3 EXPERIENCE FROM THE CONSTRUCTION BY DRILL AND BLAST UTILITY TUNNEL UNDERNEATH THE MONTREAL NEUROLOGIC INSTITUTE WITH HIGHLY SENSITIVE EQUIPMENT AT MCGILL UNIVERSITY CAMPUS

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ABSTRACT

The construction of a new utility tunnel associated with its hospital operations at the McGill University's downtown Montreal campus was carried out by drill and blast. The tunnel passes within 6 meters directly beneath and adjacent to buildings that house sensitive facilities, equipment, research laboratories, medical treatment rooms and patients.

To maintain all hospital activities during tunnel construction and protect existing infrastructure, a number of constraints related to peak particle velocities and blast overpressure, and audible blast noise measured at selected locations were imposed on the Contractor. The paper discusses considerations that were used in the alignment selection, evaluation of applicable construction methods, the process used to set baseline parameters and the monitoring program, and the results of their implementation during construction.

INTRODUCTION

There are over three kilometers of utility tunnels that are used to distribute a variety of services between the buildings of the McGill University downtown Montreal campus. These tunnels provide link between the buildings but also provide utilities such as high-pressure steam, supply and return of chilled water, sprinkler and drain lines as well as natural gas and high voltage electrical conduits. Over the years, these tunnels have deteriorated due to their age, and have become so congested with multitude of conduits and services, that new tunnels are now required, as well as optimization of services in existing tunnels.

The construction of a new utility tunnel associated with its hospital operations at the McGill University's downtown Montreal campus that started in May 2014 and finished in April 2015 was carried out using drill and blast method. The tunnel passes directly beneath and adjacent to buildings that house sensitive facilities and equipment, research laboratories, medical treatment rooms, and patients that are undergoing or recovering from various medical procedures and surgeries. It now houses new utilities to replace those that have reached the end of their service lives as well as to address overcrowding of pipe material within the existing tunnels.

In order to maintain all University activities in use during tunnel construction and protect existing infrastructure, the contract documents required the contractor to carry out drill and blast excavation in accordance with certain constraints related to peak particle velocities, blast air-overpressure, and audible blast noise measured at selected locations. The need to operate within these limits had a direct impact on blast design elements including overall powder factors, charge weights per delay, and round lengths. On the other hand, the contract documents allowed the opportunity to conduct test blasts, which permitted the relaxation of blast design criteria depending on the results of measurements.

The paper provides planning and design considerations that were used in evaluation of applicable construction methods, the process used to set baseline parameters and the monitoring program, and their implementation during construction. It also provides the experience gained during construction that is now being implemented on other projects of drill and blast in Montreal area.

PROJECT BACKGROUND

There are over three kilometers of utility tunnels that are used to distribute a variety of services between the buildings of the McGill University downtown Montreal campus. These tunnels provide link between the buildings but also provide utilities such as high-pressure steam, supply and return of chilled water, sprinkler and drain lines as well as natural gas and high voltage electrical conduits.

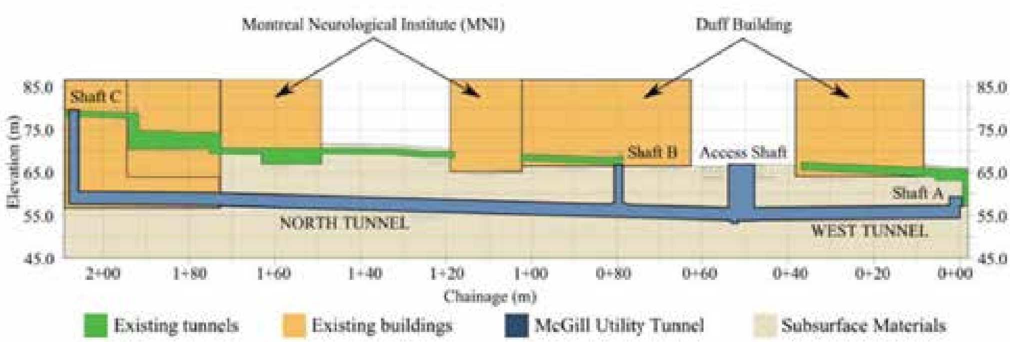
Over the years, these tunnels have deteriorated due to their age, and have become so congested with multitude of conduits and services, that new tunnels are now required, as well as optimization of services in existing tunnels. The recent construction of the North Wing of the Montreal Neurological Institute (MNI) Building has added additional demand for these services. McGill University is currently constructing a new utility tunnel associated with its hospital operations at its downtown campus. The new tunnel will route several 300 mm diameter steam lines and associated mechanical equipment between the Lyman Duff and MNI buildings. The tunnel will be approximately 210 meters in length and 3 meters in width, with one (1) access shaft and three (3) riser shafts. Drill and blast method was used to construct the new tunnel because it was judged the most applicable as explained below.

A number of the existing utility tunnels have indeed reached the end of their service lives due to constricted space and safety limitations. In addition, overcrowding of pipe material within the existing tunnels is necessitating the construction of a new utility tunnel to house new utilities to replace those currently in use, as well as to provide future expansion or the addition of services distribution. The addition of the new tunnel will therefore provide healthy and safe environments that will permit access to, and use of these tunnels for maintenance and repair by service staff.

The project location and project alignment are shown in Figure 1.

The tunnel's horse shoe shaped cross sectional dimensions, approximately 3 m wide by 3 m high, are based on mechanical and electrical space, clearance, and operational requirements (Figure 2).

FIGURE 1. Tunnel Profile with regard to existing infrastructures



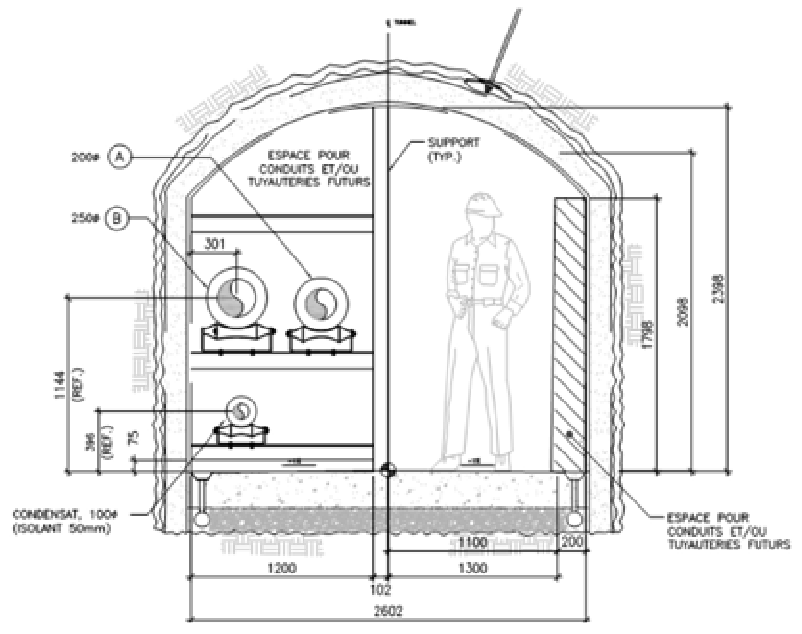


FIGURE 2. Tunnel Cross-Section with location of utilities and inspection space

Many types of advanced and sensitive equipment are in use in the Lyman Duff, Sheldon, Penfield, McConnel, New Pathology, MNI and Webster buildings on the Campus. Equipment includes a cyclotron used to produce isotopes for medical treatments, magnetic resonant imaging (MRI) units, cat scanning (CT) units, electron microscopes, centrifuges, cytometers, slide processing devices and other similarly sensitive equipment. It is also expected that various surgical procedures will be occurring in some areas of the buildings above the tunnels. Admitted patients may be resting in beds in some of the care facility areas, and laboratory animals are housed in the upper floors of the new pathology wing of the Lyman Duff building.

The Project's horizontal and vertical alignment was selected to meet a number of design and constructability requirements, namely:

- To provide adequate clearance below granular fill around existing building foundations and existing tunnels;
- To locate the new tunnel with a cover of at least 4 m of sound rock, thereby avoiding settlement impacts and minimizing vibrations caused by drill and blast excavation on overlying foundations and utilities;
- To provide adequate space for the construction of the connecting shafts;
- To provide a tunnel alignment that will provide a number of lateral connections from the facility to adjacent buildings to connect to existing tunnels;
- To slope the tunnel upward from the access shaft so that groundwater inflows and construction make-water drains away from the excavation face; and
- To maintain a minimum clear distance of 3 m from adjacent buildings.

In order to provide the connection to existing tunnels and stay within the horizontal alignment requirements, the alignment contains acute angles.

GEOLOGICAL SETTING

The geology of Montreal includes a variety of Pleistocene and Recent deposits that overlie early Paleozoic sedimentary rocks and Precambrian rocks, both of which are cut by Mesozoic intrusions. The principal events affecting the near surface rock assemblage were faulting, gentle folding, and minor metamorphism in the Mesozoic era and multiple glaciations and isostatic movements during the Pleistocene epoch (Grice 1972).

Bedrock geology in the region consists of Ordovician dolomite, limestone, and shales that are either exposed at the surface or underlie the Pleistocene and Recent deposits, except where they have been cut through by small bodies of Monteregian Mesozoic intrusives. The rocks have been faulted and gently folded and display a predominant structure that dips a few degrees to the east. Except at Mount Royal, which is an 83 m high remnant of an intrusive plug immediately to the west of the downtown area, the bedrock surface has been reduced to low relief.

There are five (5) major rock formations in the Montreal area: pure limestones or dolomites with negligible shale; shaley limestones; shales; mudstones; and massive intrusive rocks.

All these formations can be expected to be weathered and fractured and some are locally cut by dykes and sills. Altered zones do not ordinarily exceed a meter in width, adjacent to the principal faults but have been seen to be wider. For instance, the construction of Laurier Metro Station crossed the White Horse Rapids fault, which was 180 m wide (Durand 1978).

Solution cavities are rarely encountered in carbonate rocks; the principal lithological weakness is due to the softening of shale beds within limestone units and along joints and fractures zones in the shale and mudstone.

The McGill University downtown campus is located on the foothill of Mount Royal, which is one of the Monteregian intrusive hills that gently lifted sedimentary rocks. The intrusion activities were also associated with a process of faulting and folding.

The local geology is essentially composed of fine-grained limestone of the Trenton Formation, which is part of the carbonate sedimentary rocks that were deposited during the Ordovician age. On the foothill of Mount Royal these sediments, which were originally horizontally deposited, were gently lifted by approximately 10 to 15 degrees around the intrusion. The sub-horizontal bedding of the limestone at McGill University therefore dips downward toward downtown in a south to south-west orientation. Limestone beds are interbedded with slightly to moderately spaced thin layers of dark shale that are generally less than 50 mm thick. The limestone bed thickness is generally in range of 300 mm but can extend up to 1 m.

The limestone rocks in the area are cut by an orthogonal system of vertical joints and a sub-horizontal joint set that follows along the bedding planes. The orientation and spacing vary from place to place depending upon their proximity to major structural geological features such as faults, folds, and major intrusions.

There are igneous intrusions that are associated with many dikes and sills that were associated with the formation of Mount Royal. These intrusions have much higher strength than the surrounding sedimentary rocks and are irregularly scattered.

Three sets of major discontinuities are expected along the project alignment:

- The sub-horizontal bedding planes that are gently sloped toward downtown from the campus with an angle ranging between 10 to 15 degrees. These are described as tight, essentially unweathered with igneous intrusions (set 1).
- An inclined joint set dipping at 50-70 degrees which is described as fully healed with calcite infilling (set 2).

- A sub-vertical joint set that is locally known and was observed in the MNI expansion construction photos (set 3).

In addition to these three sets, there is a fourth joint set that is associated with the intrusive rocks. A combination of these discontinuities could create wedge failures if their spacings are less than the diameter of the tunnel. Though the rock core indicates that most of the joints are essentially healed, the construction photos from the MNI show the potential for the wedge failures to occur. The design has therefore taken into account the possibility of wedge failures that could occur by including provisions for these behaviors in the ground classifications as well as the initial support requirements.

Laboratory test results show that the limestone is very strong and very abrasive with a Cerchar Abrasivity Index ranging from 2.4 to 3.6 with an average of 2.7. In addition, UCS for intrusive rocks were expected to be greater than the limestone values, with strength values reported in the literature as high as 350 MPa, which may have adverse impact on drilling and excavation rates. The baseline included therefore frequency and length of intrusive rocks.

DESIGN CONSIDERATIONS

Selection of Construction Method

Alternative construction methods evaluated for the Project included a Tunnel Boring Machine (TBM), roadheaders, and drill and blast.

Despite its ability to avoid vibrations associated with drill and blast, the use of a TBM was considered impractical because of the relatively short length of tunnel and the requirement for tight corners in the alignment. Roadheader methods are generally applicable to softer rocks with compressive strengths and abrasivity characteristics that can be overcome with the cutter picks on the rotating cutterheads. The UCS and CAI values of the intact rocks that were expected to be encountered on this Project are at the top end of the technical range for large roadheaders and are beyond the range of roadheaders that could manoeuver within the 3 m tunnel (Jordan et al. 2011). Therefore, excavation using roadheaders was not considered feasible in these limestone and intrusive rocks.

For these reasons, design, and the Contract Documents were prepared for drill-and-blast method. The primary challenge for a drill and blast excavation underneath sensitive medical and research facilities and nearby existing structures is to control ground-borne vibrations, blast air-overpressures, and noise to within acceptable limits that minimize disruption to hospital operations, comfort of buildings occupants and damage to existing infrastructure.

Design of a base-case controlled blasting tunnel excavation

For the purpose of confirming feasibility, estimating impacts, and defining potential specifications for work, the design used a base-case tunnel blast design derived from direct experience at many urban tunnel projects throughout North America (Revey, 2010). The base-case assumed available best technologies, including the use of electronic detonators to assure that charges fire accurately with desired timing separation needed to prevent cumulative vibration increases.

Establishing Vibration Limits

Over the last 40 years, scaled distance relationships have been developed to estimate vibration intensities at various distances from a blast. The relationships are part theoretical, and part empirical. One important relationship involves the estimation of Peak Particle Velocity (PPV) as a function of the distance from a blast that the PPV is measured, and Maximum Charge-Weight-Per-Delay (W) used in the blast. Two important empirical factors, "K", a Rock Energy Transfer Constant, and "n", a constant that reflects the geometric attenuation of the blast energy with distance, complete the relationship. The relationship is shown in Equation 1 below.

$$PPV = K\left({}^{D}/_{\sqrt{W}}\right)^{n} \text{ or } PPV = K(D_s)^{n} \qquad \text{Equation (1)}$$

Where: PPV = Peak Particle Velocity (mm/s), D = Distance (m), W = Maximum Charge-weight-per-delay (kg), K = Rock Energy Transfer Constant (K-Factor), n = Decay Constant, and D_s = Scaled Distance (m-kg$^{-0.5}$)

The value of K in the above equation is critical, because it influences the linear relationship between PPV and the scaled distance. D_s. The higher the K value, the more efficiently vibrations are transmitted through the ground, and the higher the PPV will be a given distance from the blast. Rock formations have therefore higher K-factor values than soils. The Decay Constant is also a critical parameter in the above equation to estimate PPV.

For the ground conditions anticipated for this Project, no specific data was available from previous blasting work on the site that could be used to estimate K and n. Accordingly, a K-factor of 562.8 and a decay constant of -1.0 were recommended, primarily based on experience on past projects within similar geologic conditions. These values are on the prudent side (95% confidence of exceedance) due to the need to protect the sensitive structures, facilities, and operations.

For baseline purposes, a K-factor value of 562.8 was included in the Geotechnical Baseline Report (GBR), to be used to develop blast designs to keep PPV values to within specified limits. With known values of K and n, limiting scaled distance (Ds) limitations could be determined based on PPV limits for various structures and locations from scaled distance, $W = \left({}^{D}/_{D_s}\right)^2$.

While techniques such as decoupled and distributed charges can serve to reduce W, the contractor was advised that reducing blast round length will also be required. In addition, the contractor was given the opportunity to carry out test blasts used to confirm the actual K values along the Project alignment. Blast designs could therefore be adjusted if less conservative K-factors are evidenced. However, the Owner retained the right to resort to blast designs developed assuming the baselined K-factor if blasting exceeds PPV threshold limits.

Establishing noise and Air-Overpressure Limits

Blasts in the access shaft and tunnel create audible noise and air-overpressure that are heard or felt at different locations around the construction site.

The term "Blast noise" is a misleading because the largest component of blast-induced noise occurs at frequencies below the threshold-of-hearing for humans (16 to 20 Hz). Hence, the common industry term for blast-induced noise is "air-overpressure". As its name implies, air-overpressure is a measure of the transient pressure changes. These low-intensity pulsating pressure changes, above and below ambient atmospheric pressure, are manifested in the form of acoustical waves traveling through the air. The speed of sound varies in different materials, depending on the density of the medium. For instance, pressure waves travel at the speed of 1,500 m/s in water, whereas, in air they travel at only 335 m/s because air has a lower density.

When calculating maximum overpressure values, the absolute value of the greatest pressure change is used — regardless of whether it is a positive or negative change. The frequency of the overpressure (noise) is determined by measuring how many up-and-down pressure changes occur in one second of time. Blast noise occurs at a broad range of frequencies and the highest-energy blast noise usually occurs at frequencies below that of human hearing (<20 Hz).

When measurements include low frequency noise (2 Hz and higher) with a flat response they are called "linear scale" measurements. Air-overpressure measurements are typically expressed in decibels (dB) units and when the scale is linear, the unit designation is "dBL." Regular acoustical noise measurements taken for the purpose of monitoring compliance with local noise ordinances almost always use weighted scales that discriminate against low frequency noise. Thus, for a similar noise source, A-weighted and C-weighted scales typically used in noise ordinances usually record significantly lower levels of noise. Differences between decibel scale measurements for individual blasts will vary depending on their unique frequency-intensity spectrums. Since full-range recording of blast-induced noise can only be done with linear (2-Hz response) instruments, it is imperative that all compliance specifications for blast-induced noise be expressed in "Linear" scale decibels (dBL).

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The relationships between actual overpressure expressed in psi and decibel scale measurements are shown in the following equations. Due to the logarithmic ratios used to decibel values, seemingly small changes in decibel readings can equate to large changes in absolute overpressure (psi).

$$dB = 20\log_{10}\left(P/P_o\right) \text{ or } P = P_o 10^{(dB/20)} \qquad \text{Equation (2)}$$

Where: dB = decibels, P = overpressure (Pascals or psi), P_o = Threshold of Human Hearing (20 microPascals or 2.9 x 10^{-9} psi).

Conceptual blast layout. A conceptual arrangement of blast holes and delay timing for the tunnel was developed during the design and included in bid documents as a baseline case. This was in part to assure that a cautious but feasible blasting plan to allow prospective bidders to use for their bid.

The base-case used the following assumptions:

- All charges fire with more than 8 milliseconds of time separation.
- The powder factor for this design is 4.41 kg/m^3.
- Round length of 1.2 m

The intensity of blast-induced vibration is influenced by the size of the charge and the distance between charges and points of concern. Since the location of the shaft, tunnel and tie-in excavations cannot be changed; the only way to manage vibration levels is to reduce the size of charges fired per delay interval.

For the base-case, the size of charges was reduced to the absolute practical minimum by limiting the length of drilled rounds to 1.25 m. The heaviest charges in primary blastholes would weigh 0.56 kg. It should be noted that anything less would not be practical.

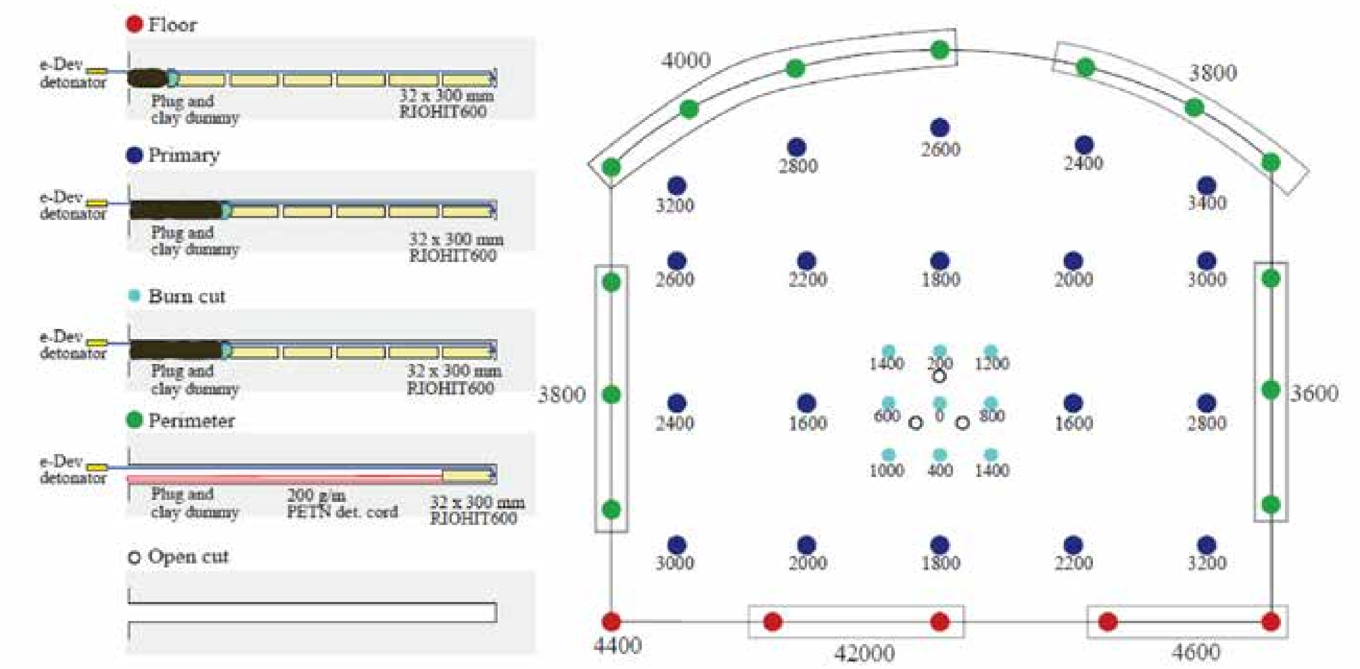
The weight of charges in buffer and smooth wall perimeter holes located in the top areas of the tunnel blasts are reduced to 0.38 and 0.32 kg, respectively. The use of very light and decoupled charges in the perimeter will improve smooth wall results and reduce vibration.

Instrumentation and Monitoring Program

The following requirements were included in contracts documents:

- A pre-construction condition surveys for all property located within 50 meters of the excavations. All such property is owned by the University.
- The installation of six seismographs and three Sound Pressure Level (SPL) devices for noise measurements. The readings, interpretations of the readings, and distribution of the results was carried out by the Engineer. The Contractor was required to coordinate all blast times with the Owner so that the blasts can be monitored. Because it will not be possible to monitor vibrations at all points of concern for each blast, a site specific blast curve was developed based on the blasting results. The curve was used to extrapolate levels of vibration or overpressure at other locations.
- The establishment of ambient noise and vibration baselines at selected

FIGURE 3. Blast layout and parameters used in base-case



locations in the facilities prior to any construction activities.
- The requirement to conduct all work minimizing damage to existing structures from ground vibrations caused by blasting and other operations.
- The requirement to monitor and record vibrations, air-overpressures for each blast detonation and other operations and to adjust blasting procedures and construction operations accordingly to ensure allowable levels are not exceeded.
- The requirement to monitor each activity expected to cause excessive noise or vibration in excess of the limits and adjust construction procedures accordingly to ensure allowable levels are not exceeded.

The following limits were specified based on industry standards and past experience. These limits were established on two main criteria: a structural criterion to avoid damage to existing facilities and a psychological criteria to minimize discomfort of buildings occupants and comply with local regulations.

TABLE 1. Specified vibration, air-overpressure and noise limits

Parameter	Review level	Alert Level
PPV for rooms with overnight hospital patients (mm/s)	10	15
PPV for typical building structures with plaster or gypsum-rock walls (mm/s)	30	50
PPV for heavy civil structures like concrete floors and walls, and heavy machinery and pipes (mm/s)	70	130
Air-overpressure (Pa)	100	120
Noise (dBA)	120	130

Risk Management and Mitigation measures

A risk register was established during the design and mitigation measures were identified to reduce the impact associated with drill and blast operations on McGill facilities and staff. A few of risk control measures that were applied include:
- Conduct an outreach program to the building occupants
- Establish predetermined blast schedules to be followed by the contractor. Two blasting time periods were initially identified and a third was added during construction. If the contractor is not ready to blast at the specified time they must wait until the next scheduled time to blast. Staff/patients will be made aware of the scheduled blast times and windows prior to construction activities.
- Maintain regular communication with the building management to ensure sensitive hospital operations are scheduled around predetermined blast schedules. The contract documents included no blast days in case some medical procedures cannot be stopped.
- A "locked down" approach was adopted for equipment that is less sensitive to vibration while not in operation such as cyclotron.
- Relocation of some activities such animals lab where vibration may interfere with research results
- Since most of the potentially affected structures are McGill properties, aggressive PPV limits were implemented that may results in cosmetic cracks as part of risk sharing strategy to allow a cautious but feasible blasting plan

In order to limits noise and air-overpressure, the following requirements were included in contract documents:
- Use of the best-available technologies, including the use of accurate electronic detonators,
- Implement smooth-wall blasting methods and use light/decoupled charges,
- Install adequate burn-holes to accommodate initial relief for rock breakage,
- Use inert stemming material in the collars of blastholes as a primary means to reduce blast noise,
- Use blast shaft covers and mats as a secondary means of containment,
- Construct a temporary noise-reduction enclosure around the shaft collar worksite,
- Ensure the contractor develops detailed plans complying with specified performance requirements.

Initial and final support systems

The excavation of the shafts and tunnel was divided into three ground classifications as follow:
- Class I: Fresh limestone with excellent quality of RQD and healed joints
- Class II: Fractured limestone with fair to good RQD and slightly weathered joints
- Class III: First 6 meters of the intersection between shafts and tunnel that is subjected to stress concentration. This class includes the potential for wedge failures as described above.

Three types of initial support were designed to match these ground classifications and included in baselines:
- Type I for Class I: A layer of fiber reinforced shotcrete.
- Type II for Class II: Spot rock bolts and a layer of fiber reinforced shotcrete
- Type III for Class III: Pattern rock bolts and a layer of fiber reinforced shotcrete

Because this is a service tunnel, little consideration was given to the aesthetics of the lining system final finish. Shotcrete was therefore specified for final lining as opposed to cast-in-place reinforced concrete to benefit from reduced schedule and cost, and take advantage of the flexibility of installing the material without formwork. Surface smoothness requirements was specified to allow for fixation of utility supports and accessories.

CONSTRUCTION CONSIDERATIONS

Blasting operations and monitoring results

The contractor blasting consultant elected to follow the blast design used in the base-case with minor changes. A compilation of instrumentation results shows a K-factor of approximately 448 and a decay constant of -0.855, which close to the values of 562 and -1 that were used in baseline, respectively. One blast round was used for the Access Shaft with a one shift operation while most of the tunnel was excavated using a two-shift operation on two blasting rounds for the tunnel. The contractor used specified blasting zones at 7 am and 7 pm to complete the cycle for a drill and blast operation with each shift completing the full cycle. The specified round lengths of 1.2 m were generally respected and the contractor was able to conduct two blasts at once in both directions after reaching a certain distance from the Access Shaft. For zones that were not close to sensitive areas, a third blast zone was added by the Owner to provide some flexibility and was used mostly as a contingency in case there was a missed blast period for various reasons.

Measurements of the vibration that were taken at ground floor level were compared to those taken in the buildings mostly at the 7th floor where sensitive equipment and operating rooms were located. As shown on Figure 4, mostly high frequencies were measured at the rock level while in the building a mix of small frequencies and high was observed. This is important for the PPV limits in the buildings that are occupied as it is a function of frequency especially for psychological criteria as shown in Table 1.

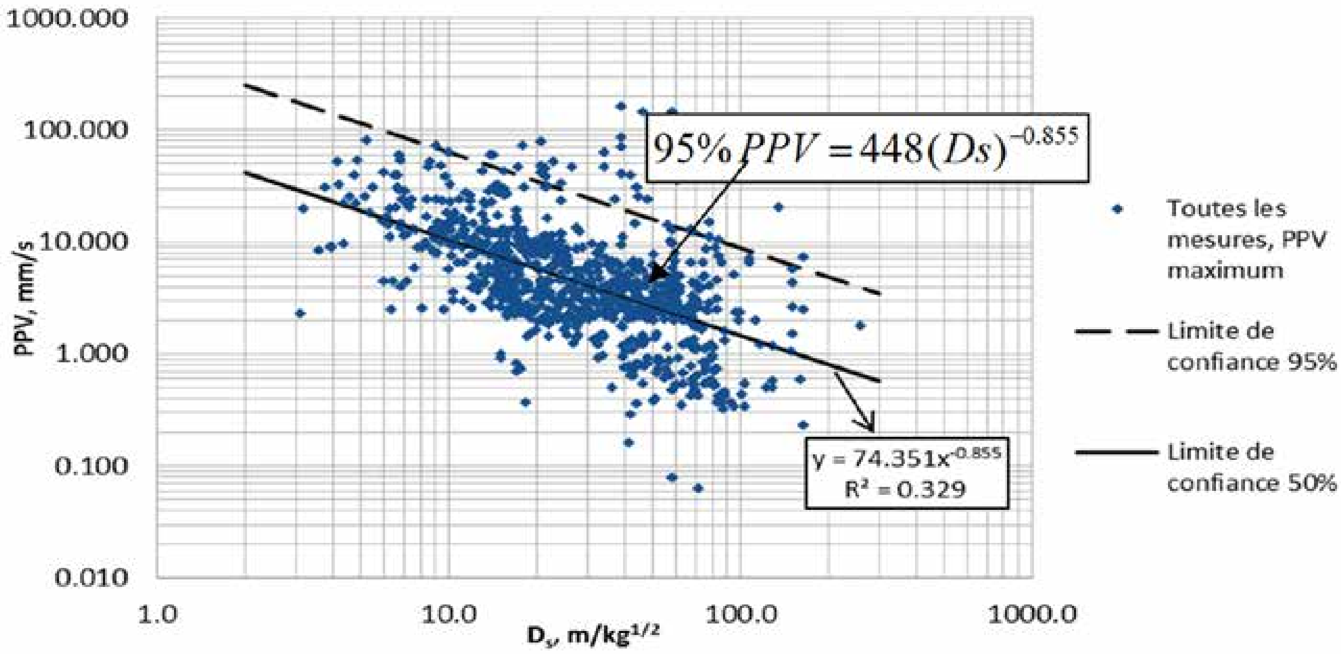


FIGURE 4. Vibration attenuation curves from monitoring data

Managing noise and air- overpressure was more challenging, particularly for initial blasts in the shafts and when the tunnel was started. Measurements of air-overpressure did also increase as the tunnel got longer. In some of the first shaft blasts, confining ground at the collars of some charges was prematurely ruptured and confining stemming was compromised. This resulted in air-overpressure that exceeding specified levels. The Contractor modified charge delay timing and hole-geometry to relieve this problem. Additional measures were used as well such as the installation of water jet curtain at the entrance of the tunnel. As shown in Figure 6, shaft covers and heavy blast mats were also used to provide additional confinement for noise reduction and flyrock containment.

Encountered ground conditions

The ground conditions turned out to be of slightly better quality than predicted with more than half of the total length being in category I as illustrated in Table 2. The contractor elected to use mesh with rock bolts to speed up the construction sequence and then apply the first layer of shotcrete at once.

TABLE 2. Comparison of baseline and encountered ground conditions

Ground Classification	Baseline	Encountered
Category I	50	61
Category II	20	17
Category III	30	22

Waterproofing membrane

The contract documents called for a final tunnel lining system that will incorporate three layers:

- A geotextile drainage layer (drainage fleece) with pore spaces to collect groundwater penetrating the outer initial shotcrete lining
- A PVC waterproofing membrane to seal water out of the tunnel space, and
- A second layer to provide a durable protective surface finish for the waterproofing membrane and serve as a robust substrate to fasten utility supports and accessories.

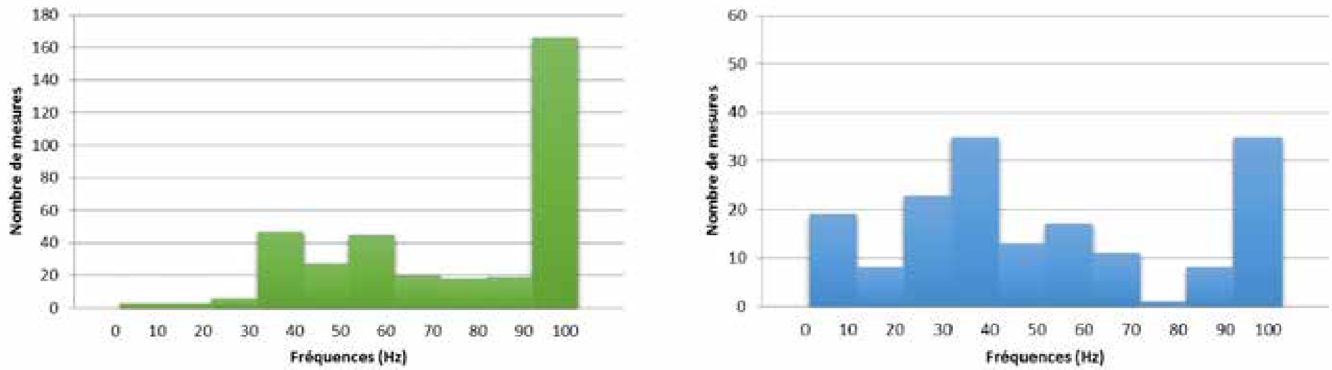


FIGURE 5. Comparison of recorded frequencies at the ground level (left) and in the buildings (right)

FIGURE 6. **Shaft cover used to limit fly rocks and blast mats used to reduce air-overpressure**

The goal of the drainage fleece and PVC membrane was to provide a drainage layer around the walls and crown of the tunnel to relieve hydrostatic pressure and direct water flows to the gravel base layer beneath the tunnel floor slab. Drainage piping installed within this gravel base layer to divert water to the sump in the access shaft; from which water will be pumped to the site drainage system.

The contractor submitted a change to use a sprayed on waterproofing membrane. Given the tunnel was mostly dry the change was accepted and a quality control program using the ITAtech Guidance for Design of Sprayed Membrane was implemented. Emphasize was put on the use of experienced specialty-contractor utilizing an experienced nozzleman. The sprayed on membrane was applied in two layers of different colors for a total of 3 mm thickness with the second layer being applied only after the Engineer approves the first layer. Final lining layer of shotcrete was then applied to the sprayed on membrane.

USE OF EXPERIENCE GAINED ON OTHER PROJECTS IN MONTREAL AREA

The experience gained on this project was used to other drill and blast projects in Montreal area, which include:

- A utility tunnel that passes underneath a major freeway with service roads on both side the freeway. The tunnel is located on a refinery site that has facilities on both side of the freeway. The tunnel will connect both facilities and will carry pipe with different oil products.
- A utility tunnel that will collect and store runoff water during a major storm event to avoid wastewater overflow into the river. The tunnel is connected to a storage facility as well as an interceptor that will convey the wastewater to a treatment plant that is located to the eastern side of the Montreal Island. The project passes underneath a residential area that will have similar restrictions as what was observed on the McGill Tunnel
- A raw water intake tunnel that will convey water from a channel to an existing clean water supply treatment plant. The project passes underneath several utilities, a residential area and a facility that houses sensitive equipment.
- An underground storage and maintenance yard for train that will connect the yard to an existing metro station. The alignment passes underneath a residential area as well as near buildings that have sensitive equipment.

CONCLUSION

The construction of McGill North East Utility Tunnel using drill and blast excavation required careful planning and execution to minimize disruption to the University operations that house sensitive medical and research equipment as well as patients. The design approach used to include a cautious but feasible controlled blasting base-case drawn from extensive experience to address the need to limit vibration, air-overpressure and noise was implemented and is proven to be effective. It first allowed realistic baseline that were used during the bidding process and it also provides the contractor with flexibility to adjust its means and methods while staying within specified monitoring limits. An effective risk assessment and risk management process allowed identifying key risks and implementing risk control measures were implemented during construction activities.

RECOMMENDATIONS

The following is recommended for a drill and blast project in urban environment:

- Use a Geotechnical Baseline Report approach.
- Use of additional long rock bolts for potential high angle wedge to be decided on field.
- Use prescriptive approach for the blasting design during the bid process that will allow prospective bidders to play on the same level field while allowing some flexibility for later on during construction to adjust some parameters
- Use a risk based approach to select vibration and air-overpressure limits to protect existing infrastructure and minimize disruption to existing facilities and their occupants
- Use of sprayed on waterproofing membrane and shotcrete as final lining should be considered for utility tunnel that do not need aesthetic considerations for cost effectiveness

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