened shotcrete had to develop a compressive strength greater than 35 MPa (5075 psi) at 28 days (in accordance with ASTM C 42) and its air-void spacing factor had to be lower than 230 µm(in accordance with ASTM C 457).

Table 1 presents the composition of the shotcrete mixture. A Type 30 high early-strength portland cement and silica fume were used to obtain good mechanical properties at early ages as well as proper protection against chloride penetration and reinforcement corrosion. Polypropylene fibers were added to the mixture to reduce the risks of cracking that could occur a few hours after placement, thus reducing damage generated by the penetration of salty water into cracks.

During prebagging operations, a powdered set-accelerator admixture was added to the dry materials. This admixture allows rapid strength development in a short time and increases the resistance to leaching of the fresh shotcrete. A powdered air-entraining admixture was also added to the dry materials to enable the shotcrete to meet the durability specifications and particularly the air-void spacing factor requirements.

Due to the tidal cycles, which limited the shotcreting periods and the use of labor bridges to support the nozzlemen, the dry-mix shotcrete operations were difficult (Figure 9). Between each shotcrete application, the concrete surfaces were cleaned with a smooth pressured water jet to remove seaweed and other unsound residues, as well as salt water, which could reduce the bonding of the shotcrete. Even with such difficult job-site conditions, the repair works were performed within the scheduled time frame and were found to be adequate to reinstate the structural integrity of the Wharf (Figure 10).

Table 2 – Tests Results for Hardened Shotcrete

Identification#	Compressive Strength 28-day, MPa (psi)	Air Content, %	Specific Surface of Air Voids, mm⁻¹ (in.⁻¹)	Spacing factor of Air Voids, µm (in.)
C-06	37.9 (5497)	—	—	
C-07	62.5 (9065)	6.3	20.3 (515)	212 (8.3 × 10⁻³)
C-08	37.6 (5453)	—	—	
C-09	37.1 (5381)	7.5	25.3 (643)	171 (6.7 × 10⁻³)
C-10	32.4 (4700)	—		—
S-02	—	8.2	15.5 (394)	193 (7.6 × 10⁻³)
S-03	—	6.0	26.1 (663)	178 (7.0 × 10⁻³)
S-04	—	6.2	20.5 (521)	219 (8.6 × 10⁻³)
S-3	—	6.0	25.9 (658)	178 (7.0 × 10⁻³)
S-4	—	6.3	29.3 (744)	149 (5.9 × 10⁻³)

Figure 10. Section after rehabilitation.

Quality Control Program

Nozzleman Certification

In the specifications prepared by S.E.M. Inc., the contractor's nozzlemen appointed to the project needed to have the necessary skills to properly apply the shotcrete. To verify such skills, a certification session according to the Province of Quebec DOT specifications (CCDG 16.7.6) was held a few weeks before the beginning of the repair works.

During the certification session, the nozzlemen had to shoot dry-mix shotcrete into reinforced panels. The following parameters were analyzed: nozzling technique, distance and angle of the nozzle from the receiving surface, and consistency of the freshly applied shotcrete mixture. A few days later, the shotcrete panels were cored and sawed to evaluate these characteristics:

- **Rebar encasement:** Evaluation of the rebar encasement was based on the "Core Grade System" in ACI 506.2-95.
- **Homogeneity of the shotcrete:** Any shotcrete surface of 25 x 25 mm (1 x 1 in.) on the 3 sawed faces of the panel had to include visible aggregate of nominal diameter of 2.5 mm (0.1 in.) (the first 20 mm [0.8 in.]) from the bottom of the panel was not considered in this evaluation because of coarse aggregate rebound in the first bedding layer of the shotcrete).
- **Presence of major voids:** A maximum allowable area of voids was fixed at 150 mm^2 (0.2 $in.^2$) on the 3 sawed faces of the panel.
- **Compressive strength:** Performed on three cores at 7 days according to ASTM C 42: minimum of 35 MPa (5075 psi).
- **Air void spacing factor**: Maximum of 300 μm (0.012 in.) according to ASTM C 457.

To be certified, the nozzleman has to produce shotcrete while meeting the categories listed above. The experienced nozzleman appointed by the contractor was certified without any problem.

Test Program During Repair Works

During shotcreting operations on site, panels were filled for 28-day compressive strength measurements (ASTM C 42) and air-void system characteristics determination (ASTM C 457). The results are presented in Table 2. All results (with the exception of a compressive strength test result for the C-10 panel) met the specifications. This indicates that the mixture design was adequate for such a repair project.

Evaluation of the Repaired Sections

After completion of the work, Canada Public Works representatives carried out inspections of the repaired sections. Only minor deficiencies were detected and these did not have any significant effect on the structural integrity of the Wharf.

CONCLUSION

For this project, the dry-mix shotcrete was found to be an appropriate repair technique. Numerous advantages are related to this technique: its rapid execution, concrete placement with minimum formwork, high flexibility, and adaptation to field constraints were all validated. The properties of the concrete cores sampled from panels indicated that the in-place shotcrete has a good mechanical resistance and a proper air-void system. Finally, Public Works and Government Services Canada considers the La Romaine Wharf rehabilitation project a success. This technique will be used for other wharf repair projects in the near future.

Martin Gendreau completed a master's thesis in concrete technology at Laval University in 1992. He has worked for 2 years as a project engineer for material control in laboratory, and for 4 years as a research engineer for Concrete Canada at Laval University. Since 1996, Mr. Gendreau has been technical director attached to Service d'Expertise en Matériaux (S.E.M.) Inc. and he has been involved in many projects on the rehabilitation of civil engineering structures using the shotcrete technique.

Pierre Lacombe completed a master's thesis in concrete technology at Laval University in 1996. He worked for 2 years as a research engineer for the Industrial Chair on Shotcrete and Concrete Repairs at Laval University before joining the Service d'Expertise en Matériaux (S.E.M.) Inc., in July 1998. He has been working on numerous projects using shotcrete and other special concretes. He is a member of ASA's Underground and Certification/Education committees as well as ACI Committee C 660 (Certification of Shotcrete Nozzelman), ACI Committee 506 UG (Shotcrete for underground support) and 506 F (fiber reinforced shotcrete).

Mr Ropars obtained an engineering degree from E.N.T.P.E. in Paris (France) and a Master degree in civil engineering (marine hydraulics) from university Laval in Québec. He has been working for the last 20 years for the Canadian federal government designing harbour and coastal structures.