The Toronto – York Spadina Subway Extension – An Overview

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1 Introduction
The Toronto – York Spadina Subway Extension (TYSSE) is the first subway tunnel project to be constructed for Toronto Transit Commission (TTC) since the Sheppard Subway Line was successfully completed and opened in November 2002. It is an extension of the existing TTC subway system and the first subway line to cross the municipal boundary between the City of Toronto and the Regional Municipality of York (York Region). The intention of this paper is to provide a high level overview rather than a detailed technical description.

2 Subway and LRT Construction in Toronto, Past, Present and Future
It was fitting that Yonge Street, the World’s longest street and the dividing spine of the city, was the location of the first subway from near the lakeside and the railway hub, Union Station, 7.4km north to Eglinton. Constructed mainly in open-cut with extensive traffic decking, work began in September 1949, requiring the demolition of many dwellings. Where the alignment traversed beneath important buildings, underpinning was performed using a combination of concrete caissons and heavy steel girders. Only the section under the Canadian Pacific tracks near Shaftsbury Avenue was mined. The first section was planned to open in 1953 but the outbreak of the Korean War resulted in a shortage of steel delaying completion till 1954. The subway system continued to expand with the University Subway to St George completed in 1963. The first East – West line, the Bloor Danforth Subway from Keele to Woodbine, opened in 1966 and was extended further to Islington and Warden in 1968 and Kipling and Kennedy in 1980. The Yonge Line was extended to York Mills in 1973 and the following year to Finch. The Spadina Line was extended to Wilson in 1978 and Downsview in 1996. The second East – West line, the Sheppard Subway, Yonge to Don Mills was completed late in 2002. Figure 1 depicts the present TTC system, together with the upcoming TYSSE.

TYSSE is the first of a tranche of new transit projects. The Yonge Line will be extended north from Finch and it will also cross the municipal boundary and terminate within York Region. Eight lines of Light Rail Transit (LRT), 126km in total, are planned under the banner of Transit City and are currently in the preliminary design phase. At 33km long, Eglinton Crosstown in the most ambitious of the Transit City projects; one third of this alignment will be tunnelled.

3 Toronto-York Spadina Subway Extension (TYSSE)
The total length of the Toronto-York Spadina Subway Extension (TYSSE) is 8.6 km. 6.2 km is within the City of Toronto and 2.4 km in York Region. The estimated cost of the extension is $2.63 billion. The extension comprises a total of 6.7 km of twin bored tunnels with 6 new stations, associated cross-overs, storage track and a yard connection. Additionally there are 7 Emergency
Exit Buildings (EEBs) and 7 cross-passages (CPs). There is a tail track with a cross-over structure at the northern terminal station and a turn back facility mid-alignment within a double-ended pocket track. The 6 stations are Sheppard West Station, situated on Parc Downsview Parklands, Finch West Station, located at Keele Street and Finch Avenue, York University Station situated within the heart of York University, Steeles West Station at Northwest Gate and Steeles Avenue, Highway 407 Station adjacent to Highway 407 and Jane Street and Vaughan Corporate Centre Station located near Highway 7 west of Jane Street. There is a total of 2,900 new parking spaces at three of these stations. The subway line revenue service will start in late 2015. A schematic of the alignment is depicted in Figure 2.

Detailed design assignments for the stations were awarded in September 2008 followed one month later by the award of the twin tunnels design contract. Other consultant assignments were activated around that time including geotechnical investigation and tunnel ventilation design. At the time of writing this paper (November 2009) the station designs have progressed to between 10% and 30%. The twin tunnels design is approaching 60% level. The first TYSSE construction contract, the connection to Wilson Yard, was awarded late October 2009. Early in 2010 smaller advanced work contracts will be awarded. The main construction contracts, described later in this paper, will be awarded between October 2010 and January 2011.

Due to the way the project developed and its location, there are three approved Environmental Assessments (EA) for the TYSSE. A Provincial EA for the portion Downsview to Steeles West was approved in March 2007 followed one month later by the portion Steeles West to Vaughan Corporate Centre. A Federal EA for the entire project received approval in March 2008.

### Figure 1

#### 4 Project Funding and Organization

Funding for the Project is secured. It is jointly funded by the Government of Canada who have committed $697 million. The Province of Ontario has provided $1059 million, the City of Toronto and The Regional Municipality of York have committed $526 million and $352 million respectively.

An Executive Task Force (ETF) was established for the purpose of overseeing the development and construction of the project. It is made up of representatives from both municipalities and the province. Three project consultant roles have been identified in the TYSSE organisation. The Project Management Consultant (PMC) was appointed in April 2008. The appointee, Spadina Link JV, comprises three consultants, Hatch Mott MacDonald, Delcan Corporation and the MMM Group. Around the same time the Project Controls Consultant (PCC), Stantec, was appointed. A Request for Proposal (RFP) is being prepared for the third consultant, the Construction Management Consultant (CMC).
There are over 100 stakeholders involved in the project. The four funding partners, all the different departments of TTC, including TTC Operations, the ultimate client as they will operate the facility upon completion. The municipalities have their own numerous departments, as does the Province. Property owners, environmental protection agencies, crown corporations, the list goes on, suffice it to say that all entities affected in some way, or that have an interest in the project, have been identified and their needs and aspirations taken into account at each stage of the project. Unsurprisingly, sometimes the stakeholders have conflicting requirements, or requirements which are deemed by the designers to be too onerous. This represents one of the many challenges for the project and a separate group within PMC has been established solely to deal with stakeholders’ issues. The PMC oversees and coordinates the efforts of the design teams. The designs for Sheppard West and Highway 407 Stations are undertaken by AECOM. Finch West and Steeles West Stations are being designed by The Spadina Group Associates (TSGA). York University and Vaughan Corporate Centre Stations are being designed by Arup. Additionally there is a Project Geo-Engineering Consultant (PGEC), Golder Associates, and two Geo-technical Engineering Consultants (GEC), Inspect-Sol and Coffey. Tunnel Ventilation design is being carried out by a separate team from AECOM and another team from Arup carried out a system-wide study into the feasibility of installing Platform Edge Doors within the existing 69 TTC stations and made recommendations for future extensions of the system, including TYSSE.

While the station locations and tunnel alignment were set in the EA, subsequent adjustments to station locations as well as to the vertical and horizontal alignment have been made during the detailed design to improve the stations functionality, overall subway operational efficiency, constructability and cost efficiency. The alignment changes were performed in parallel with the design development of station and tunnel components.

Geotechnical investigation commenced at the end of 2008. 350 boreholes were completed for the initial investigation phase. At one time as many as 11 drilling rigs were working on the project. The overall geology consists of alluvial deposits, Upper Till, which is stiff to hard, predominately cohesive but interspersed with cohesionless zones, and very stiff to hard Lower Till. In places the till layers are separated by the very dense Upper Sand and Silt formations.

5 Project Delivery Strategy

Opinion was sought from consultants and contractors and internally from TTC in various Project Delivery Strategy workshops held in late 2008 following which TYSSE adopted a Design Bid Build approach with six main contract packages. Some long ‘lead in’ delivery items have been procured directly by TTC in order to protect the project schedule. These items include TBMs, precast tunnel liners and some systems elements. The main contract packaging aims to divide the work into contracts of “reasonable” size, under $400 million. In addition to the main contracts, smaller advanced contracts are planned. Tunnelling long drive lengths would have been advantageous for the tunnel schedule and TBM utilisation but these would present disadvantages for the stations, systems/trackwork activities and the overall schedule. Hence the present option with five pairs of drives using four TBMs. Advance utility contracts will commence from early 2010. A connection into the main yard commenced late 2009 with the Wilson Yard Connection. Advance launch shafts will commence April 2010 together with enabling works at Highway 407 Station. Station and tunnel construction will start from late 2010. The typical duration of station construction is 44 months. The twin tunnels will be completed in just over two years.

While TTC is negotiating in good faith with property owners, a parallel process of expropriation to acquire properties is underway to fall back to in cases where negotiations break down since the expropriation process takes up to 18 months.

A project of this magnitude will inevitably lead to traffic disruption. The fact is that the TYSSE alignment runs diagonally to the major street grid. Therefore, traffic will be disrupted on three
adjacent main streets in the north-south direction (Dufferin, Keele, Jane) as well as three main streets in the east-west direction (Finch, Steeles and Highway 7), creating a large traffic disruption zone. The station excavations will obstruct the free flow of traffic with the additional volume of construction traffic also being a significant factor. The project team is endeavouring to minimise these disruptions.

The Occupational Health and Safety Act (OHSA) in Ontario mandates that only one “Constructor” may occupy a designated site at any given time. On occasions when two or more contractors are required to be on a given site, one of these contractors is designated the role of “Constructor” under the act or else this role reverts to the owner. Recognition of this has influenced some of the decisions which have been made with respect to construction packages and interfaces. Topography and surrounding infrastructure has also had a bearing. From cost and construction efficiency perspectives it is preferable to start TBM mining from one end of the alignment and retrieve the TBMs at the other end, mining or dragging TBMs through stations. Land availability at Downsview and at Vaughan Corporate Centre, prevented these two locations from being used as tunnelling sites. Additionally, operational tunnel drives through a station delay construction activities within the station until the tunnel driving has been completed. In order to drag TBMs through previously excavated station pits, the station excavations must be completed well ahead of the TBMs arriving. Since the major construction contracts will be concurrent and cannot be postponed due to the set project delivery date, the desired long, uninterrupted drives through stations could not be implemented. However, exceptions had to be made based on local situations. For instance York University Station is shoe-horned in between campus buildings. Building the station itself here will stretch construction logistics without the added complication of either supporting a tunnel operation or retrieving TBMs, hence this station must be mined through prior to the station excavation. For that reason this is one of the first TBM drives. Typically, cross-over and tail track boxes allow a clean break to be made between the station contractor and the tunnel contractor who can launch or recover his TBMs and complete the permanent work at this location in a clearly defined and separate site. The interface cannot be clearly defined when the launch shaft is within the station footprint. This is why Sheppard West Station and Highway 407 Station, which are suitable tunnel launch sites but where there are no cross-over or tail track structures, are contractually combined with the twin tunnels drives emanating from them.

In total there are six main construction packages for TYSSE as described below. Contractors for all major contracts will be pre-qualified. The main prequalification categories will be for station general contractors, tunnelling, and specialist contractors, such as compensation grouting.

5.1 Northern Tunnel and Highway 407 Station Package

This package comprises Highway 407 Station and 3.6 km of bored twin tunnel from the double-ended pocket track north of Finch West Station to Vaughan Corporate Centre Station. TBMs will be launched from both ends of Highway 407 Station. This package includes the double-ended pocket track north of Finch West Station. A 55m long launch shaft within the south end of Steeles West Station cross-over box is to be excavated and supported by others under an Advanced TBM Launch Shaft contract. The "drive through" headwalls at York University Station are also constructed under this contract. The TBMs will drive though the York University Station continuing on to the extraction shaft at the northern wye of the double-ended pocket track. Compensation Grouting is required for settlement management at the Schulich Building. The extraction Shaft within the north end of Steeles West Station will be completed by the Steeles West Station Contractor but the Northern Tunnel Contractor will be given possession of this shaft for the purposes of recovering both TBMs during a mile-stoned possession period. This is not an ideal interface but it is unavoidable. A 45m long TBM extraction shaft is required within the south end of Vaughan Corporate Centre cross-over box. Three CPs and three EEBs are also part of this package. Two of the EEBs are oversized as they will be used as systems dropshafts after tunnelling has been completed.
5.2 Southern Tunnel and Sheppard West Station Package

Includes Sheppard West Station together with 2.9 km of bored twin tunnel from Downsview tail track to Finch West Station. The TBM launch shaft on the west side of Sheppard West Station for the drives to Finch West Station will be excavated and supported by others under an Advanced Launch Shaft Contract. This Contractor will excavate, support and construct the external launch shaft on the east side.
of Sheppard West Station for the drives to Downsview tail track. A 45m long extraction shaft is required within the south end of Finch West Station cross-over box. Part of the Downsview tail track structure has to be demolished and re-built to accommodate the TYSSE alignment and a TBM extraction shaft is required here. Four CPs and three EEBs are also part of this package.

5.3 Finch West Station

This contract comprises the station construction together with a cross-over box at the south end of the station up to the interface with the TBM extraction shaft. Surface facilities include a bus terminal and Passenger Pick Up and Drop Off (PPUDO).

5.4 York University Station

This contract comprises the station construction with no notable surface transit facilities.

5.5 Steeles West Station

This contract comprises the station box together with a cross-over box at the south end of the station up to the interface with the launch shaft. A TBM extraction shaft is required at the north end of the station. Surface facilities include two bus terminals, one for York Region, the other for the City of Toronto and a PPUDO.

5.6 Vaughan Corporate Centre Station

This contract comprises the station box together with a cross-over box at the south end of the station up to the interface with the extraction shaft and a tail track structure. Surface facilities for York Region include a small bus terminal and a PPUDO.

5.7 Early Contracts

Early contracts include the Wilson Yard Connection, which provides a non-revenue connection between TYSSE and the subway car yard, two advanced TBM launch shafts, a new Firehall on Keele Street. Advanced enabling works are required at Finch West Station and include utility relocates, modifications of the existing road network ahead of the station construction and creation of a new car parking facility. Enabling works at Highway 407 Station include the construction of a 6-lane access bridge across Black Creek, relocation of the creek itself and a sanitary sewer.

6 Station Design Philosophy

The involvement of architects from around the world has been encouraged and achieved. The TYSSE design philosophy encourages section designers to incorporate the simple flow of space, bright, open spaced, column-free structures with high ceillings with daylight penetrating deep within the stations to platform level. The design of all elements is required with strong aesthetics and including integrated art. Well renowned artists have been assigned to each of the stations. While some of the early concepts were scaled down, the philosophy of the concepts has been largely preserved. All stations have a 152.4m long centre platform. Platform Edge Doors (PEDs) are to be installed at some date although not necessarily on the opening day. Examples of the concepts for Sheppard West and York University Stations are shown in Figures 3 and 4.
**7 Twin Tunnels**

There are 6.7km of 5.4m internal diameter twin bored tunnels in total. The tunnel lining is procured directly by TTC. The tunnel diameter on TYSSE is slightly larger compared to the previously built TTC tunnels to satisfy the tunnel evacuation walkway clearances recommended by NFPA 130 (2007). The trapezoid/parallelogram six segment lining rings are gasketted and typically reinforced with welded wire mesh. TTC is considering steel fibre reinforced concrete (SFRC) for future projects and will be installing 100 SFRC trial rings as part of the TYSSE project. Other notable features of the lining include ionic and diffusion limits for concrete for the lining durability, 60 MPa concrete, self-locking dowels and guide rods to ensure proper ring build as well as bar code traceability of individual segments from production to installation and future maintenance.

TTC is procuring four TBMs. Lovat has been awarded the TBM supply contract after a competitive tender process. Since tunnelling settlement control is an important concern on this project, two-component grouting through tail-seals has been mandated as well as full time earth pressure balance operation. Features of the TBMs include vacuum segment handling, inflatable emergency tail-seals and Lovat on-site maintenance support throughout the tunnelling duration.

The subway alignment passes beneath a developed, urban environment. The bored tunnels pass directly under 17 buildings and close by many others. They are in close proximity to Hydro One 500kV and 230kV towers, under a CN line north of Steeles Avenue, and under Highway 407. There are also numerous underground utilities crossings. To assess the impact of the tunneling on these structures the designers have assumed TBM face loss of 1% for analysis although the anticipated value, based upon experience from the Sheppard Subway, is less than 0.5%. The influence of the settlements on the buildings has been assessed using 3D frame analysis.

Analysis showed that settlement mitigation is required at the Schulich Building, immediately to the south of York University Station (as depicted in Figure 3). The station virtually abuts the building. Settlements will occur from the passage of each TBM and from excavation of the station. An assessment was carried out for various depths of tunnels to see whether there was significant benefit in lowering the alignment at this location. Whilst the influence from tunnelling lessens with depth, settlement from the station excavation increases with depth eliminating the benefits of deepening the tunnel alignment. In any case, building damage prediction remained unacceptably high and hence settlement mitigation was required. Having decided to maintain the original vertical alignment to control the station cost, compensation grouting was brought forth as the selected building protection method. The compensation grouting shafts and grouting arrays will be constructed well in advance of the tunnel drives and the ground will be preconditioned and pre-heaved. A sophisticated real time instrumentation programme will be required to support this process. A contracting strategy debate arises how best to procure the services of the compensation grouting contractor with multiple contractors contributing to the settlements.

Seven EEBs and seven CP’s are currently proposed. Small diameter (200mm diameter) connections (negative ties) are also required between the twin tunnels to cross connect traction power lines. The EEBs support of excavation system (SOE) will be installed and the shafts will be excavated down to tunnel level and backfilled ahead of the passage of the TBMs on either side. This avoids the possibility of damaging the tunnels by installing SOE close to the tunnels or a blow out of the pressurized TBM face into the empty EEB shaft. Some EEBs are strategically located at the alignment low points where they incorporate a pumping station. The spacing of the EEBs complies with NFPA 130 (2007). Cross-passages are used mainly for TTC maintenance personnel access but they also house some small systems equipment.

A short-turn facility is required at mid-alignment requiring the introduction of a double-ended pocket track, located just north of the Finch West Station beneath the Hydro One transmission corridor. The structure will consist of around 165m of triple-track structure, with box structures
housing the wye tracks. There are a significant number of buried and overhead utilities at the pocket track location. Of particular concern is a series of high-voltage overhead power lines that allow a working vertical clearance of just 6.7m, which is generally considered impractical for the installation of the commonly used soldier pile and lagging shoring system. Alternative solutions were considered. The investigation and geotechnical assessment concluded that Sequential Excavation Method (SEM) is feasible and the most advantageous method for constructing the triple–track portion of the pocket track. The wyes will be located well outside the low overhead wires and will be constructed by traditional cut and cover. This will be the first large scale use of soft ground SEM in the Toronto area.

8 Systems Installations / Trackwork

Separate systems installation contracts will follow the main station and twin tunnels contracts. These contracts will include production and installation of elastomer isolated concrete double ties, trackwork, automatic train control, communications and signals, SCADA, traction power, emergency tunnel ventilation, fare vending and collection equipment and other service elements.

9 Conclusion

The project team face a plethora of challenges. The schedule is extremely aggressive in order to achieve project completion by the opening deadline in late 2015. It limits time, from “EA” level design to tender in under one and half years and from construction start to revenue service in less than 5 years. There are a number of staging and contract interface issues. Architectural aspirations have led to creative tensions and budget pressures. Additional budget demands have surfaced early in the design stage as the project has to absorb costs not contemplated earlier in the programme. Geo-engineering investigation parallel to design has created technical design pressures on all involved. Open-cut structures are to be built on postage stamp sized sites whilst at the same time maintaining traffic flows and services in their vicinity. There are many environmental issues including tunnelling under the woodlots where disturbance of the hydrology could affect the woodlot health, bird nesting and archeological investigations. There are major crossings to be considered including railways lines, oil pipelines, watercourses and major highways. Over 40% of the alignment involves tunnelling under non-municipal properties. Tunnelling under existing buildings, namely Schulich Building at York University, is particularly challenging. There exists, however, an incredible “can do” spirit within TYSSE and amongst the consultants involved to date and the hope and anticipation is that this infectious strive to succeed ethos will carry over from the design stage into construction leading to the successful completion of the project with respect to budget, schedule, quality and stakeholder aspirations.

References and Acknowledgments

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