Lessons Learned from Recent EPB Tunnel Projects in Toronto

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1. Introduction

This paper outlines a select set of lessons learned from recent EPB tunnel projects in the Toronto area. We learned that more emphasis should be given during design, planning, tendering and the construction stages in the following areas: Safety and Security training; Environmental Management Plan Awareness Training; Project Planning and Monitoring Implementation and Execution Plans; Construction Monitoring and Identification of sources of delays.

2. Safety and Security

Occupation Health and Safety (OH&S) is an important component of every construction project, in particular with EPB tunnel projects there are a number of ancillary works associated with the construction activities. EPB technology advancements have made tunnelling in difficult ground possible and as such have increased the exposure to ground conditions previously considered to be too difficult to work within. Ground conditions are seldom uniform, and although a thorough Site Investigation program reduces uncertainty, it does not eliminate it.

Many of safety issues are related directly to the contractors means and methods. As such, it is appropriate that the Owner, designer and construction manager let the contractor deal with the safety issues and provide a safety management plan for the project.

Safety is not just another program. There needs to be a commitment to conducting operations in a way that protects people, property, communities and the environment. The safety of site staff, clients and subcontractors should be a Project Core Value, beginning with top management and extending to every employee. Every accident or injury is avoidable. That being said the industry needs to establish a “zero tolerance” policy with respect to the tunnel workplace safety and health incidents. Owners can only take immediate action to stop unsafe work procedures if immediate peril to life is at risk. That being said, the contractor has the primary responsibility for safety within the construction zone.

Security can be a major issue on a tunnel project. There will be hundreds of workers needing access to the construction site. The owner needs to develop a security plan identifying security and site access procedures. Approval on matters such as site clearance for contractors, obtaining badges or identification cards and if necessary, delineating free access and restricted boundaries, establishing construction traffic ingress and egress routes, equipment delivery, storage and staging areas.

Outputs to safety and security that may have an impact EPB tunnel projects:

- Risk to Owner – Delays, Costs, Losses
• Risk to Contractor – Accidents, Delays, Profit loss, Bonding Capability, Reputation
• Risk to Third Parties – damage to dwellings, structures, infrastructure
• Risk to Environment – damage to land, contamination of water, damage to Environmental sensitive areas

3. Environmental Management Plan

Environmental Protection = Adaptive Management * (Collaboration & Communication)$^2$

The Environmental Management Plan (EMP) is an important document that identifies environmental receptors vulnerable to construction works. It also identifies contingencies as well as means and methods to address contingency actions as appropriate. Through assessment and planning, the EMP is a document that supports the construction schedule and the operation of the contractor by identifying and requiring responsible management of the construction site and construction operations. EPB tunnel projects in the Toronto area that involve significant dewatering have begun developing EMP’s as means to guide construction activities in order to manage and protect local area ecological features. Specifically, York Region’s YDSS Interceptor Sewer tunnelling project in 2006 through 2008 and the recently tendered Southeast Collector Project and the Toronto-York Spadina Subway Extension are three examples of EPB tunnel projects that have developed, or are developing EMPS. Through developing and implementing the EMP, the operation of these projects has and will be the product of extensive consultation with the jurisdictional conservation authority, Toronto and Region Conservation Authority (TRCA).

An integral part of the EMP is Adaptive Management, three key features of which include: Iterative decision – making; Feedback between monitoring & decisions; Embracing risk & uncertainty. Applying Adaptive Management requires testing of assumptions, adaption and finally learning by doing.

Collaborative Adaptive Management entails that decisions need to be structured, informed & facilitated. Principles & practice of collaborative adaptive management highlights excellence & innovation, promotes best practices, appropriate programs and develops capable, collaborative & communicative leadership. Strategizing Your Management styles entails Communication, both verbal and written, Your interaction from observation and Adapting to different individuals and groups. Public communication and learning calls for public meetings to educate the public on the technology of EPB tunnelling, proactive response to issues such as settlement and media attention on other projects where EPB technology and tunnelling in general has impacted the public, public awareness and positive talk about the technology and the less attractive alternatives.

Lessons Learned with EPB and sealed shaft technologies in the Toronto area show that these technologies do not impact on water wells and water supply, they avoid the need to lower the groundwater to facilitate construction of infrastructure, they avoid water ingress into shafts and tunnels for the contractor and they reduce surface settlements.

As part of the learning experience, weekly toolbox meetings should continue to be used to bring awareness to workers and educate them on the EMP and its connection to the Permit To Take Water process, EMP assignments during the shift, EMPACT (Environmental Management Plan Awareness and Compliance Training) Program delivered directly to crews and all levels of Management and Agencies. By using the weekly Toolbox time, this builds success from the bottom up with co-operation, definition of roles and responsibilities, open communication and transparency between the Owner, Consultant and Contractor. A brief Lessons Learned from the following projects is summarized below:

YDSS Interceptor Sewer EPB Tunnel Project, York Region
The 19th Avenue YDSS Interceptor Sewer EPB Tunnel project developed the EMP to minimize the impact on domestic wells and the natural environment caused by construction activities. Adaptive management developed for this project anticipated construction impacts, established a monitoring program to quickly detect the impacts and coordinated a predetermined response plan which set out a protocol and schedule for a phased response to ensure action to prevent or minimize negative impacts on domestic wells and the natural environment. These procedures achieved the aim of initiating the response plan after “early warning” parameters were observed during the monitoring of domestic wells and the natural environment, preventing irreversible impacts. The EMP successfully minimized work stoppages that negatively impact the progress of construction while simultaneously avoiding negative impacts on the natural environmental features and domestic wells protected by the plan.

Southeast Collector Tunnel Project, York and Durham Regions
The EMP for the Southeast Collector EPB Tunnel project in York and Durham Regions is still in development; however, a document is being designed for specific monitoring, mitigation and adaptive management for the various natural environmental conditions based on the lessons learned from the YDSS Interceptor Sewer Tunnel Project. Given the diversity and sensitivity of the project area, a specific well-developed plan for implementation during construction will create an immediate line of defence and protection against anticipated construction potential impacts. An important element of the plan is the description and presentation of baseline data for the ecological receptors to be monitored. These elements are organized by watershed to ensure that like features are grouped together allowing the efficient development of monitoring, mitigation and adaptive management, as features within similar environments will require similar monitoring and mitigation methods, eliminating duplication throughout the plan. By grouping protected ecological features, the contingency and adaptive management plans being developed will be most effective during implementation.

To ensure efficient and immediate management of natural ecological features within the area of influence of the construction works, a clear understanding of accountability and responsibility is beneficial for all staff on site to ensure that actions are taken in a timely manner which will ensure that the greatest degree of protection is provided. By training and creating an environment of awareness for the EMP and its purpose, the staff on-site will be able to implement the means and methods of the Plan efficiently and responsibly.

Toronto – York Spadina Subway Extension
The Toronto-York Spadina Extension (TYSSE) is an EPB tunnel project that will be required to produce an EMP to comply with the project’s governing environmental legislation. The EMPs for this project are being developed to manage all project construction activities. Through consultation with TRCA, construction management and mitigation is being developed to ensure the protection and mitigation of adverse impacts on the ecological receptors throughout the project area resulting from construction activities.

TYSSE has developed its EMP throughout the design process. By evolving the EMP over the duration of design, the organization and contents of the document will be the result of months of coordination and consultation. During its development, discipline input has been included within the contents and format of the EMP, including environmental and geotechnical considerations that complete the understanding of the existing conditions of the project area while also creating an understanding of the conditions that will be encountered during construction and the measures that should be taken to protect the ecological features. The EMP for this project is being completed in an evolutionary manner allowing expert evaluation and consultation to confirm and advance the planned procedures and methodology for this project. Planning for contingency events, in effect the most likely risk register events are anticipated and the resolution is pre-planned for immediate implementation, decreasing the response time for contractors and environmental agencies. Additionally, by pre-planning the events and scheduled interventions, the response will be a better developed and environmentally sustainable solution.
Lessons Learned on a select number of EPB projects demanded that cost management and accountability are important, but especially during the development of an EMP. While development of the plan during design is the preferred methodology, developing the contents of the plan too prematurely can lead to the redundant completion of sections that must be adjusted later in the design process to respond to design changes. A way to avoid inefficient development of the EMP is to identify the sensitive receptors and the zone of influence for the construction works. After these have been developed, the organization of the document and the required elements can be finalized, as well the identification of responsible parties for these sections and elements can also be completed. The format of monitoring and reporting can also be developed in advance so that later in the design process the procedures and elements can be input into the predetermined framework. It is preferable however, that the contents and the detailed plans to be included within the EMP are not developed until after 60% design, when the EMP means and methods can be fully developed reflective of the final design.

While completion of the plan details cannot be completed until later in the design process, besides the organization of the document itself, consultation with conservation authorities and stakeholders involved in the EMP can also be initiated during design. Consultation during this period can allow thoughtful discussions and developments of the management activities that will meet the requirements of the stakeholders and authorities whose approval is required to complete the plan. Completing the consultation at this point will also expedite the development of the plan when it is initiated after 60% as a result of the pre-planned organization and format of the document and its elements.

4. The Importance Early Constructability Review and Risk Management

Risk management is a broad term which includes risk identification, risk assessment, risk analysis, risk elimination and risk mitigation and control. It is well known that tunnelling is not a risk free technology. Tunnels in the general construction industry are regarded as “heavy risks” and each tunnel is a specific and unique project. The construction of tunnels can be affected by potential risks to the different active parties including owner, Engineer, Contractor and Supplier as well as the public. Additionally, environmental and political issues must also be included in the project’s risk management activities. Risk can be defined as:

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\text{Probability} \times \text{Impact} = \text{Likelihood} \times \text{Consequences} = \text{Probability of Occurrence} \times \text{Cost of Event}
\]

Types of EPB Tunnel risks include:

- Contract Procurement stage
  a) TBM and pre-liner segment procurement risk by owner
- Tendering Stage
  a) Delay in tendering
  b) Shortage of qualified contractors
- Environmental stage risk
  a) Regulatory/Approval or Permit risk
  b) Utility removal/Crossing risk
- Construction stage risk
  a) Geotechnical risk (Geotechnical data is inconsistent with field data)
     a) Risk of EPB pressure loss and tunnel collapse or settlement
     b) Risk of public protest caused by the problems of tunneling projects
     c) Utility crossing risk

Lessons Learned from the YDSS Interceptor tunnel project were used to aid in the Southeast Collector Tunnel risk management process.

5. Adherence to Cost Control
The YDSS Interceptor Sewer Tunnel Project accumulated a total of approximately $1M in change orders. This value is 1.32% of the total contract value. The cost distribution for this $1M in change orders was as follows:

- Environmental Issues: 9.2%
- Engineering Changes: 74.85%
- Tunnelling: 0%
- Safety and Security: 8.68%
- Traffic Management: 7.27%

Although it is difficult to avoid change orders during big projects, it was noted that number of change orders and associated costs could be minimized by 50%, if proper action had been taken during the initial stages of the project. The engineering changes (75%) could be minimized if all stakeholders (specifically the owner’s operation team) had confirmed their requirements during the design stage.

6. Improving Tunnel Progress Tracking

During construction of the YDSS Interceptor Sewer Tunnel project, tunnelling progress tracking and monitoring of the EPB tunnel machine data was completely controlled by the contractor. The contract mandated a real-time progress monitoring screen be installed in the owner’s field office, unfortunately, no guideline was specified in the Contract Documents for the Owner data collection and the associated data handling process. The Contract did not include contingencies regarding the possibility of lost and/or damage of data stored on the contractor’s TBM server.

To improve the Tunnel Progress Tracking process and to establish improved management of tunnelling data, it is recommended that future contract documents mandate the use and operation of Tunneling Process Control software. This type of software has the advantages of establishing user friendly data readouts and diagrams, integration to all data sources, real time graphic display of EPB operations, TBM location and ring install, provides a display activation by the user, allows flexible system operation continuously, in real time or on a daily/weekly/monthly reporting format and will allow for remote access and display.

The cost for such software is much more user friendly, reliable and accurate in comparison to the in-house Access database that was used for the YDSS Interceptor Sewer Tunnel project. It is strongly recommended that consultants use commercially available software packages.

7. Settlement Design and Monitoring: Closing the Gap

During construction of the YDSS Interceptor Sewer Tunnel project, Surface Monitoring Points (SMPs) and Surface Monitoring Arrays (SMAs) were used to monitor surface settlement. The monitoring points and arrays were specified at a maximum distance of 100m with a minimum distance of 15m and an average distance of 50m. The SMP and SMA allocation shows that the purpose of these monitoring points is to get successive settlement values. It was not designed to analyze preceding settlement data and deformation of the ground at the front of the TBM face.

This type of settlement monitoring is not entirely suitable in urban areas, especially when EPB TBMs are passing through any settlement sensitive zones, for example railway crossings. We strongly recommend that settlement monitoring be designed to obtain information for all settlement associated with tunnelling, including:

- Preceding Settlement
- Deformation of ground at the front of the TBM face
- Settlement during passage of TBM shield
- Settlement due to tail voids
- Succeeding settlement
8. Tunnel Alignment Improvements and Specifications

Surely, tunnel alignment is the most important factor which impacts construction due to the difficulty associated with mining along a curve versus mining in a straight line. To avoid problems with design and construction of sharp curves allowable tolerance and the following information should be investigated early in the project and not left to figure out during the tender stage:

- Tolerance of articulation sensors
- Suitable Operator training and experience
- Tolerance of the EPB TBM guidance system
- Tolerance of TBM and segment installation (vertical and horizontal)
- Cutter wear and platting
- Geology (including abrasiveness of boulders and soils)
- Establishing proper thrust pattern for the operator

9. Role of Monitoring the TBM

Monitoring, recording and storing TBM data is an important project element. Normally the TBM data is transferred from the TBM to the surface computer via a cable. Frequently the cable can be broken due to worker error and in most cases the missing data can be recovered from TBM computer.

The ultimate goal is to: Store the TBM data in a safe place, receive and record the TBM data in real time, have the ability to conduct on-line analysis and interpretation of the data in real time and have the ability to archive the data safely.

EPB manufacturers provide software built into the TBM guidance system with licensed software that is only active during the duration of the TBM mining cycle. The data recorded from sensors is generated in ASCII file format within the TBM's HDD. Some of the operational data collected includes functions of: Articulation, Propulsion, Power, Hydraulics, Grouting, Gas monitoring, Consumable Oils, Cutterhead wear, Soil conditioning, Belt conveyor, Guidance system.

The data is stored on the HDD as well as on CD and is later analyzed by tunneling experts every day. Figure 1. below shows a sample display of an EPB pressure chart. That being said, guidance system data needs separate software, therefore, the contractor needs to coordinate with the guidance system manufacturer to deal with issues during construction.

![Figure 1: Snap shot of EPB Pressure monitoring](image-url)
10. Ground Treatment

Soil treatment includes a number of means and methods, some of which include: Permeation grouting, Compaction grouting, Hydro fracture grouting, Jet grouting, Compensation grouting, Deep soil mixing.

Jet grouting was used successfully during construction of the YSDD Interceptor Sewer Tunnel project. The design of the jet grouting system was based on geotechnical parameters investigated by the contractor along the tunnel’s alignment and also based on local experience. The GBR did not include specific parameters for jet grouting. That being said, there is a need to consider jet grouting parameters for inclusion in GBRs.

Jet grouting is widely used in EPB tunneling projects throughout Canada and the USA to stabilize existing soil conditions at shaft break-in and break-out zones, in areas to protect surrounding utilities prior to the TBM approach.

11. Soil Conditioning Problems:

The transition from till into a full face of sand demanded a change in the type of soil conditioning used. The detergent based foam used in the till was switched to a polymer-based agent that made the excavated material thicker and thus easier to handle. This transition took some time to achieve with numerous attempts to use foam continuing within the sand deposits. This resulted in more difficulties in the control of earth pressures and inappropriately conditioned muck discharged from the screw conveyor. Figure 2 below shows the effect of inadequate use of soil conditioner, while Figure 3 shows the effect of adequate soil conditioner.

![](image1.png)

**Figure 2:** Using inadequate rate of soil conditioner

**Figure 3:** Using adequate rate of soil conditioner

12. Summary Remarks on Sources of Delays

EPB tunnel projects are complex construction works that require planning and broad consideration during design to ensure that construction proceeds as scheduled. In an effort to better predict a realistic schedule for construction, the sources of delays should be considered during design, planning, tendering and confirmed prior to construction to prevent their negative impact on the Project’s schedule. An example of some sources of delay include: permits and
approvals, equipment and material procurement as well as stakeholder changes and community impacts.

Some areas of delay can be easily planned and avoided with careful preparation and adherence to application requirements. For example, environmental permits and approvals, as required for construction works, should be planned and applied for well in advance of tendering and construction. Our experience is that this approval process can take anywhere from 6-12 months for review and approvals. These approvals require the appropriate documentation and supporting materials to meet the criteria of the application, should the application be incomplete at submission further delays can result. Ensuring the applications are complete and documents are approved on time is an important element in managing possible delays. In the Toronto area, the Toronto and Region Conservation Authority (TRCA) and the Ministry of the Environment (MOE) approvals are important applications that should be submitted with complete applications and required supporting documents with enough time for the Authorities to review, comment and finally to provide approval. Environmental organizations, while seeming to introduce additional hurdles during the design and planning process in reality refine the process of construction by ensuring that appropriate means and methods of construction are completed in environmental safe and sustainable ways not only for the natural environment but for the resident population of the project area.

Another source of delays that can be mitigated and avoided with careful and through investigations early in the planning and design phase is utility sign-off and permission. Tunnelling activities that cross utilities, both above and below ground, require careful adherence to the utilities specifications for crossing. In order to receive permission, the tunnel’s alignment must be designed to the crossing specifications of the utility as well construction methods for tunnelling works and construction related to tunnelling in the immediate area of utilities also often require approval.

Sources of delays that are less easily prevented through planning are community and stakeholder impacts and responses. A controversial project can be hung during design and community input if not responsive and mindful of the concerns of the local community and the key stakeholders who will be impacted by the project’s works, during both construction and operation. To avoid these impasses and delays, the design team must have a communication and planning team that liaises openly and regularly with community stakeholders; ensures concerns are addressed and considered early in the design process. The establishment of a trusting relationship between the Project’s owner, designers and constructors is important to prevent significant delays, either in the form of community protest or legal action.

Numerous tunnel construction case histories confirm that boulders have been a major contributor to conflicts, delays and cost overruns during EPB tunnel projects. Assessment of the source of delays during construction of the YDSS Interceptor Sewer Tunnel project indicated that roughly 5% of the experienced delays involved boulders and ground conditions.