Geo-engineering investigations and management strategies for the Toronto-York Spadina Subway Extension (TYSSE) project

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ABSTRACT

The Toronto-York Spadina Subway Extension Project (TYSSE) is the first subway extension that crosses Toronto borders and connects the City of Vaughan (York Region) to the existing Toronto Transit Commission's (TTC) system in the City of Toronto. A challenge with the TYSSE project is managing a schedule that requires completion of the geotechnical investigations concurrent with the design phases. Management strategies included the development of a geo-engineering team comprised of TYSSE, a principal consultant, and two field consultants, division of field investigations into two phases to correspond with the design schedule, and development of an efficient work flow and content management system accessible by internal and external users. These strategies resulted in meeting the TYSSE project schedule and completion of 1080 boreholes, 21,900 metres drilled, and 192 reports in less than the proposed 2.5-year investigation schedule.

RÉSUMÉ

Le projet du metro «Toronto-York Spadina Subway Extension» (TYSSE) est le premier projet de prolongement du metro qui traverse les frontières de Toronto et relie la ville de Vaughan dans la region de York au système existant de la ville de Toronto «Toronto Transit Commission» (TTC). Un defi posé par ce projet est la gestion du calendrier en vue de completer les investigations coincident avec les phases de conception. Les strategies mis en place on inclus le developpement d'une équipe de géo-ingénierie, composé de TYSSE, un consultant principal et deux consultants-technique de terrain, des multiples de phases de l'enquête de terrain pour compléter le calendrier de conception et un flux de travail efficace et un système de gestion de contenu spécifique au géo-ingénierie disponible à tous les membres du projet. Les strategy ont permis la rencontre du calendrier et la réalisation de 1080 forages, 21.900 mètres forés et 192 rapports en moins 2.5 ans avant de l'enquête du calendrier proposé.

1 INTRODUCTION

The Toronto-York Spadina Subway Extension (TYSSE) project, planned by the Toronto Transit Commission (TTC), was initiated in late 2008 and is scheduled to be completed in 2015. The objectives of the TYSSE alignment are to connect the City of Toronto with the City of Vaughan in the municipality of York Region and planned connections to existing transit systems such as GO and York Region Transit, York University and the highway infrastructure (TTC, 2006). Figure 1 shows the 8.6 km long TYSSE alignment and its major components. The planned alignment includes twin bored tunnels, six subway stations, two crossover tracks, a tail track, and a Double-Ended Pocket Track Housing structure (DEPTHs).

The planned alignment crosses a number of sensitive and challenging surface and subsurface locations and involves multiple private and public stakeholders. Significant areas include federal park land (Park Downsview Parc), Finch West and Steeles West Hydro Corridors, Black Creek, York University Campus (comprised of environmentally sensitive woodlots and historical buildings), above ground infrastructure including arterial roads, Highway 407 and CN Rail / GO Barrie Line, surface and subsurface utilities and potentially contaminated industrial areas. Stakeholders and/or regulatory agencies involved in the project include the federal, provincial and municipal governments, Hydro One, Ontario Realty Corporation, the Ministry of Environment, Toronto and Region Conservation Authority, 407 ETR, York University, utilities owner and private entities.

Traditionally in subway design and construction projects, geotechnical investigations have a lead time of approximately 6 months to 1 year over the design stages (USNCTT, 1984). However, for the TYSSE project, a strategy was developed at the project onset to conduct geotechnical investigations and design phases concurrently - a trend more frequently being used during schedule-driven projects. Under the developed strategy, the geotechnical investigations and station and tunnel design were allocated a 2.5 year period to meet tender and construction deadlines. This required the development of a management system specific to overcoming challenges to the TYSSE project including conducting geotechnical investigations that would meet the station and tunnel designers requirements; responding to and accommodating critical design stages and milestone; ensuring internal and external communications; avoiding unplanned costs associated with investigations; and, avoiding delays caused by the location of the alignment, involving multiple stakeholders and time needed to obtain permissions to enter, and difficult site conditions.

This paper presents the strategies developed by the TYSSE project management to overcome challenges associated with the schedule driven project and allow for a successful outcome. Geo-engineering investigation data is also summarized and presented to outline the extent of the geo-engineering investigations and successes of the adopted strategies.

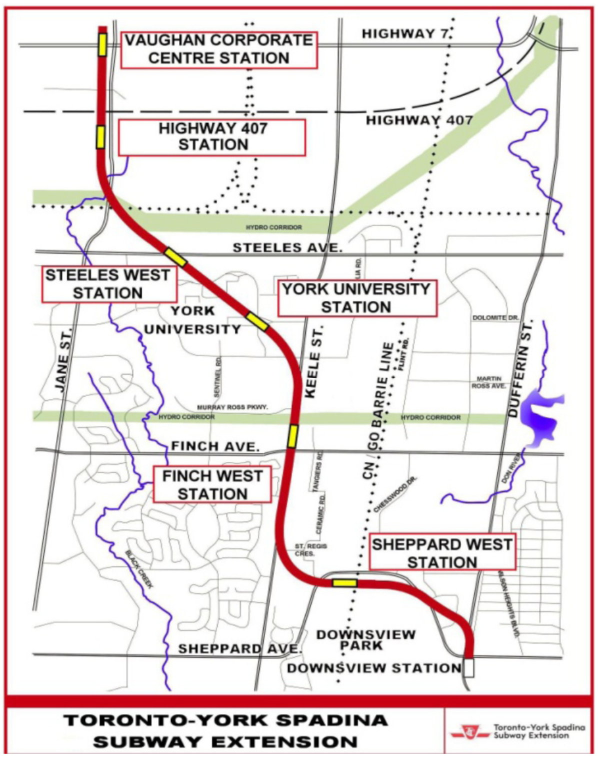

Figure 1: The planned TYSSE alignment including 6 new subway stations

2 PROJECT CHALLENGES

In November 2008, TTC concurrently awarded contracts to the geo-engineering consultants and station and tunnel designers to conduct the geo-engineering investigations and to develope the TYSSE design, respectively within a 2.5 year period. Typical geo-engineering investigations, tasks and coordination matters were expected to be exacerbated due to the adopted strategy. Challenges specific to the TYSSE schedule driven project included:

- Providing geotechnical input to designers according to the aggressive design schedule;
- Coordination with public and private property owners/tenants to quickly obtain permissions to conduct site investigations;
- Redevelopment of the geo-engineering investigation work plans in areas where there were unanticipated conflicts with high density utilities;
- Timely response to regulatory authorities requirements such as environmental protection of and relocation of the Black Creek at the planned Highway 407 station and protection of natural water resources;
- Consistent interpretation of sub-surface data due to the variability in ground conditions associated with glacially derived soils encountered along the alignment;
- Management and inclusion of geo-environmental investigations and soil and groundwater chemical analyses due to location of the alignment in industrial/commercial areas with potential subsurface impacts;
- Timely response to and additional development of geo-engineering investigation work plans to address the concurrent design and alignment refinements.

TTC's appreciation for the geo-engineering investigations was driven by a new and pro-active approach for subsurface risks management by providing contractors with all relevant subsurface data and defining subsurface conditions in a Geotechnical Baseline Report (GBR) (Walters et al., 2011). A budget of 0.8% of the overall project budget was assigned to the TYSSE geo-engineering investigations by the TYSSE project management.

3 PROJECT MANAGEMENT STRATEGIES

The TYSSE project management team is composed of the Spadina Link JV including Hatch Mott MacDonald, MMM Group, Delcan, TTC staff and Stantec. At the commencement of the project in early 2008, the TTC appointed a TYSSE Geotechnical Coordinator (referred to as "Coordinator" herein) to lead, organize and coordinate the geotechnical investigation works and act as a primary point of contact for the geotechnical team. TYSSE geotechnical management strategies were developed to accommodate the schedule, the anticipated challenges and the project strategy to conduct the geotechnical investigations and subway design concurrently. Based on historical information, case studies and experiences summarized in USNCTT (1984) and previous TTC projects the geo-engineering team was assembled with clearly defined roles and responsibilities to ensure optimal division of work and flow of information, consistency of scope and responsibility, prioritizing investigations and provide one point of contact with the section designers. The systems were implemented to:

- minimize the lag time between field investigation work and reporting in order to allow preliminary interpretation of findings and reporting on design parameters to facilitate design completion; and
- facilitate frequent and uninterrupted communications between the geo-engineering team

members, TYSSE departments/team members, section designers and third parties.

3.1 Geo-Engineering Team & Responsibilities

The TYSSE geo-engineering team consists of the TYSSE members ("Coordinator") as lead and coordinators; a Principal Geo-Engineering Consultant (PGEC) to provide subsurface risk management advice and geo-engineering expertise during design and construction; and, two Geotechnical engineering consultants (GEC) to conduct the field investigations. Figure 2 shows the relationship schema among the geo-engineering teams. The responsibilities of the Coordinator included organizing and supervising all geotechnical work on the project by defining priorities and strategies, and communicating and coordinating with TYSSE section designers and geo-engineering consultants, and assigning tasks to the geo-engineering consultants at the request of the designers and TYSSE staff, reviewing and commenting on work products of the consultants and overseeing contracting and phases of work related to geotechnical activities.

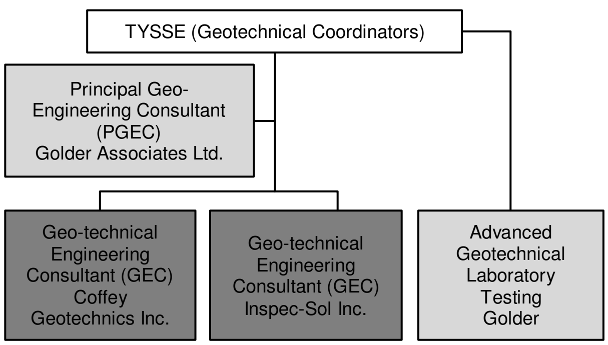

Figure 2: Schematic of the geo-engineering team

In November 2008, Golder Associates Ltd. ("Golder") was retained by TTC as the PGEC. Golder's responsibilities for the geo-engineering investigations include preparing investigation work assignments based on TYSSE defined priorities and requests from station and tunnel designers, reviewing and advising on technical aspects of the GECs work plans and data reports, summarizing and interpreting data to provide design, soil/groundwater management and environmental recommendations and providing baseline reports of subsurface conditions for construction tendering. The two GECs retained were Inspec-Sol Inc. ("Inspec-Sol") and Coffey Geotechnics Inc. ("Coffey"). They are responsible for performing all field geotechnical and geo-environmental investigations, in-situ testing, laboratory testing, and reporting factual data. Golder was also previously retained by the TTC to conduct discretionary laboratory testing for the field investigations.

3.2 Flow of Geo-Engineering Information

A system was established for the flow of geo-engineering information and data including work plans and reporting. Figure 3 presents the developed system of information and data flow within the geo-engineering team. The objectives of this system were to provide efficient development and review of investigation work plans, optimize schedules, minimize project costs as well as minimize the time of receipt, compilation and interpretation of the data. Overall, the result of this system reduced delays, provided consistent quality of work, ensured targeted scopes of investigations, expedited investigation works and reporting, ensured competitive costing and maintained consistency in reporting.

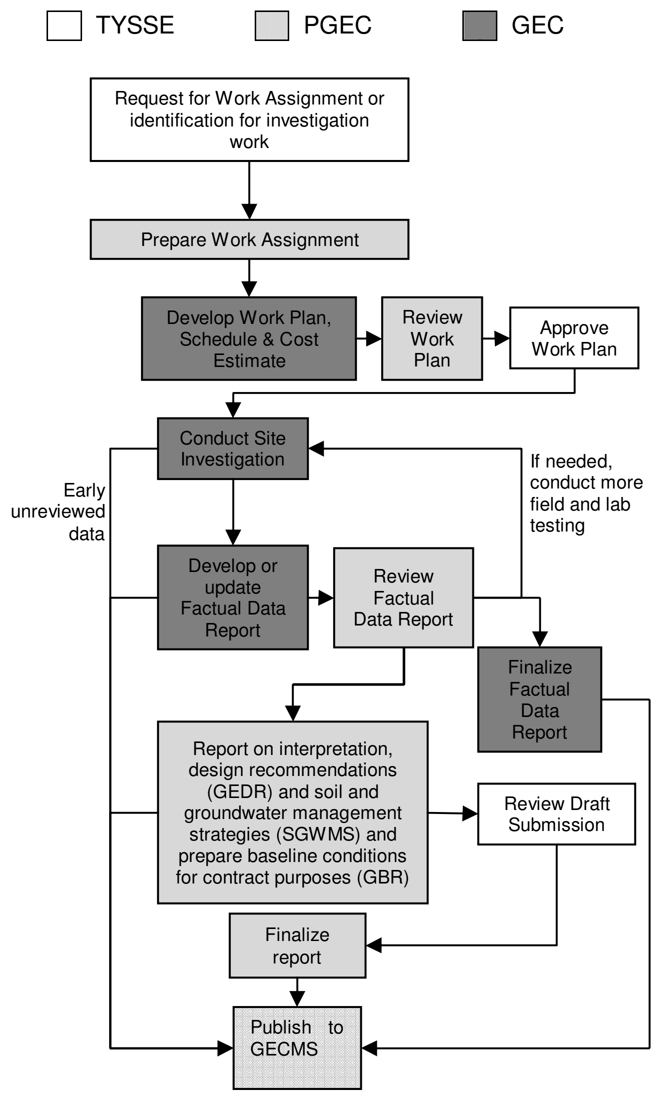

Figure 3: Geo-Engineering work and information flow chart for TYSSE, the PGEC (Golder) and the GECs (Coffey and Inspec-Sol).

3.3 Geo-Engineering Investigation Programs

The scope of work for the geo-engineering investigation program on the TYSSE project included geotechnical, geo-environmental, hydrogeological, geophysical, and Environmental Site Assessments (ESAs). The site investigation programs were divided by the TYSSE in accordance with project delivery strategy and contract packaging to set the priorities for reporting and facilitate inclusion of reports in the tender documents. This included site investigation programs for each of the six planned subway stations, south tunnel (extending from the existing Downsview Station to the planned Finch West Station) and north tunnel (extending from north of the planned Finch West Station up to the planned Vaughan Corporate Centre Station). The south and north tunnel investigations included site specific exploration for Cross Passages (CP's), Emergency Exit Buildings (EEBs), Launch Shafts (LS), Extraction Shafts (ES), and the DEPTHS.

A phased site investigation approach was adopted by the TYSSE geo-engineering team and involved initial and complementary investigations including advanced testings. The objective of this approach was to carry out the site investigations in correspondence with section designers progress and completion deadlines and allow the PGEC to report on critical subsurface conditions in the initial investigation at an early stage of design so that areas requiring additional or more sophisticated geotechnical data could be identified and addressed in the complementary investigation phase. Critical design milestones that were considered in the implementation of the phased investigation approach included a 10% and 30% preliminary design submission, 60% design submission, 90% pre-final submission and contract tender ready 100% design submission.

For the 10% design, TYSSE required the PGEC to compile historical data and issue initial Design Briefs for section designers. At the same time, PGEC was to prepare initial investigation work plans.

The phased investigation program for this project consisted of initial investigations involving the following objectives for a 30% design submission requests:

- Characterization of subsurface soil and groundwater conditions in areas of proposed station and tunnel sections;
- geotechnical laboratory testing on select soil samples to assess geotechnical properties for design requirements;
- analytical testing of select soil and groundwater samples to characterize them for environmental properties and to determine disposal options during construction;
- groundwater level measurements and hydraulic conductivity testing (ie. single well response tests).

Table 1 provides a list of the tests that were conducted as part of the initial investigation program. Results from the initial investigation provided an overview of the subsurface conditions along the alignment which was intended to be refined in the complementary investigation phase. Initial Geo-Engineering Design Reports interpreting the results of the initial site investigations were provided to TYSSE and tunnel and station designers for review and incorporation of geotechnical parameters in their 30% design submission.

Table 1: In-situ and Laboratory Testing Conducted in the Initial Investigation Phase

Initial Investigations
Borehole Drilling (150 m maximum borehole spacing for tunnels)
Standard Penetration Testing
Geotechnical Laboratory testing
- Water content
- Grain Size Distribution
- Atterberg Limits
- Density
Soil and Groundwater Chemical Testing
- Ontario Regulation 153 (metals, inorganics, pH, PHCs, VOCs, PCBs and PAHs)
- Toxicity Characteristic Leaching Procedure
- Organic vapour and headspace readings
Hydrogeological testing
- Single well response test
- Infiltration testing
Phase I Environmental Site Assessments for 54 properties

The purpose of the complementary investigations was to carry out further investigation on areas requiring additional geo-engineering data due to alignment refinements and design changes. During initial investigations and groundwater monitoring, the geo-engineering team realized that buoyancy would be an issue for consideration during design of the station due to architectural concepts adopted by the station designer that required new provisions for daylight to reach the interior of the stations. As such, work plans for the complementary investigation were developed to address buoyancy and other design requirements. Table 2 provides a summary of the types of in-situ and laboratory tests conducted during the complementary investigation phase, in addition to what is given in Table 1.

Table 2: Additional In-situ and Laboratory Testing Conducted in the Complementary Investigation Phase

Complementary Investigation – including advanced testing
Borehole Drilling (75 m maximum borehole spacing for the tunnel)
Standard Penetration testing
Geotechnical Laboratory testing
Soil and Groundwater Chemical Testing
Hydrogeological testing
- Pumping test
PQ coring
- Triaxial and isotropic consolidation testing
Pavement testing

- Multi-point deflectometer testing
Pressuremeter Testing
Corrosivity Testing
Geophysical Surveying to obtain shear wave velocities
- Vertical Seismic Profiling
- Multi-Channel Analysis of Surface Waves
- Cross-hole Seismic Testing
Phase II Environmental Site Assessments

The complementary site investigation programs were developed based on the overall results from the initial investigation phase that indicated substantial subsurface heterogeneity, variability of groundwater conditions, and subsurface impacted soil and groundwater. Approximately 600 additional boreholes (including all geotechnical, environmental and pavement boreholes) were drilled to further characterize the heterogeneous subsurface particularly for stations and in areas where the alignment was refined and at the CPs, EEBs, potentially contaminated properties) (Walters et al., 2011) (Table 3). Table 3 provides a summary of the extent of geotechnical tests conducted during the initial and complementary investigations.

Table 3: Summary of Geotechnical Testing Completed in the Initial and Complementary Investigation Phases

No. of[1]	**Phases**		**Total**
	Initial	**Complementary**	
Boreholes drilled	460	620	1080
Monitoring Wells	266	298	564
Soil Samples	5373	3663	9036
Water Content	5055	3271	8326
Grain Size Distribution	1379	1183	2562
Atterberg Limits	1089	1071	2160
Density	333	559	900
Pressure Meter		37	37
PQ BH		29	29
Triaxial		93	93
Pavement		57	57
Corrosivity		86	86
Total Drilled Depth (m)	10170	11700	21870

Table 4 provides a summary of the hydrogeological testing carried out in both phases of the investigations. Pumping tests were conducted at all the stations and at critical tunnel locations to assist with developing applications for the Permit To Take Water (PTTW) for contracts and baseline requirements established by the Ministry of the Environment (MOE) and to respond to concerns on construction dewatering activities and ground settlement by regulatory agencies Toronto and Region Conservation Authority, private entities and municipalities.

Table 4: Summary of Hydrogeological Testing

Activities	**Phase**		**Total**
	Initial	**Complementary**	
Pumping tests		14	14
Infiltration tests	3	4	7

Geophysical surveying was conducted at all six station locations using vertical seismic profiling (VSP), multi-channel analysis of surface waves (MASW) and at several locations along the alignment using cross-hole hole seismic testing. Table 5 provides the summary of the geophysical testing. A detailed description of the geophysics testing included in the complementary investigations can be found in Phillips, 2011.

Table 5: Summary of Geophysical Survey

Tests	**No. of Testing Locations**
Vertical Seismic Profiling	19
Multi-Channel Analysis of Surface Waves	5
Cross-hole seismic testing	15

Efforts to assess environmental impact by additional soil and groundwater sampling and chemical testing were conducted in conjunction with the geotechnical borehole drilling as well as through the implementation of the Phase II ESAs. The Phase II ESAs involved intrusive sampling at sites where the Phase I ESA deemed necessary and only on properties with permanent surface takings. For properties with large surface temporary takings, environmental baseline investigations involving shallow soil testing were conducted. The strategy to conduct as much environmental investigation in conjunction with the geotechnical investigations and focus only on surface takings minimized the cost of the geo-engineering investigations and maximized the chemical impact information needed to anticipate quantities for disposal during the construction phase. Table 6 provides the extent of chemical testing on soil samples.

In the interim of the Initial and Complementary investigation phases and to assist the section designers with their 60% design submission, a formal “Request For Information (RFI)” system was adopted and involved the section designer submitting any interim geo-engineering requests and/or questions to TYSSE and PGEC. All responses to RFI were incorporated into Final GEDRs and submitted one month prior to 90% design submissions. This system assisted in expediting the response time of geo-engineering data and information to section designers.

Table 6: Summary of geo-environmental chemical testing on soil samples

Tests[1]	Phase		Total
	Initial	Complementary	
pH	403	204	607
Metals	414	188	602
PHCs	335	113	448
BTEX	328	39	367
VOCs	306	102	408
PAHs	215	25	240
PCBs	37	25	62
Leachate	46	7	50
Other[2]	19	16	35

[1] Acronym Definitions:
PHCs = Petroleum Hydrocarbon Fractions F_1 to F_4
BTEX = Benzene, Toluene, Ethylbenzene, Xylene
VOCs = Volatile Organic Compounds
PAHs = Polycyclic aromatic hydrocarbons
PCBs = Polychlorinated biphenyls
[2]Includes Pesticides, Herbicides and Glycol

3.4 Communications & Data Management Systems

Three key communications and data management systems were created including a Geo-Engineering Content Management System (GECMS), a borehole data information tracking system entitled "Borehole Birth Certificates" and a monitoring well tracking system entitled "Master Well List". These systems are described in the sections below.

3.4.1 Geo-Engineering Content Management System (GECMS)

The GECMS is a secure web-based information management system designed to function as a document manager, subsurface data manager and construction monitoring instrument data manager. TYSSE management defined a concept for GECMS. The GECMS was designed and is managed by the PGEC. Specifically, the GECMS provides three primary components for storing project data related to geo-engineering services, specified as the "Geo-Engineering Document Manager", the "Spatially-based Investigation Data Manager" and the "Construction Monitoring Data Manager".

The Geo-Engineering Document Manager stores borehole logs, geotechnical reports, design memoranda, applicable figures and field visit reports uploaded by the PGEC and the GECs. The Spatially-based Investigation Data Manager provides a GIS based database that allows access and display of all spatially based data including, borehole and test pit data, laboratory test results (geotechnical and analytical), site photos and in-situ test results. The Construction Monitoring Data Management provides a web-based GIS database that will allow access and display of all construction monitoring data by an extension to the GECMS.

The overall goal of the GECMS is to facilitate internal and external communications and optimize convenient, quick access to geotechnical and environmental information for the TYSSE project team and between TYSSE and external parties. Parties provided access include TTC/TYSSE team members, the GECs, station and tunnel designers, and public stakeholders (ie. City of Toronto and York Region). Figure 4 shows a snapshot of the GECMS portal and spatial search engine.

3.4.2 Borehole Data Information Tracking System

A borehole data information tracking system was developed by TYSSE and Golder to summarize critical information on every borehole drilled for the project. The purpose of the tracking system was to provide management with compiled borehole information in a unified format for the record and a statistical tool to track the extent of field and laboratory tests conducted for budgetary purposes. A log sheet named "Borehole Birth Certificate" was created for each borehole and information was recorded on the drilling date, drilling methods, drilling depths, as well as types, sample/analysis dates, sample depths and numbers of geotechnical, geo-environmental and hydrogeological samples/tests. The Borehole Birth Certificates were completed by the GECs (Inspec-Sol and Coffey) based on the geo-engineering information contained in the factual data reports.

Figure 4: GECMS Spatial view of York University Station site borehole layout

3.4.3 Monitoring Well Data Tracking System

Monitoring wells installed during the geo-engineering investigations were to be protected during construction or decommissioned by the Contractor based on his schedule. Monitoring wells to be protected were chosen by PGEC for groundwater monitoring elevation and water quality testing purposes during construction dewatering activities as required by MOE and as needed on temporary property takings such as construction staging areas to assess environmental quality damages (if any) upon exit of the property taking. The Monitoring Well Tracking System was created to communicate the current and proposed status of all the monitoring wells to the section designers, TYSSE Construction team, TYSSE Third Party Relations team and the contractors. It contains details on the following:

- location (northing and easting coordinates, property address, proposed use of the property, screen location with respect to the geologic unit)
- Ministry of Environment Well Tag no.
- Installation/construction details (ground surface elevation, depth of well, well diameter, screen length, pipe material, flush mount or stick-up casings)
- Conditions and proposed status of the monitoring wells (i.e. to be protected or to be decommissioned, decommissioning activities and records).

The section designers were able to use this information to confirm the monitoring wells that needed to be decommissioned within the excavation or construction areas while the other recipients of the Well Tracking System used it as an information database primarily during property acquisition and construction.

4 ACHIEVEMENTS

The management strategies adopted for the geo-engineering component of the TYSSE project resulted in successful completion of geo-engineering investigations and submission of deliverables on time with critical design and project deadlines.

In summary, approximately 95% of the geo-engineering investigations were completed within the allotted 2.5 year period. An illustration of the amount of borehole investigations completed parallel to the project's design schedule is shown in Figure 4. The number of boreholes and total drilled depth per month are plotted alongside the design phase schedule of each station and tunnel, showing evidence of peak periods of investigation during 10%-30% and 60%-90% design periods, consistent with design requirements of geotechnical information at 30% and 90% design submissions.

Table 7 provides a summary of reports submitted for the project by the geo-engineering team. To date, a total of 192 final reports and technical memoranda have been issued. Reports were produced at an average rate of 2 reports bi-weekly.

Table 7: Number of Geo-Engineering Reports and Technical Memoranda[1]

Geotechnical Summary Report for TBM Procurement (Golder)	1
Initial Geo-Engineering Factual Data Reports (Inspec-Sol and Coffey)	10
Initial Geo-Engineering Design Reports (Golder)	9
Complementary Geo-Engineering Factual Data Reports (Inspec-Sol, Coffey and Golder)	16
Final Geo-Engineering Design Reports (Golder)	13
Soil and Groundwater Management Strategy Reports (Golder)	8
Geotechnical Baseline Reports (Golder)	8
Environmental Site Assessment Reports (Inspec-Sol, Coffey and Golder)	42
Response to Request for Information (RFI) (Golder)	48
Technical Memorandums (Golder)	38
Total	**192**
Bi-weekly Rate	**2**

[1]Includes final reports only.

To date, a total of 1080 geotechnical, environmental, hydrogeological and pavement boreholes (21,900 metres drilled length) have been drilled for the 8.6km alignment in less than the allotted timeframe (Table 3). On average, 1.5 boreholes and 30 m of drilling were completed per day given a total period of investigation of 700 days.

Past tunnelling projects indicate an optimum level of investigation efforts corresponding to a borehole to tunnel length between 0.5 – 1.5 and a geotechnical program cost of 3% of the total project budget (USNCTT, 1984). For the TYSSE project, the geotechnical sampled borehole to tunnel length ratio was 0.55 and the geo-engineering investigation and reporting cost is estimated to be at 0.8% of the total project budget.

5 CONCLUSION

Overall, the geo-engineering team succeeded in carrying out the required investigations to meet schedule constraints. This was achieved through the early recognition of the challenges specific to the project. As a result clear management strategies were implemented to optimize costs and minimize schedule impacts that in essence led to the successful completion of the geo-investigations for the TYSSE project.

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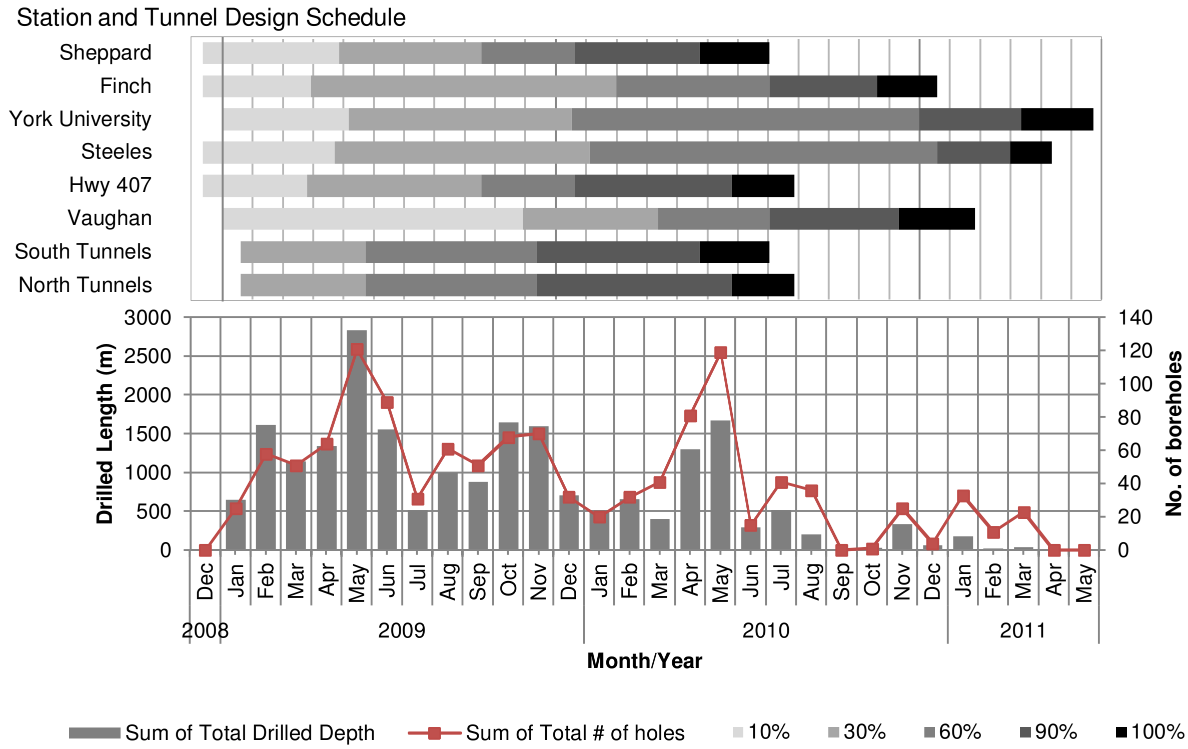

Figure 5: Comparison of Design Schedule to Number of Boreholes and Total Depth Drilled

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