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Since the start of the program, many milestones have been achieved and many hurdles have been overcome. From 1997 to 2001, about 450,000 gallons of acrylamide (Avanti International’s AV-100 and AV-118) solution grout has been successfully injected throughout the tunnel structures to stop water infiltration. In consideration of the difficult working conditions and the short nightly work window available, the success has been exceptional. The whole grouting operation has become extremely efficient over time, enabling the completion of approximately four locations per shift. Presently, the program has two work cars, a drilling car and a grouting car. As a result, a steady level of production could be maintained.

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Grout Formulations
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Water infiltration had been a problem with the TTC since the time of construction. The water accelerates the life cycle of many operational components and systems affecting the safe operation of the system. Rail plates and anchors need replacement, electrical signal components require significant upkeep and replacement, drains become plugged, etc. Until the start of a remediation grouting program, only emergency repairs had been performed on an as-required basis. Given that water infiltration into the tunnels was the leading contributor to a large range of problems with electrical and mechanical systems and components, including the structure itself, tunnel leak remediation was deemed a primary objective and focus of the commission.

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Since their construction in 1954, the tunnels had not received any major restoration of any kind. The requirement for a structure maintenance program was in great need, due to the persistent and progressive water infiltration that was causing extensive concrete and steel deterioration.

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The tunnel leak remediation program was built around a solid foundation of expertise in the specialty field of grouting, restoration, and rehabilitation.
In locations of the subway system that allowed it, the cut and cover tunneling system was used whereby a concrete box tunnel construction was utilized. Approximately 80 percent of the subway tunnel was constructed by the cut and cover method.

The standard concrete box structure portion of the tunnels comprises a rectangular concrete box of vertical walls, roof and floor slabs, with a central wall dividing the tracks, which run in opposite directions.

The use of the precast concrete liner was preferred over the cast iron liner due to the overall lower cost.

Cast iron liners were used to line the inside of the bored tunnel. The tunnel was excavated behind a shield, the liner was erected immediately behind the shield, and the 40 mm annulus between the ground and liner was grouted with neat cement.

The precast concrete liners were used to line the inside of the bored tunnels in a manner similar to that of the cast iron liner. These liners were usually used in conditions where the groundwater table was below the tunnel axis. The use of the precast concrete liner was preferred over the cast iron liner due to the overall lower cost. The cast iron liner was only used in areas of the tunnel where groundwater table conditions prevented the use of the precast concrete liner.

The mechanism for water infiltration into the tunnels is predominately via the expansion and construction joint systems. In the case of the bored tunnels, the infiltration is primarily along the radial and longitudinal joints, but has also been observed coming in via the bolt holes and also through cracks. The groundwater table is typically above the tunnel roof and is the source for all the water infiltration problems. For the most part, our hydraulic conductivity tests reveal an “infinite” permeability (infinite meaning our equipment cannot supply water fast enough to register an effective pressure after taking into account the head losses in the system). The hydraulic conductivity tests are continually performed using the acrylamide solution grout as the testing fluid.

All tunnel leak remediation work is performed at night when the subway is not in service. On average, the actual maintenance window from which work can be performed is approximately two hours per night, with a six-hour working window available on Sunday mornings. Due to the short working window, it was necessary to develop and implement a strategic and innovative design solution to execute the leakage repairs in a swift, effective, and efficient manner. Given the vast number of other maintenance activities that are also performed at night, the availability of work zones in the same area night after night is not always possible.

The majority of the grouting operations are performed from a 26-yard long work car that was custom built for this program. The work car was designed to be self-sufficient for power, storage space, and carry enough water for the entire shift. The work car has two working platforms strategically separated to allow work to be performed on two expansion joints simultaneously. The work car is electrically powered by a 350-CFM compressor. The cost of the work car alone was $1 million. The work car is loaded with grout material at the start of every shift.

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In the concrete box tunnel sections, the grouting is targeted in the soils immediately behind the expansion joint. In essence, a mini-grout curtain or grout bulb is created immediately behind the expansion joint, preventing water from entering the joint via the back of the structure. Grouting (“back-wall grouting”) is carried out via mechanical injection packers installed at a 1 to 1.5 meter spacing along the expansion joint. The holes are drilled by means of rotary air percussion techniques, using stopper and jack-leg drills. Drill holes are 35 mm in diameter. A ball valve, in conjunction with a hydraulic connection system, is then attached to the mechanical injection packers so that a grout hose can be hooked up when grouting is to take place. Multiple hole grouting with up to six holes at a time is performed.

A second work car was made available for the tunnel leak remediation program on a permanent basis starting in mid-1999. The addition of the second work car increased the production and efficiency of the overall operation. The second work car became the “drilling” car, preparing areas for grouting and allowing grouting to be carried on seven nights a week by the grouting work car.

The grouting repair techniques that have been successfully used to stop the water infiltration into the tunnels has been the “back-wall” or exterior soil grouting approach, using acrylamide-based solution grouts. Avanti International’s AV-100 and AV-118 Durflex have been used for this project. The manner in which these leak repairs are carried out is slightly different in the circular bored tunnel sections compared to the concrete box tunnel sections.

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The grouting operations are slightly different for the circular bored tunnels. Given the nature of the circular tunnels, a larger scope external soil grouting operation is performed. Naturally, there are many more potential infiltration points in the circular tunnels compared to the concrete box tunnels. Again, through extensive hydraulic conductivity testing, it was determined that a preferential hydraulic pathway exists immediately behind the liner. This is likely the result of ungrouted or unsuccessfully grouted tunnel annulus during the original tunneling.

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In all cases, the effective grout injection pressures are kept to a maximum of 15 psi above the hydrostatic pressure at that location. Due to time constraints, grout volumes have been predetermined and fixed volumes of grout are placed at each location.
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Program background

In April 1996, the consulting firm, Klohn Crippen Consultants Ltd., completed a detailed investigation and report by analyzing the current leakage conditions within the existing subway tunnels. The findings clearly indicated the need to implement a comprehensive maintenance and repair program, thus was born the tunnel leak remediation program. On average, approximately 30 percent of the underground tunnel structures required some form of remediation.

The start-up of the present in-house specialty leak remediation crew was done from the ground up. Prior to the spring of 1997, the TTC had no professional grouting equipment, no material, and very limited in-house expertise in the field of grouting, restoration, and rehabilitation. The TTC hired the outside expertise to train its employees to become skilled and knowledgeable in grouting procedures and applications. The proper training and guidance of the in-house staff before operations began was invaluable to the success of this project.

The Tunnel Leak Remediation Crew is made up of 13 employees: a foreperson, a lead hand, three structure mechanics, two special vehicle operators, and six structure repair persons.