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Managing subsurface risk for Toronto's Rapid Transit Expansion Program

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ABSTRACT: The design and construction strategy adopted to manage subsurface risks on Toronto's Rapid Transit Expansion Program are described. Measures include a "risk sharing" approach to construction contracts, a commitment to comprehensive pre-construction site investigation and appointment of a Program Geotechnical Consultant. The role of the Program Geotechnical Consultant in planning investigations, ensuring consistency in quality and providing a consistent interpretation of subsurface data is described. The level of site investigation effort for the major tunnelling contracts is related to construction risks, such as change orders, to assess the optimum level of investigative effort. The "risk sharing" approach to construction requires preparation of a Geotechnical Baseline Report and the appointment of a Disputes Review Board for each major civil works contract. The approach to providing "baseline" conditions for typically contentious issues, like boulder frequency, is described.

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 Toronto's Rapid Transit Expansion Program to minimize and control subsurface risks.

Toronto's Rapid Transit Expansion Program was originally planned to include two new subway lines (the Sheppard and Eglinton Subways), extensions to two existing subway lines (the Bloor-Danforth and Spadina Subways), an extension to the Scarborough LRT line and expansion of the Wilson subway yard facilities. In total 25 km of new transit lines were planned, with 9.6 km of twin bored tunnel and 19 stations. The majority of construction was to take place within glacially derived soils that are typical of southern Ontario and much of the northern United States. The extent of underground construction required that management of subsurface risk be considered at the onset of the projects and measures to control the risks be integrated into the management and planning of the program. Though funding cuts have reduced the program to construction of the single 6.4 km Sheppard Subway (with 5 underground stations) the measures adopted to manage subsurface risk on the program continue to be applied on this project.

2 SUBSURFACE RISKS

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 the thickness and extent of deposits, the strength and compressibility of deposits and their permeability. The variation in soils is large compared to other engineering materials; for example permeability can vary by up to 10 orders of magnitude between materials encountered on a single construction site. Added to the inherent natural variability are man-made hazards such as subsurface contaminants, which are to be expected in most urban areas.

The variability and uncertainty of ground conditions often can require changes to construction methods/equipment, this can cause delays and result in construction claims that frequently are 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 associated with ground movement or contaminant migration. The publicity arising from such third party impacts can compound the costs to the project and, indeed, threaten public support for large urban infrastructure projects. Recent examples of sinkholes forming above tunnelling works in London, Los Angeles, Sau Paulo and Seoul made headlines world-wide and attest to the risks associated with underground construction (World Tunnelling 1996, ENR 1995, World News 1997, Chung et al 1995).

3 RISK MANAGEMENT STRATEGY

The keys to managing subsurface risks for the Toronto transit expansion program were considered to be understanding and assessing the risks during design and clearly allocating and communicating the 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 affects 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 to 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 subsurface risk management system are described in the following subsections.

3.1 *Risk Sharing Contracts*

Fundamental to the TTC's subsurface risk management strategy 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, the TTC has accepted the risk of "changed" conditions and undertook to provide tenderers with all relevant subsurface data and to define subsurface conditions in a Geotechnical Baseline Report (GBR). This approach is consistent with a trend toward 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, subsurface conditions which deviate from what could reasonably be anticipated at the bidding stage, often provide a basis for contract claims. Reasonable interpretations of 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 collecting "changed" conditions claims, and the risk that some claims may not be successful, contractors are forced to carry "risk" money in their tendered prices. Thus, when an owner is forced to pay a "changed conditions" claim, it in effect pays 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 tenderers bid against the same interpretation of the subsurface conditions and the tenderers have no 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. Further, because the owner is accepting the subsurface risk, it is encouraged to more thoroughly define subsurface conditions at the design stage; this in itself reduces risk and claims during construction. Finally, because a baseline is defined at the time of tender and the risk is allocated, 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 Review 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 a member appointed by the owner, one by the contractor and a third jointly selected by the two appointees, provides a mechanism for the two sophisticated contracting parties to resolve any disputes that arise. Though DRB decisions are non-binding, its opinion is compelling, given the construction experience and expertise its members typically posses; the judicial alternative would offer a far more expensive decision and one that is likely to be less well technically grounded.

3.2 *Management Responsibility*

Management of Toronto's Rapid Transit Expansion Program is by a joint venture of Delcan-Hatch and staff from the TTC who were integrated with other consultants to form the program management team. The TTC selected Golder Associates Ltd. as Program Geotechnical Consultant (PGC) at the onset of the program; thus, subsurface expertise was integrated with the management team from the start.

The geotechnical consultant's responsibilities have included setting program-wide investigation and reporting standards, planning subsurface investigations, interpreting subsurface data, preparing design and baseline reports, reviewing designs and contractor's submittals and managing construction instrumentation data (Shirlaw et al 1996). As a number of consultants undertook site investigations on behalf of the TTC, a key role of the PGC is to ensure that the level of effort and quality of basic subsurface data is consistent across all contracts and projects; this minimizes the contractual risk associated with different contractors receiving different amounts or quality of data. By interpreting the subsurface data the PGC minimizes the risk of interface design anomalies, which can arise if different designers interpret similar subsurface conditions in different ways. Indeed, the individual section designers are responsible for assessing the likely third party impacts of construction for their particular design contract; basic criteria for such assessments (soil properties, settlement relationships, etc.) are established by the PGC, who also reviews the designer's findings so that there is consistency in the manner that third party risks are assessed and in the measures that are adopted to mitigate such risks.

The PGC's involvement during construction to manage instrumentation data allows construction experience to be efficiently fed back into the design of future contracts. Ground movement data from the early Sheppard Tail Track contract was interpreted and supplied to station designers so that the anticipated ground movement adjacent to excavations (and its effect on adjacent structures) could be refined. This construction contract also provided field data on boulder frequency that dictated a change in the tunnel boring machine head design (Busbridge et al 1998, Boone et al 1998a).

3.3 *Site Investigation Program*

Site investigations for the Rapid Transit Expansion Program are undertaken by investigation consultants retained directly by the TTC, who execute investigation work plans prepared by the Program Geotechnical Consultant. The program geotechnical standards provide 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.

The site investigation program is carried out in phases, consistent with the progress of a particular project's design. Sampled boreholes were the primary investigative tool, and maximum borehole spacing for the various phases is provided in Table 1. The Phase 1 drilling was carried out at the start of the program to provide an overview of conditions along each alignment. The Phase 2 drilling was typically started at the beginning of the detailed design of any section and Phase 3 investigation followed shortly thereafter, during detailed design.

Table 1. Maximum Borehole Spacing for Phased Investigation Program.

Investigation Phase	Maximum Borehole Spacing (m)
Phase 1	450 m
Phase 2	150 m
Phase 3	50 m Stations 75 m Tunnels

The object of the phased investigation program is to provide subsurface data through the design process, consistent with project needs. The phasing also allowed the investigation program to be optimized, with more detailed investigations and sophisticated sampling and testing carried out where preliminary design assessments showed it to be warranted. Without a phased approach to a large transit project, one would risk spending excessively where there is not the need, or not having sufficient information at critical locations.

For the Sheppard Subway the borehole investigation work completed to date is summarized in Table 2. The total cost of this investigation work is $2.0 million (Cdn.); this cost is for data collection and reporting only - the costs for interpretation,

Table 2. Extent of Investigations for Sheppard Subway.

	Entire Alignment	Tunnels Only
Number of Boreholes	244	65
Average Spacing (m)	29	52
Total Length Drilled (m)	4940	1480

design, baseline and environmental report preparation, design support and design review is also expected to total about $2.0 million (Cdn.) for the Sheppard Subway (about 0.75% of the construction budget).

The average borehole spacing is significantly smaller than the maximum spacing required by the program standards. The additional drilling is associated with ancillary structures (bus terminals, parking structures, upgraded roadways) and the need to more thoroughly investigate locations such as tunnel cross-passages, structures susceptible to damage from construction work and contaminated sites.

The appropriate level of investigative effort is often difficult to assess, especially when budgetting 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 by Figure 1, 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.

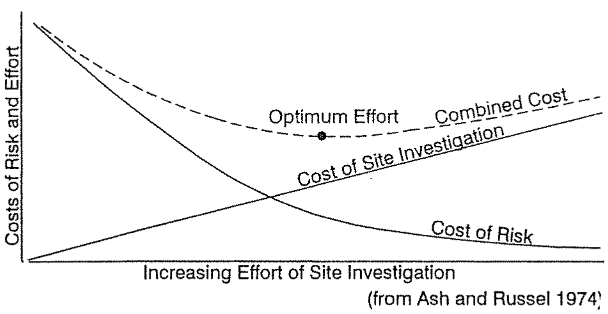

Figure 1. Establishing the optimum extent of site investigation

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 2, 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.

The budget estimate of the civil works cost for the Sheppard Subway is $511 million (Cdn.). This budget estimate, and the actual extent and cost of the site investigation for the Sheppard Subway, has been used to plot the "Cost of Investigation" line on Figure 2 (Note that for purposes of plotting the "Cost of Investigation" line it has been assumed that the Engineer's Estimate for all projects will be the

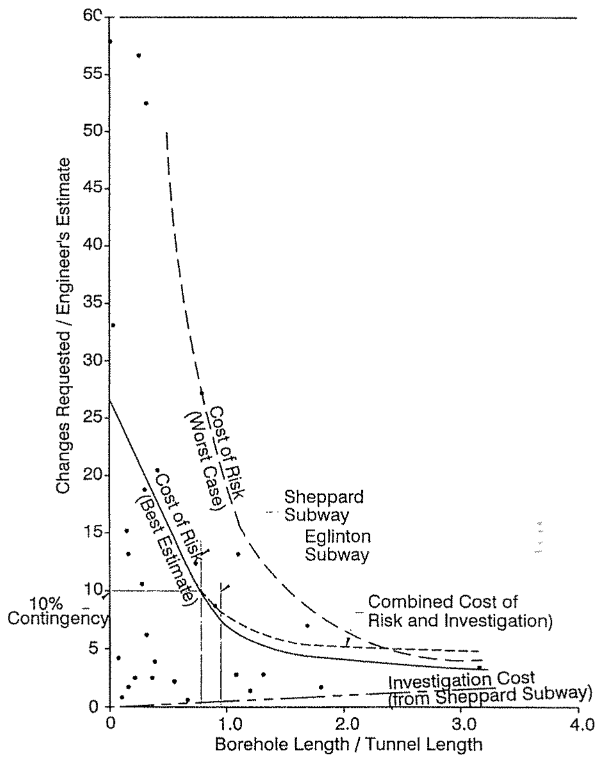

Figure 2. Cost of risk and investigation based on available data

same as the Budget Estimate). 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 about 10 per cent of the Engineer's estimate.

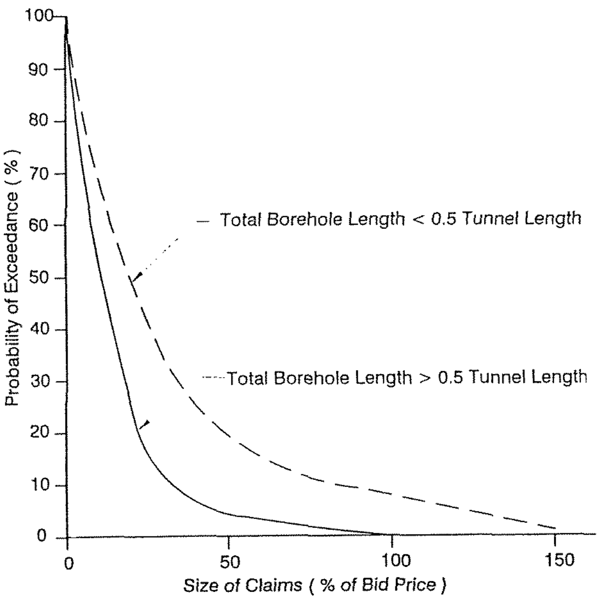

Figure 3. Probability of claims exceeding a given size for different levels of investigation effort

The probability of claims is explored further in Figure 3, where the tunnelling claim data has been interpreted to provide "probabilty 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 per cent chance that the claims will exceed 50 per cent of the bid price and a 60 per cent chance that the claims will be greater than 10 per cent of the bid price. Where greater investigation takes place these probabilities drop to 5 per cent and 38 per cent respectively.

The affect of investigative effort on the cost certainty of underground construction projects is further illustrated by Figure 4, in which the ratio of completed project cost to the Enginner's estimate is plotted against the borehole length to tunnel length ratio. Where the borehole length ratio exceeds about 0.8, the completed construction costs rarely exceeded the Engineer's estimate.

The plot on Figure 5, which shows the ratio of bid prices to Engineer's estimate against the borehole length ratio shows that bid prices can be expected to be below the Engineer's estimate when the borehole length ratio is greater than 0.5. From Figures 2 through 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. On Figures 2, 4 and 5 the borehole length ratios for the Sheppard and Eglinton subways are plotted. Both projects were planned on the basis of the same maximum borehole spacing criteria; the difference in borehole length ratios is

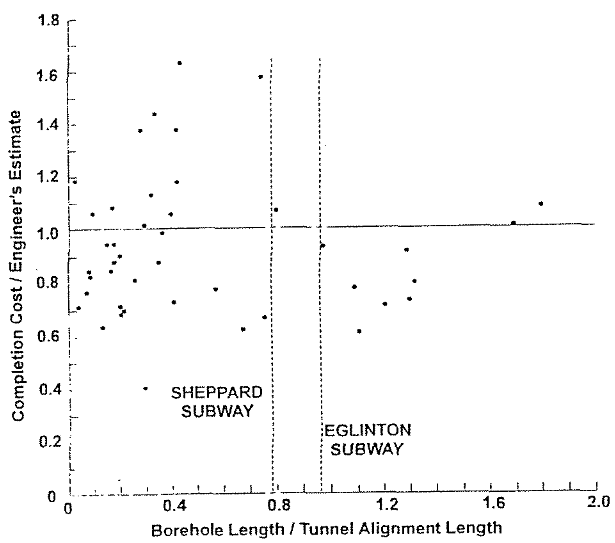

Figure 4. Effect of extent of investigation on certainty of construction cost

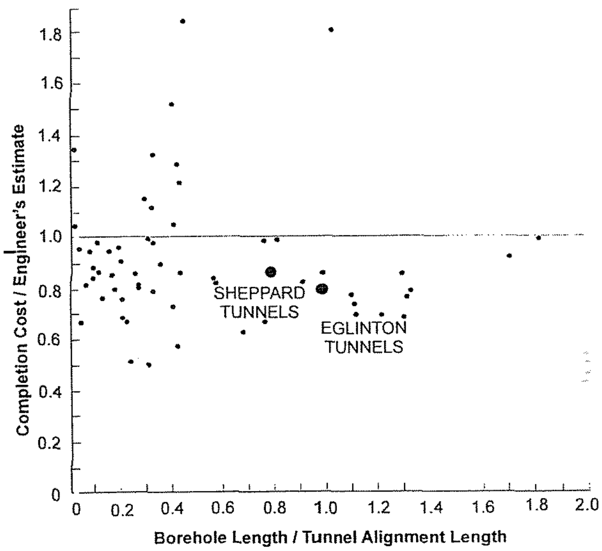

Figure 5. Effect of extent of investigation on certainty of construction cost

attibutable to the greater depth of the Eglinton Subway alignment and the particularly challenging subsurface conditions at the Eglinton tunnel launch shaft. 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. Claims records will be reviewed at the end of the Sheppard Subway project to determine if the investigation has indeed been optimized.

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 (Boone et al 1998). 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.

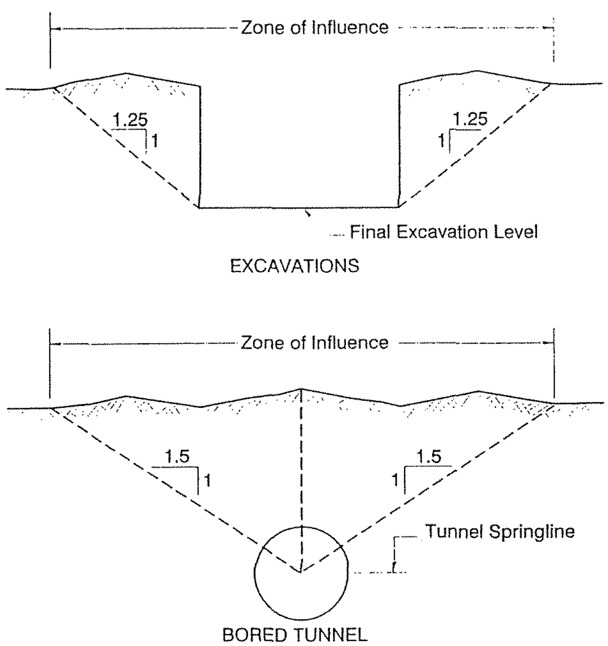

Figure 6. Zone of influence used to determine structures that undergo level 1 damage assessment

The process recognizes that it is impossible to cause no damage to structures and established classification criteria (Boscardin and Cording 1989) are used to assess the level of induced damage. 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. 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 via an instrumentation program and damage to structures is assessed via 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*

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

An early activity on the Rapid Transit Expansion Program projects was a thorough historical land-use review of all alignments. Sources of information included air photos, fire insurance maps, land registry records, government waste generator and fuel storage tank records 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 contaminants might be anticipated.

The program geotechnical standards require that all soil samples obtained be examined by the investigation consultant for visual or olfactory evidence of contaminants. Organic vapour tests are required to be made of the air trapped at the top of each sample jar. Similar tests are required at the top of all sampling well riser pipes. These field screening measures provide a relatively inexpensive means of identifying potentially contaminated areas, provide a rational basis for selecting soil and groundwater samples for analytical testing and identify locations where further subsurface investigation is necessary.

The findings of the investigation and testing is 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 contaminants are not identified during design, the contract documents none-the-less include provisions for handling and disposing of waste materials on a unit price basis. Estimated quantities of various classifications of waste material are included as line items in the contract to avoid the risk associated with excessive charges that could be levied for disposal of such materials on a contract change basis.

3.6 *Geotechnical Baseline Reports*

A Geotechnical Baseline Report is bound into all major civil works contracts for Toronto's transit expansion. The GBR establishes the ground conditions for construction against which all tenderers bid. The GBR provides an interpretation of the thickness of deposits between boreholes, highlights anticipated subsurface hazards, provides discussion on the way that ground conditions have influenced the design and the contract provisions, and describes the anticipated behaviour of the ground in relation to construction operations. 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 have made 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 worse 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 1998a). 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. For the Sheppard Subway, the data from two early cut and cover contracts were correlated with borehole records of "hard" drilling (an indicator of cobbles and boulders) to estimate the boulder frequency for other contracts. A relative boulder volume is now provided in the GBR for each contract; site records are kept during excavation and payment is made to the contractor if the boulder quantity exceeds the baseline.

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 changed 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 is best being served if a project claims record shows him to be wrong half of the time.

3.7 *Insurance Coverage*

The use of geotechnical baseline reports within a "risk sharing" contracting philosophy allocates subsurface risk between owner and contractor; 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. The TTC negotiated a Wrap-Up insurance package that includes public liability and property damage insurance, professional liability insurance and builder's risk insurance. This insurance package 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 on the Sheppard line is $100 million (Cdn) aggregate for the project and per incident on the project. A $5000 (Cdn.) deductible per incident applies; the deductible includes adjusting fees. For the project work completed to date, claims have been relatively small and the inclusion of adjusting fees in the claim cost has provided contractors with a strong incentive to be active with the community to resolve small issues before they escalate into a claim. For the very large claims that may arise from ground settlement, there has been concern that the level of the deductible does not provide sufficient incentive for contractors to minimize such incidents. This might true if the insurance deductible provided the only mechanism to influence the contractors workmanship. However, for the Sheppard subway, 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

Toronto's Rapid Transit Expansion Program has incorporated many of the investigation and contracting practices that have been advocated at tunnelling conferences for the last decade, or so. It is considered that no single practise can reduce claims and, indeed, the inherent risks in underground construction make it impossible to anticipate all events. However, costs can be controlled, and third party impacts minimized, if the potential risks are recognized and a comprehensive subsurface risk management system is put in place at the start of any project. This paper has summarized the subsurface risk management plan for Toronto's transit expansion; 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.

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