Managing subsurface risk for Toronto-York Spadina Subway extension project

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2011 Pan-Am CGS
Geotechnical Conference

ABSTRACT
The project management team studied design and construction strategy to manage subsurface risks on the Toronto-York Spadina Subway Extension (TYSSE) project. The adopted strategy is similar to the Subsurface Risk Management Strategy implemented for the Sheppard Subway Project in the 1990s. Measures include a “risk sharing” approach to construction contracts, a commitment to comprehensive pre-construction site investigation, appointment of a Principal Geo-Engineering Consultant, preparation of Geotechnical Baseline Reports and the appointment of a Disputes Resolution Board for each major civil works contract. The level of site investigation effort for the major tunnelling and stations contracts is related to construction risks, such as change orders, to assess the optimum level of investigative effort.

RÉSUMÉ
L'équipe de gestion de projet a étudié une stratégie de conception et de construction pour gérer les risques souterrains dans le cadre du projet de métro « Toronto-York Spadina Subway Extension » (TYSSE). La stratégie adoptée est similaire à la stratégie de gestion de risques souterrains mise en œuvre dans le cadre du projet « Sheppard Subway Project » dans les années 1990. Les mesures comprennent une approche de répartition du risque envers les contrats de construction, un engagement à des études de site exhaustives avant le début de la construction, la nomination d’un consultant principal en géo-ingénierie, la préparation de rapports géotechniques de référence et la nomination d'un « Disputes Resolution Board » pour chaque contrat majeur de travaux de génie civil. Le degré d'effort à investir dans les études de site pour les contrats majeurs de creusement de tunnels et de stations est lié aux risques de construction, tels que les ordres de modification, afin d'évaluer le degré d’étude optimal.

1 INTRODUCTION

"A tunnel is a hole in the ground with an engineer on one end, a lawyer at the other and a contractor stuck in the middle." Such is the gallows humour of the underground construction industry and a reflection of the reality that subsurface construction is inherently risky and characterized by projects that often involve lengthy disputes, eventually resolved by litigation. This paper describes the management strategy adopted for the Toronto-York Spadina Subway Extension (TYSSE) Project to minimize and manage subsurface risk.

The Toronto Transit Commission’s (TTC’s) underground transit projects started in the 1940s. Extensions to the TTC system continued through the 1990s. In the 1990s, TTC developed a Subsurface Risk Management Strategy (SRMS) for the Sheppard Subway Line which opened in 2002. The strategy similar to the SRMS is now being implemented for the TYSSE project. The location of TYSSE project and existing TTC subway system is shown in Figure 1.

The TYSSE is to extend from the present Downsview Station terminus in the City of Toronto to Vaughan Corporate Centre Station in the City of Vaughan. TYSSE’s 8.6 km route includes 6.2 km of earth pressure balance (EPB) bored twin tunnels, a 220 m sequential excavation triple tunnel section, and six (6) new stations which are to be constructed using cut and cover methods.

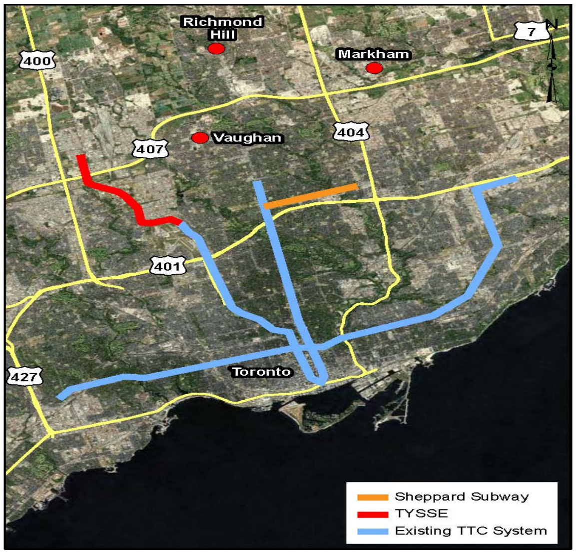

Figure 1. Location of TYSSE project and existing TTC subway system

The TYSSE project alignment is shown in Figure 2. Construction is to take place within glacially derived soils that are typical of Southern Ontario and much of Northern

United States of America. The extent of underground construction required that management of subsurface risk be considered at the onset of the project and measures to control the risks be integrated into the management and planning of the project.

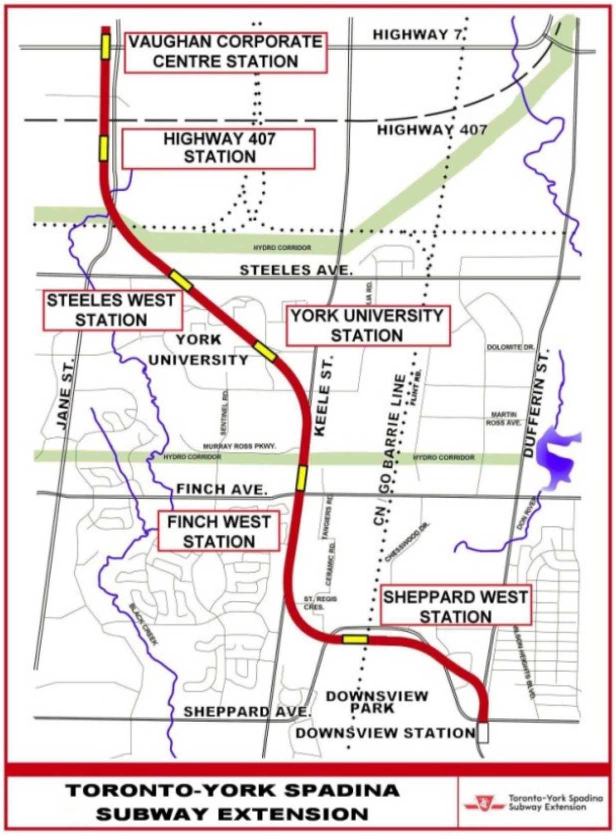

Figure 2. Map of the Toronto-York Spadina Subway Extension route

2 SUBSURFACE RISK

Subsurface risk arises from the variability of ground and groundwater conditions and the limits to which such conditions can be practically explored prior to construction. The variables include:

- Thickness and extent of soil deposits;
- Soil strength;
- Compressibility; and
- permeability.

The variation in soil properties is large compared to other engineering materials; for example permeability can vary by up to 6 orders of magnitude between materials encountered on a single construction site. Added to the inherent natural variability are man-made hazards such as subsurface contamination, which is to be expected in most urban areas.

The variability and uncertainty of ground conditions can often require changes to construction methods/equipment. This can cause delays and result in construction claims that are frequently costly to resolve. In addition to disputes between the parties to construction contracts, the uncertainty with respect to ground conditions can lead to damages to third parties resulting from ground movement or contaminant migration. The publicity arising from such third party effects can compound the costs to the project and threaten public support for any large urban infrastructure projects (Tunnelling Journal 2010, Tunnel Talk 2009 and Tunnels & Tunnelling International 2004).

3 RISK MANAGEMENT STRATEGY

The keys to managing subsurface risk for the TYSSE Project are:

- Understanding, identifying, and assessing the risks during design; and
- Clearly allocating and communicating these risks during tender and construction.

The first key relates to planning and managing the site investigation program, interpreting the data obtained consistently and providing appropriate systems to assess anticipated construction methodology and effects on third parties. These design processes are directed toward developing site specific contract documents that identify minimum design and performance criteria for construction.

The construction criteria relate directly to the second key of the subsurface risk management approach - contractually allocating and communicating subsurface risk. The objective of this aspect is to reduce costly disputes that can get mired in resolving responsibility for incidents and determining the foreseeability of incidents, rather than solving inevitable construction problems. The specific components of the SRMS are described in the following subsections.

3.1 Risk Sharing Contracts

Fundamental to the TTC's SRMS is the implementation of "Risk Sharing Contracts". Whereas many major civil works contracts in the past have attempted to assign all subsurface risk to contractors via exculpatory clauses; TTC has accepted the risk of "changes in subsurface conditions" and undertaken to provide bidders with all relevant subsurface data and to define subsurface conditions in a Geotechnical Baseline Report (GBR). This approach is consistent with the now generally accepted practice of risk sharing for major underground projects in North America.

This trend recognizes that exculpatory clauses have not stood up well, as courts generally seek means of preventing owners from making a representation and then disclaiming responsibility for it (USNCTT 1984). Thus, the actual subsurface conditions which deviate from what could reasonably be anticipated at the bidding stage often provide a basis for contractual claims. Reasonable interpretations of subsurface conditions can vary significantly without a clearly defined baseline and, in a low bid environment, contractors are encouraged to make optimistic interpretations of ground conditions. However, given the cost of proving "unforeseen subsurface conditions" claims, and the risk that some claims may not be successful, contractors are forced to carry "risk" money in their bid prices. Thus, when an owner is forced to pay an "unforeseen subsurface conditions" claim, it in effect pays it three times: once for the claim itself, once for the risk allocation built into the bid price and once for the cost of resolving the claim.

The "risk sharing" philosophy works on several levels to reduce claim costs:

- All bidders bid against the same interpretation of the subsurface conditions and they do not need to carry subsurface risk money in their bid (unless they choose to make a more optimistic interpretation of conditions or behaviour than has been made by the owner in preparing the baseline).
- Since the owner is accepting the subsurface risk, greater efforts are made to more thoroughly define subsurface conditions at the design stage; thus reducing risk and the potential for claims during construction.
- Since a baseline is defined at the time of tender and not subject to optimistic interpretation by the bidders, the cost of resolving claims is reduced.

For the TTC projects, the efficient resolution of disputes is aided by requiring contractor's bid documents to be held in escrow and a Disputes Resolution Board (DRB) to be appointed for each major civil works contract. The escrow bid documents allow for fair assessment of claims, as settlement is based in part on the assumptions made during bidding, not on an inflated cost born of opportunism. The DRB, formed of one member selected by the TTC and approved by the contractor, one member selected by the contractor and approved by the TTC and a third member jointly selected by the two members and approved by both parties, provides a sophisticated mechanism for the two contracting parties to resolve any disputes that arise.

The DRB decisions are often non-binding; however, for the TYSSE project, the TTC has established a process by which both parties may agree, prior to the DRB convening on an issue, to be bound by the DRB decision. In such situations the parties can only appeal to the courts on a matter of law, not on technical interpretation. The judicial alternative would offer a far more expensive decision and one that is likely to be less technically grounded.

3.2 Management Responsibility

Project management of the schedule-driven fast-track TYSSE project is being carried out by a joint venture of Delcan-Hatch-MMM and staff from the TTC who are integrated with other consultants to form the project management team. Details of management responsibilities are provided in the comparison paper by Bidhendi et al. (Bidhendi et al. 2011).

Golder Associates Ltd. (Golder) was appointed by TTC as Principal Geo-Engineering Consultant (PGEC) shortly after the onset of the project; thus, subsurface expertise was integrated with the management team from the start. The PGEC's responsibilities include setting/establishing the subsurface investigation program and reporting standards, planning subsurface investigations, interpreting subsurface data, preparing design and baseline reports, reviewing Section Designers' and Contractor's submittals, managing construction instrumentation data and providing construction support related to geotechnical issues. Two Geotechnical Engineering Consultants (GECs), Inspec-Sol Inc. and Coffey Geotechnics Inc., were selected by TTC to undertake site investigations.

Key roles of the PGEC are to ensure that the level of effort and quality of basic subsurface data is consistent across all contracts; this minimizes the contractual risk associated with different contractors receiving different amounts or quality of data.

A lesson learned from the Sheppard Subway project is the inefficiency of paper-based document and data management and retrieval systems for the large volume of data. One of the PGEC's deliverables is to develop and maintain a Geo-Engineering Content Management System (GECMS) - a web-based application that manages geo-engineering documentation and spatial data. Microsoft's SharePoint was fused with ESRI's ArcGIS Server to integrate the following three components into a one-stop portal that could be easily accessed by the project participants:

1. Document management and viewing,
2. Spatial data management and viewing, and
3. Instrumentation data management and monitoring.

Properly implemented, this will act to reduce subsurface risks by ensuring that all relevant data is available and considered each time a subsurface decision is required at a particular location.

3.3 Site Investigation Program

The site investigation program for the TYSSE Project was undertaken by Geo-Engineering Consultants (GECs) who executed investigation work plans prepared by the PGEC (Bidhendi et al. 2011). These work plans provided minimum requirements for the field and laboratory work, a standard format for the investigation reports and standard forms for borehole logs and laboratory test data.

As part of the investigation program, geophysical testing consisting of Multi-Channel Analysis of Surface Waves (MASW), Vertical Seismic Profiling (VSP) and Crosshole Seismic testing was completed (Sol et al. 2011). The geophysical information was used for:

- Seismic hazard site classification in accordance with the National Building Code of Canada (NBCC, 2005) and Ontario Building Code (OBC, 2006);
- Seismic design of the tunnel and station boxes; and
- Material damping characteristics used in vibration related analyses for the structures and track work.

The site investigation program for each contract/section was carried out in two phases, consistent with the progress of a particular section's design. Sampled boreholes, typically instrumented with groundwater monitoring wells, were the primary investigative tool. The initial drilling was carried out at the start of the program to provide an overview of subsurface conditions along the alignment. The complementary drilling was typically started at the beginning of the detailed design phase of each particular contract and included pressuremeter and geotechnical laboratory testing to estimate the strength and deformation characteristics of the soils along the TYSSE alignment. Hydrogeological testing was also carried out to determine the hydraulic conductivity, sustainable yield and transmissivity of the soil deposits.

The object of the phased investigation program is to provide subsurface data through the design process, consistent with project needs. The phasing also allows the investigation program to be optimized, with more detailed investigations and sophisticated sampling and testing carried out where preliminary design assessments shows it to be warranted.

For the TYSSE Project, the borehole investigation work is summarized in Table 1. This work is associated with station box structures, ancillary structures (such as bus terminals, parking lots, new and/or realigned pavements) and the need to more thoroughly investigate locations such as tunnel cross-passages, emergency exit buildings structures and contaminated sites.

Table 1: Extent of investigations for the TYSSE project

	Entire Alignment	Tunnels Only
Number of Boreholes[1]	483	126
Average Spacing (m)	-	50
Total Length Drilled (m)	9,800	3,400

[1] geotechnical sampled boreholes

The total cost of this investigation work amounts to C$12 million; this cost is for field investigation only - the costs for data collection, interpretation, design, baseline and environmental report preparation, design support and design review is expected to total about C$8 million for the Project. The total cost of geo-engineering works is estimated to be about 0.75% of the project budget.

The appropriate level of investigative effort is often difficult to assess, especially when budgeting at the start of a project. It has been argued that there is an optimum level of investigative effort that balances the reduced cost of risk resulting from greater investigative effort against the increased cost of more comprehensive subsurface investigations. This is schematically illustrated in Figure 3, in which the "Cost of Risk" is added to the investigation cost and plotted against the "Extent of Investigation", to determine the minimum combined cost, or optimum level of investigation. This schematic figure provides a rational basis for determining the optimum level of investigation; however, while attaching a cost to the level of investigation may be relatively straight forward, assessing the "Cost of Risk" with varying levels of investigation is a greater challenge.

Data compiled by the U.S. National Committee on Tunnelling Technology in 1984 is reproduced in Figure 4 where "Changes Requested" (i.e. claims made) as a percentage of the Engineer's project estimate are plotted against the ratio of the total borehole length to tunnel alignment length. The line of best fit through this data is considered to represent the "Cost of Contractual Risk" associated with varying levels of site investigation. It is speculated that a relationship for third party risks would show a similar pattern.

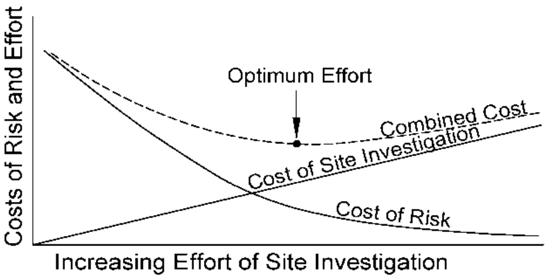

Figure 3. Establishing the optimum extent of site investigation (from Ash and Russel 1974)

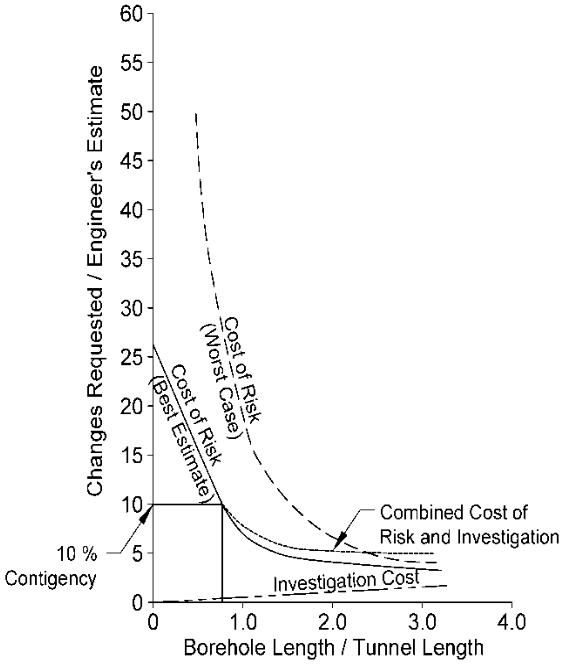

Figure 4. Cost of risk and investigation (from Boone and Westland 2004)

The cost of investigation relative to potential claims is striking, as is the absence of a minimum along the line representing the combined cost of risk and investigation. While the limitations of the relationship must be recognized (it does not account for borehole depth or spacing and there is little data for high borehole length ratios) it appears that there is not a clear optimum level of investigative effort, but rather a point - at about a borehole length to tunnel length ratio of 1.5 - beyond which increased investigation provides little, if any, net benefit. At a ratio of about 0.75, it is probable that claims will be less than 10 percent of the Engineer's estimate.

The probability of claims is explored further in Figure 5, where the tunnelling claim data has been interpreted to provide "probability of exceedance" curves for projects in which the ratio of total borehole length to tunnel length is less than 0.5 and for projects with a ratio greater than 0.5. In the former case there is a 20 percent chance that the claims will exceed 50 percent of the bid price and a 60 percent chance that the claims will be greater than 10 percent of the bid price. Where greater investigation takes place these probabilities drop to 5 percent and 38 percent respectively.

From Figures 4 and 5, it is apparent that the optimum level of investigative effort for major tunnelling projects corresponds to a borehole length to tunnel ratio of between 0.5 and 1.5. For the TYSSE Project, the level of subsurface investigation is considered to have been sufficient to allow thorough assessment of subsurface risks at the design stage and to communicate these risks for construction of tunnels and stations. Claims records will be reviewed at the end of the TYSSE project to determine if the investigation has indeed been optimized.

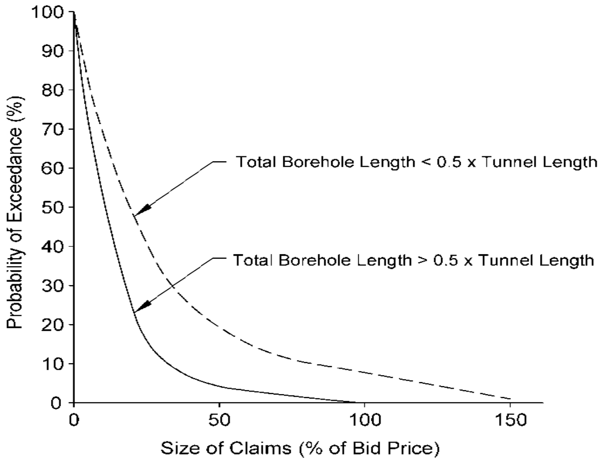

Figure 5. Probability of claims exceeding a given size for different levels of investigation effort (from Boone and Westland 2004)

3.4 Assessment and Control of Third Party Impacts

The potential affects of construction on third parties are assessed as part of the design process. The greatest subsurface risk to third parties is considered to arise from ground movements induced by tunnelling and deep excavations. For each design contract, all structures including utilities, within a prescribed zone of influence (see Figure 6) are subject to a "Level 1 Damage Assessment". The Level 1 assessment is a screening mechanism in which established empirical relationships between site geometry (tunnel/excavation depth, building founding level and set-back) and broad soil types are used to conservatively assess likely ground movements associated with conventional construction techniques.

An empirical relationship between ground conditions and settlements adjacent to braced excavations was used during design stage as a tool for evaluating the potential performance of soldier-pile and lagging excavation support system (see Figure 7). For stiffer excavation support systems, deformations were considered to be about half those illustrated in Figure 7 (Boone and Westland 2004). On the basis of experience obtained on other deep excavations in similar ground conditions the Toronto area, maximum settlements (δ_{max}) at the excavation edge for the TYSSE Project supported with properly engineered and constructed shoring systems, are expected to be less than a value equal to 0.2% times the depth of excavation, H (i.e., δ_{max} = 0.2%H) provided that the design and construction specifications are fully complied with. The assumed Zone of Influence width for the settlements is assumed to extend horizontally from the edge of the excavation outward to a distance of twice the depth of the excavation.

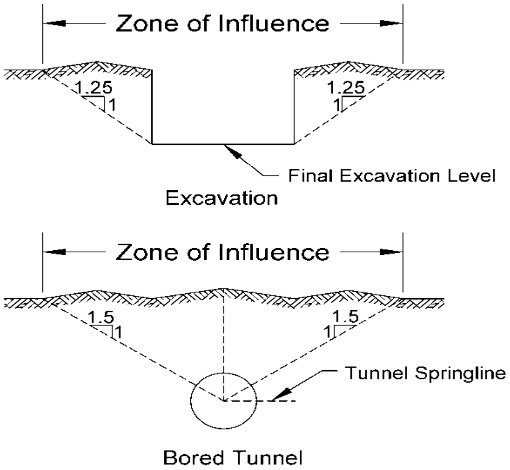

Figure 6. Zone of influence used to determine structures that undergo Level 1 damage assessment (TTC, Geotechnical Standards)

The process recognizes that it is impossible to cause no damage to structures and established classification criteria are used to assess the level of induced damage (Boscardin and Cording 1989). The goal is to limit damage to slight or less because slight damage is unlikely to disrupt occupants of structures and such damage can be repaired relatively inexpensively with minimal inconvenience.

Where the Level 1 assessment suggests the potential for moderate or greater damage, a Level 2 assessment is carried out. This more detailed analysis utilizes sophisticated modelling tools and geotechnical testing to assess ground movements and often requires a structural engineering assessment of a particular structure's tolerance to settlement. Modelling and assessment of progressively more elaborate construction techniques is carried out until the "slight" damage criteria is met.

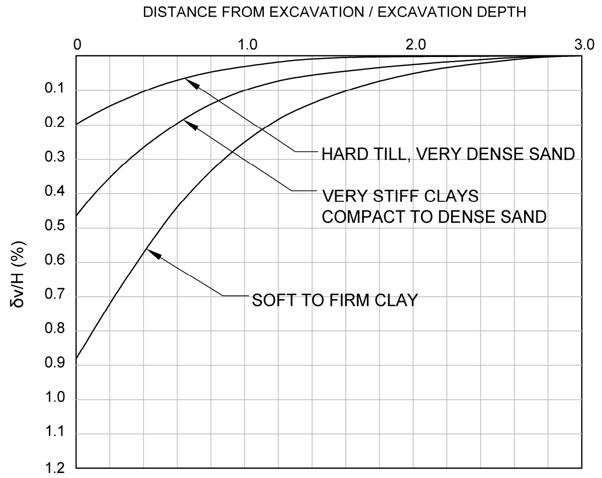

Figure 7. Empirical relationship between ground type and anticipated displacement due to deep excavations (from Boone and Westland 2004)

The costs of such measures are then compared to measures such as utility relocation/replacement or property purchase. The end result is a site-specific protection strategy that minimizes cost, while at the same time reduces risk of construction damage that would lead to third party claims.

This design exercise is tangibly reflected in the contract documents as minimum design requirements that are imposed on contractor's temporary works and as performance criteria (maximum ground or structure movements) that must be met during construction. Compliance with such criteria is measured during construction through an instrumentation program and damage to structures is assessed by a program of pre and post condition surveys. These latter provisions also serve the important function of minimizing the risk of false claims arising from parties seeking to take advantage of the "deep pockets" of a large, publicly funded agency.

3.5 Soil and Groundwater Management

Environmental contamination must be anticipated in the soil and groundwater for large urban infrastructure projects. Efforts to detect impacted materials at the design stage will minimize the costs and delays during construction that will arise when impacted materials are unexpectedly encountered.

An early activity on the TYSSE project was to prepare Phase I Environmental Site Assessments (Phase I ESAs). Phase I ESAs include thorough historical land-use review of all surface taking properties. Sources of information included air photos, fire insurance maps, land registry records, regulatory authorities records, government waste generator, review of existing ESA reports (where available), fuel storage tank records, tenants' interviews and walk-by inspections. The review focused on identifying present or past land uses that are associated with chemical releases to the environment, such as service stations, land fills, dry cleaning operators and industrial facilities. Mapping of such information was used as a planning tool to optimize the subsurface investigation; wherever possible, boreholes were located adjacent to, or on the side of the alignment closest to sites where contamination might be anticipated.

The TTCs geotechnical standards require that all soil samples obtained be examined by the GECs for visual or olfactory evidence of impacts. Organic vapour tests were made of the air trapped at the top of each sample jar. Similar tests were carried out at the top of all monitoring wells. These field screening measures provide a relatively inexpensive means of identifying potentially impacted areas, providing a rational basis for selecting soil and groundwater samples for analytical testing and identifying locations where further subsurface investigation is necessary. Air was sampled in some monitoring wells that had elevated headspace readings during earlier investigations, using SUMA Canisters to analyze for methane and other light hydrocarbon gases and volatile organic compounds (VOCs).

Phase II ESAs were carried out at locations containing potentially impacted materials as identified in Phase I ESA, to evaluate the environmental conditions for the purpose of providing sufficient information regarding the nature and extent of impacted materials.

The findings of the investigation and testing are used to develop a strategy for handling and disposing of soil and groundwater at each site. The findings also provide the basis to quantify expected volumes of waste materials to be handled during construction. At sites where impacted materials are not identified during design, the contract documents include provisions for handling and disposing of waste materials on a unit price basis.

Environmental baseline investigations have also been completed for non-permanent property takings to provide a baseline for comparison of pre and post construction environmental conditions. Environmental site investigations and studies were used to plan and negotiate property acquisition and easement agreements by the TYSSE.

3.6 Geotechnical Baseline Reports

A GBR prepared by the PGEC, with assistance from tunnel and station designers is bound into each major civil works contract for the TYSSE project. The GBR establishes the ground conditions for construction against which all tenders bid. The GBR provides:

- An interpretation of the thickness of deposits between boreholes;
- An established baseline for groundwater conditions;
- Anticipated subsurface hazards;
- Discussion on the way that ground conditions have influenced the design and the contract provisions;
- The anticipated behaviour of the ground in relation to construction operations; and

- The baseline conditions associated with management strategies for excess materials, groundwater discharge and subsurface gases control.

Establishment of baseline conditions in this manner reduces the risks arising from claims of unforeseen subsurface conditions for both parties to the contract. Because the GBR is a basis for tendering, the document is written with definitive wording; speculative wording (such as may, might, is possible) is avoided because it creates ambiguity, making it unclear if a contractor should or should not make provision for an event in its tender.

This requirement presents a challenge because of the variability of ground conditions and the limits to which the ground can be investigated. However, where there is uncertainty, the key is to make a clear professional judgement as to the likely behaviour and, in the spirit of risk sharing, be prepared to fairly compensate contractors when the ground conditions or behaviour are materially different than those established in the GBR.

For example, glacially derived soils are known to contain boulders, but borehole investigations rarely encounter boulders that can be core sampled and documented (Westland et al. 1996, Boone et al. 1998). If the GBR were to state that the ground may contain boulders, there would be no basis for assessing how frequent such obstructions might be and what their impact on construction might be. Therefore, data collected from Sheppard Subway Line was used to estimate boulder frequency for the TYSSE Project since the soils are similar in origin for both projects. Detailed site records will be kept during excavation and payment will be made to the contractor if the boulder quantity exceeds the baseline quantity.

This example illustrates another important point regarding risk sharing contracts and preparing baseline reports. It is tempting when determining the baseline for something as uncertain as boulder frequency to be conservative, so that unforeseen subsurface condition claims are not made against the owner and the report author is not perceived as being "wrong". This approach is costly, as contractors will build into their prices the costs associated with the conservative baseline. It must be accepted by all parties that for issues such as boulder frequency it is impossible (or highly improbable) for the geotechnical engineer to be "right", and that the interests of the owner are best served if a project claims record shows him to be “wrong” about half of the time.

3.7 Insurance Coverage

The "risk sharing" contracting philosophy allocates subsurface risk between owner and contractor as per the baseline subsurface conditions provided in the GBR; however, it is recognized that some high cost, low probability events would be onerous for either party to bear and insurance coverage is typically obtained for such events. TTC has negotiated a Wrap-up comprehensive liability insurance package that provides coverage for the TTC, third parties, TTC's consultants and contractors, as applicable.

The Wrap-Up coverage is a key component of the subsurface risk management strategy, as it provides protection against third party property and injury claims, including damage that could arise from excessive ground movement. In negotiating this coverage the entire subsurface risk management strategy was presented to the insurers, so that when preparing their quotations they would have an appreciation of the site investigation program, the manner in which third party impacts are assessed, and the contractual measures that would be implemented to minimize such risks.

The limit of liability for the public liability and property damage coverage for the TYSSE Project is C$200 million aggregate for the project and per incident on the project. A C$100,000 deductible per incident applies; and the deductible includes adjusting fees. For very large claims that may arise from ground settlement, it may be argued that the insurance deductible may not be sufficient to influence the contractors to minimize that risk. This may be true if the insurance deductible was to be the only mechanism to influence the contractor’s workmanship. For the TYSSE project; however, the site specific temporary works design criteria that are imposed, and the contractual power to halt work and order that corrective measures be taken that is granted to the owner if ground and structure movement limits are not achieved, provide a strong incentive for contractors to carry out construction in a manner that minimizes third party impacts and the claims which can arise from such incidents.

4 CONCLUSION

The TYSSE Project has incorporated many of the investigation and contracting practices that have been advocated at tunnelling conferences for the last couple of decades. It is considered that no single practise can reduce claims and the inherent risks in underground construction make it impossible to anticipate all events. Costs can be controlled, and third party impacts minimized; however, if the potential risks are recognized and a comprehensive SRMS is put in place at the start of any project.

This paper has summarized the SRMS implemented for TYSSE project and it is hoped that it will prove to have been well conceived; however, it is recognized that construction experience will provide "lessons learned" that will allow subsurface risk management systems to be improved.

ACKNOWLEDGEMENTS

The writers thank the TTC, and in particular Mr. A. Bertolo, Chief Project Manager, for permission to publish this paper and recognize the efforts of all the project team members for this project.

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