2015 Outstanding Repair and Rehabilitation Project

Société de transport de Montréal—Metro Yellow Line Tunnel Repairs

By Kevin Robertson, Patrick Giguère, and Ntam Nda-Ngye

The Montreal Metro is an underground metro system and the main form of public transportation in the city of Montreal, QC, Canada. The Metro, operated by the Société de transport de Montréal (STM), was inaugurated on October 14, 1966. It originally consisted of 26 stations on three separate lines, but now has 68 stations on four lines totaling 43.0 miles (69.2 km) in length, which serves the entire greater Montreal area. 1.2 million passengers now ride the system daily. The Yellow Line is the only metro line that runs between the island of Montreal and the south shore.

The project (Metro Yellow Line Tunnel Repairs) was released for tender on September 23, 2013, and was awarded to Construction Interlag Inc. of Saint-Léonard, QC, Canada. Construction Interlag Inc. is a civil construction company with expertise in all aspects of concrete repair and rehabilitation. Their shotcrete team, which employs several ACI Certified Nozzlemen, has over 75 years of combined shotcrete experience in the civil and mining markets.

Engineering Scope

The initial feasibility study was completed by an outside consulting engineering firm. However, an internal STM engineering group took over the design work, conducted a delamination survey, and performed a finite element analysis of the tunnel walls.

The STM engineering team identified approximately 6500 ft^2 (600 m^2) of overhead area requiring removal and replacement, most of which ranged in thickness from 18 to 35 in. (450 to 900 mm) (Fig. 1). The sequence for the work to be completed was specified as:

1. Removal of deteriorated and delaminated concrete;
2. Installation of rock anchors and wire mesh; and
3. Placement of shotcrete (dry-mix process).

The majority of the work was undertaken in a 2.5 mile (4 km) stretch of tunnel between the Berri–UQAM station and the Longueuil–Université-De-Sherbrooke station. This stretch of tunnel runs underneath the St. Lawrence River. To complete the project with minimal disruption to the Montreal commuters, it was decided that the work schedule would be spread over 207 nights with the majority of the concrete replacement (shotcrete) being completed over 25 weekends. The shotcrete placement was split into two phases in an effort to further accommodate transit riders during some of Montreal's major arts and cultural events, not the least of which was the Montreal Grand Prix. During the time when the stations were closed, a shuttle service that bypassed the construction zone was offered to the public.

Shotcrete Materials

The material specification called for a prepackaged, high-quality shotcrete mixture that would provide long-term durability, so the STM engineers specified the same parameters that are used by the MTQ (Quebec Ministry of Transportation) in their shotcrete specification. Key aspects of the specified mixture design were:

1. Air entrainment: The most important performance durability criteria remains the determination of air void distribution, as per ASTM C457. In-place, hardened shotcrete requires an average air void spacing factor of under 0.0118 in. (300 μm), with no individual results over 0.0125 in. (320 μm). In a dry-mix shotcrete application, air-entraining admixture should be added in powdered form and preblended with other components at the point of manufacturing. The shotcrete mixture producer should have a proven track record producing prepackaged, air-entrained, dry-mix shotcrete and should be able to provide ASTM C457 test

data that reflects the recommended air-void spacing factor for dry-mix shotcrete.

2. Silica fume: Silica fume is a highly pozzolanic admixture that has been proven to improve both the plastic and hardened properties of concrete placed using the shotcrete process. The use of silica fume in shotcrete increases adhesion to the bonding surface and cohesion within the shotcrete, consequently allowing thicker placement of shotcrete before sloughing (especially in overhead applications). Although there is no standard ASTM or ACI test to measure attainable thickness in one pass, testing and field performance has proven that the benefits of silica fume from the perspective of overhead and vertical repairs are obvious.
3. Aggregates: Aggregates should meet the recommendations in ACI 506R, "Guide to Shotcrete," and use Gradation No. 2 (the mixture with both fine and coarse aggregates), due to the thickness of the applications. To ensure optimum durability, including resistance to freezing and thawing and alkali-aggregate reaction, all concrete aggregates should also meet the minimum requirements outlined in ASTM C33. The use of larger (0.4 in. [10 mm]) coarse aggregate also has a positive effect on the ability to pump and shoot the shotcrete mixture. The abrasion of coarse aggregate against the inside lining of the hose reduces the cement buildup and improves material flow. Consequently, a coarse aggregate gradation will allow the use of longer transportation hoses and reduce plugging.

Significance of Shotcrete

The greatest challenge faced by the STM management team and the contractor was, without a doubt, to complete the project in a timely manner while limiting disruption to the STM ridership. The engineering group not only had to design the structural elements of the repairs but also had to find a solution that would allow a fast turnaround time so the completion of the concrete repairs, crack injections, and electrical work would stay within the allocated 25 weekends. With that in mind, the decision to specify dry-mix shotcrete checked all the boxes for the STM engineering team.

The nature of the shotcrete process allowed the crew to continually place concrete much quicker than form-and-pump placement methods. More importantly, the elimination of formwork resulted in reduced labor and allowed the contractor to mobilize, shoot, cut, and finish without having to transport, install, and later remove complex, curved forms. The result was not only an accelerated construction schedule but also a more cost-effective repair method (Fig. 2).

Logistical Challenges

Mobilization of the crew and transportation of the required materials and equipment to the worksite was extremely challenging. Access to the worksite by train was the only option available to the contractor, so Construction Interlag Inc. developed a system using two special flatbed train cars that were designed to carry all of the components, including the dry-mix shotcrete gun, pre-dampener, forklift, compressor, tool box, and enough bulk bags of shotcrete material to last the shift. This system allowed them to maximize the work hours during the weekend shutdowns of the metro line (Fig. 3).

Fig. 1: The material specification called for a prepackaged, high-quality shotcrete mixture that would provide long-term durability

Fig. 2: The STM engineering team identified approximately 6540 ft^2 (600 m^2) of overhead area requiring removal and replacement, most of which ranged in thickness from 18 to 36 in. (450 to 900 mm)

Fig. 3: Construction Interlag Inc. developed a system using two special flatbed train cars which were designed to carry all of the components, including the dry-mix shotcrete gun, pre-dampener, forklift, compressor, tool box, and enough bulk bags of shotcrete material to last the shift

Before starting the shotcrete process, both flatbed cars were positioned side-by-side along parallel tracks and a platform connecting the two cars was installed to allow personnel to move between the cars. Another platform was erected to allow the nozzleman to position himself the proper distance from the receiving surface (approximately 3 to 5 ft [0.9 to 1.5 m]). An adjustable netting system was designed and placed around the shooting platform to prevent rebound from falling into the track area and thus reducing cleanup time at the end of the shift (Fig. 4).

The benefits offered through the dry-mix method of placement made it the natural choice for the contractor:

1. Sufficient pre-blended material to last a full shift could be transported, stored, and placed through the dry-mix gun, allowing the crew to maximize production.
2. The shotcrete crew could easily start and stop when moving from one repair area to the next.
3. A special high-early-strength, accelerated shotcrete mixture allowed the contractor to place thicker passes and complete the finishing process without having to return at a later time to complete the repair.
4. Less cleanup time allowed the contractor to maximize shooting time and improve productivity.

Despite these benefits, dust control (preventing dust from contaminating the metro stations and ventilation system) remained the primary concern for the STM project managers. The Construction Interlag Inc. management team worked closely with the experts from the material and equipment suppliers to convince the STM project managers that an experienced shotcrete crew, using well-maintained, quality equipment and a high-quality consistent material can easily alleviate concerns about dust. The Interlag team used a number of tools to minimize dust including a well-maintained dry-mix shotcrete rig (with a pre-dampening unit and gun). The pre-dampener added a controlled amount of moisture to the dry-mix prepackaged, pre-blended shotcrete material and a hydro-mix nozzle with a water ring approximately 10 ft (3 m) back from the nozzle tip was used to further reduce dust emissions (Fig. 5).

Despite the effectiveness of these measures, a secondary dust control system that used a simple sprinkler/mist net system was installed downwind from the shotcrete crew as added insurance against dust emissions. The Interlag crew proved that dry-mix shotcrete, placed in a confined location, can be relatively dust-free if the proper procedures are followed by an experienced team of professionals. A collaborative approach involving Construction Interlag Inc., the STM, and the material supplier (King Shotcrete Solutions) resulted in a successful project that was completed on budget, on time, and with limited inconvenience to the Montreal commuters.

Fig. 4: Removal of deteriorated and delaminated concrete, installation of rock anchors and wire mesh, and ready for placement of dry-mix shotcrete

Fig. 5: Proof that dry-mix shotcrete, placed in a confined location, can be relatively dust-free by using a well-maintained dry shotcrete rig (with a pre-dampening unit and gun)

The Outstanding Repair & Rehabilitation Project

Project Name
Société de transport de Montréal—
Metro Yellow Line Tunnel Repairs

Project Location
Montréal, QC, Canada

Shotcrete Contractor
Construction Interlag Inc.

General Contractor
Construction Interlag Inc.

Architect/Engineer
Société de transport de Montréal

Material Supplier/Manufacturer
King Shotcrete Solutions*

Project Owner
Société de transport de Montréal

*Corporate Member of the
American Shotcrete Association

Kevin Robertson *is a Technical Sales Representative for King Shotcrete Solutions and is responsible for the Greater Montreal Area and northeast U.S. markets. His area of expertise includes shotcrete materials, applications, and equipment, focused mainly on concrete repair and rehabilitation. Robertson is a member of ASA, the American Concrete Institute (ACI), and is the Vice-President of the Quebec Province Chapter of the International Concrete Repair Institute (ICRI).*

Patrick Giguère*, P.Eng., is a Project Manager and Estimator for Construction Interlag Inc. His areas of expertise include structure and road rehabilitation. He has over 20 years of experience in the industry and received his degree in construction engineering from Écoles de Technologie Supérieur, Montréal, QC, Canada.*

Ntam Nda-Ngye*, P.Eng., is a lead structural and civil engineer for the Société de transport de Montréal. His areas of expertise are project management, structural analysis, and design of steel and concrete structures. Ntam has over 15 years of experience in design and more than 5 years in project management. He was the project engineer on the Metro Yellow Line Tunnel Repairs project, for which he led a team of electrical, civil, and structural engineering specialists. He received his civil engineering degree from the University of Innsbruck, Innsbruck, Austria, and his master's degree from École Polytechnique de Montréal, Montréal, QC, Canada.*