

APPENDIX P

CONSTRUCTION METHODS REPORT



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1. Introduction

The Spadina Subway Extension consists of the addition of a new double-track segment approximately 6.2 km long that would extend from the existing Downsview station to a new terminus station at Steeles Avenue (see Exhibit 1). The project area is an urbanized area with numerous commercial, light industrial, institutional and residential buildings. Other key features include streets with associated utilities, parking lots and other open spaces.

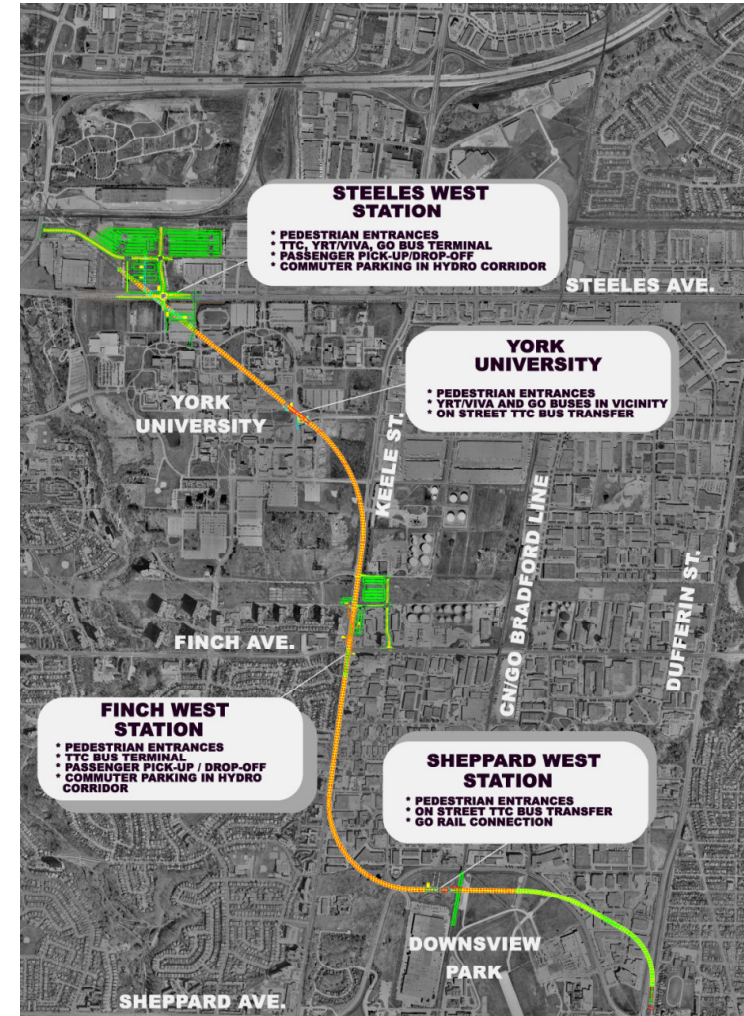
Through the development of alignments and the assessment of associated impacts to the environment, the Environmental Assessment has determined that the recommended alignment will be below grade. Therefore, this report:

- Evaluates alternative construction methodologies
- Identify a preferred method of construction for the recommended alignment
- Discuss potential impacts and possible refinements to the preferred methodology in response to site-specific concerns.

This report refers to the Design Manual (DM) of the Toronto Transit Commission (TTC).

The findings of this report are preliminary in nature and is intended to provide some technical insight into construction and planning. Significant research and analysis are required to confirm the ultimate construction methodology, which will be finalized in consultation with CN and GO during the design phase.

Exhibit 1: The recommended alignment



2. Geological Features Extracts

2.1 SITE GEOLOGY

As part of this EA, a geotechnical investigation was undertaken (see Appendix D). The following is a summary of this report. The soil deposits in the Toronto region consist predominantly of glacial till, glaciolacustrine, and glaciofluvial sand, silt, and clay deposits. These deposits were laid down by glaciers and associated glacial rivers and lakes. The soil deposits overlie the Georgian Bay Formation bedrock which consists primarily of shale with interbeds of limestone and siltstone. This bedrock formation is generally found about 50 to 75 m below the ground surface in the region of the proposed subway alignment.

2.2 SUBSURFACE CONDITIONS ALONG PROPOSED ALIGNMENT

In general, the stratigraphy at the site is defined by a sheet of predominantly cohesive glacial till (Upper Till) encountered from near the surface to depths typically on the order of 5 to 15 m thick. In some areas, however, this glacial till layer may be found to depths of 20 to 25 m. Below the Upper Till deposits of relatively uniform glaciolacustrine or glaciofluvial sand and silt (Upper Sand/Silt) are commonly encountered with thicknesses on the order of 5 to 10 m. The Upper Sand/Silt Deposit is notably thicker near the Sheppard West Station, between the Finch West and York University stations, and between the York University and Steeles West stations. Cohesive deposits were encountered below the Upper Sand/Silt in many of the boreholes that penetrated this deposit. In some cases, the samples included coarse sand and fine gravel and were interpreted as indicative of glacial till. For more detailed information see Appendix 'D'.

Station	Base Slab Elevation (m)	Founding Soil	Head Difference to BaseSlab (Piezometer) (m)
GO/SheppardAvenue	180	Silt;Clayey Silt(Interstadial)	+9
Keele/Finch	178	Clayey Silt to Silty Clay Till;Clayey Silt (Interstadial)	+15
York University	175	Sandy Silt to Sand and Silt Till	+24
Steeles Avenue	180	Clayey Silt to Silty Clay Till	+16

Note: 1) Elevation of base slab is estimated from the subway vertical alignment profile provided by URS;

to be reviewed as needed with the final EA alignment.

2) The head difference is obtained using the latest water level measurements in piezometers.

3) (+) refers to water head (in metres) above the elevation of base slab at each proposed station.

3. Alternative Project Delivery Methods and Issues

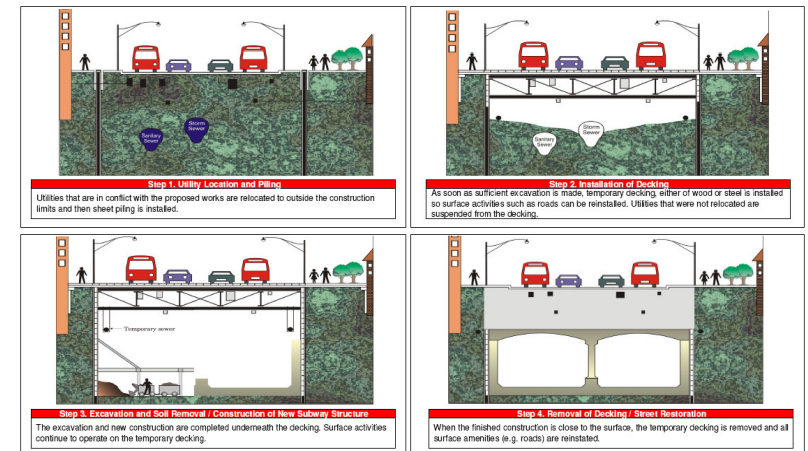
The following is a general overview of construction methods that may be implemented for subway construction. Issues including recent local experience in subway construction, availability of local construction expertise, schedule requirements and funding stream, and cost estimates may influence the final choice.

3.1 CUT AND COVER

This method has been used to construct transit subway systems for more than 100 years. The ground surface is opened (cut) a sufficient depth to construct the subway tunnel structure and ancillary facilities. The sides of the excavation are usually supported by vertical temporary walls to minimize the volume of material excavated and to protect adjacent facilities and buildings. The walls require cross-bracing or tiebacks for support. Once the construction excavation is complete, the contractor constructs from the bottom to the top of the construction site. Once the construction is complete, the surface is reinstated.

The cut-and-cover method results in larger quantities of excavated material and is suitable for shallow cuts (no more than 20 m depth). It also requires few special procedures and can be constructed in an expedited manner.

When cut-and-cover methods are used within existing roads and streets, traffic may be maintained (with some restrictions) on the road by means of temporarily covering the excavated area with decking that is supported on the side support of excavation walls. Existing utility lines must be supported or relocated.



Limitations

Alignments constructed by means of cut-and-cover methods may cause significant drawdown of the groundwater table near the cut, depending on the type of excavation support walls used. As a result, the bearing strength of shallow foundations for nearby buildings may be jeopardized, resulting in damage to the supported structure. Relatively watertight support of excavation walls constructed by tight sheet piles, the slurry trench-tremie concrete, or the soil-mix method will avoid this occurrence.

3.1.1 Locations For Cut-and-Cover

3.1.1.1 Stations

Subway stations are commonly constructed by means of the cut-and-cover method because their irregular shape is not suitable for a TBM. As per the geotechnical report, dewatering will be required at Finch West station, York University station and the Steeles west station. Cut -and-Cover method will be used at

1. Sheppard West Station
2. Finch West Station
3. York University Station
4. Steeles West station

3.1.1.2 Crossover Tracks and Tail Tracks

Crossover tracks are built alongside some stations. They are used to change the travel directions of trains either at the terminal stations or when they are making short turn trips. They include track switches and curved tracks with shorter radii for the trains to move from one track to another. These sections have to be built to fit the track geometry and can only be done by Cut-and-Cover. Tail tracks are associated with terminal stations and are used for the storage of trains during off-peak hours. As with the crossover tracks they also have switches and changeover tracks and have to be built using the cut and cover method. On the Spadina Subway Extension crossover tracks are provided at Finch West station and Steeles West Station and Tail Tracks are provided at the Steeles West station.

3.1.1.3 TBM Launch and Removal Sites

Tunnel Boring Machine (TBM) launch and removal sites have to be done by open cut. The actual tunneling process is described in the next section. The launch sites preferably have to be on a tangent section of the alignment. The TBM is assembled in the cut before tunneling. Similarly the removal of the TBM is also done in an open cut where it is taken apart and removed from the ground. The possible locations for a TBM launch is at the crossover track location south of Steeles West station or along a tangent section inside Parc Downsview Park and the north end of the existing tail track at Downsview Station.

3.1.1.4 Shallow Running Structures

Tunnel Boring Machines operate generally at a depth of 1.5 to 2 tunnel diameters. For shallow Tunneling running structures TBM operation becomes impractical. Cut-and-cover construction methods may result in a more economical project at locations along the alignment where unoccupied spaces or roadways occur on the surface, and the subway profile can be positioned closer to the surface. Twin or single concrete box structures are used in such locations and are built by cut-and-cover method. The section of the subway inside Parc Downsview Park lands is a potential location for cut-and-cover method of construction.

3.2 TUNNELING

Tunneling uses a large machine, usually built for the specific project, to excavate a tunnel, handle the excavated material, and place the initial tunnel lining, in a continuous, highly automated process. The front end of the machine consists of a circular cutting face that excavates the soil and pulls it into its round shell.

Because most of the tunneling activity occurs below the ground level, disruption to traffic and buildings is minimized. Tunneling method is proposed for the running structures from Sheppard West Station to Steeles West Station and from Sheppard Avenue West to Downsview station. Earth Pressure Balance (EPB) tunneling methodology maintains a constant pressure along the cutting face through the use of a continuous injection of a slurry mixture. Excavated soil and slurry mixture are removed and the soil and slurry are separated to allow the reuse of the slurry. EPB reduces construction related settlement above the tunnel and minimizes the amount of ground water that enters into the construction area. Figures of Tunnel Boring Machine are provided in Chapter 7 of the EA report.

Limitations

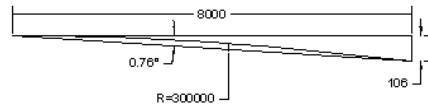
Although tunnels are generally non-disruptive to anything on the surface they have to maintain minimum vertical clearances to building foundations and structures above. The general clearance maintained is 1.5 to 2 tunnel diameters (9-12m). This causes the alignment to be deeper in some locations as under the Schulich School of Business. As a consequence of this, the adjoining York University station might be much deeper than the others. This increases the construction cost of the station.

Tunneling provides great challenges at curves with very short radii. Although tunnels have been made with very short radii they are done with customized machinery. For the Spadina Subway Extension the shortest tunneling radii, has been set at 300m. This is dealt with in details later in this section.

Tunnels built on a small radius also present a challenge to the design and installation of the precast concrete liner segments if used as the initial lining. The segments must have varying widths and out-of-plane joint faces. The jacking force from the TBM that is imposed on the liner is also out of plane in the curved section. If segment joints are not placed as designed, the joint filler may move or segment joint faces may spall, resulting in leaks.

3.2.1 TBM Construction Methods at short curves

Construction of sharp curves along the alignment using TBM are always challenging. The TBM consists of 8m long segments arranged in succession. The curve is formed by tunneling chord lengths of 8m. This would cause the alignment of the TBM segment to be out of line with the subway alignment. The shortest curve on the subway extension alignment is 300m immediately north of Downsview Station. For a 300m curve the approximate deflection angle is 0.76°. This would cause an 8m segment of the TBM to be off the design alignment by about 106mm.



Superelevation is provided on curved alignments to a maximum of 100mm. As per the TTC Design manual DM-204-02 Fig 1.8.9 the shift in alignment on curves is a function of the superelevation provided. For a superelevation of 100mm the horizontal shift in alignment is calculated to be 109mm. Therefore the shift in alignment due to tunneling is within the required shift due to superelevation.

The other challenge is the ability of the TBM to successfully negotiate through soft ground, with low risk of misalignment. In response, the project team undertook the following research:

- Discussion with Lovat Inc (manufacturers of TBM) in discussion with Golder Associates (Geotechnical Consultant), has concluded that the absolute minimum radius to construct a tunnel using TBM is 300m. This would however necessitate the use of custom designed TBMs and liners for such a curve.
- Although the short curvature of the alignment is a limitation of tunneling, various tunnels have been constructed with radii below 300m. The following list of project show the tunnel diameters and the shortest curves on the alignment.

References Regarding Tunnel Curvature and TBMs

- Rapid Excavation and Tunneling Conference, June 1993.
"The Fort Lawton Parallel Tunnel," Seattle, Wa., by B. Fulcher. This paper reports on a 2.5 km tunnel for a sewer, 4.72 m diameter, in soft ground, using a TBM with steel rib/lagging liner. The alignment had two curves with radius equal to 152 m.
- Rapid Excavation and Tunneling Conference, June 1995.

"Construction of the Passante Ferroviario Link," Milan, Italy, by P. Marcheselli and J.Y. Peron. This paper reports on a 2.6 km transit tunnel, 6.9 m diameter, using a TBM in soft ground on alignments with a radius equal to 360 m.

- Rapid Excavation and Tunneling Conference, June 2001.
"Starter Tunnel and TBM Mining on Construction Package No. 3A," Boston, Ma., by Jeff Salai. This paper reports on a 1.3-km tunnel in rock for water supply, having a diameter of 4.94 m, excavated with a TBM. The alignment included a radius of 275 m.
- Rapid Excavation and Tunneling Conference, June 2003
"The Airside Road Tunnel" Heathrow Airport, U.K., by A.W. Darby. This paper reports on a 1.3-km vehicle tunnel, 8.8 m in diameter, in soft ground excavated with a TBM, on alignments with a radius of 400 m.
- Civil Engineering, February 1990.
"Downtown in Soft Ground," Seattle, Wa., by J.W. Critchfield and J.F. MacDonald. This article describes a 1.5-km vehicle tunnel, 6.5 m in diameter, in soft ground excavated with a TBM on alignments including radii of 172 m and 81 m.

3.3 OTHER METHODS OF SUBWAY CONSTRUCTION

3.3.1 Mining with Sequential Headings (NATM)

This method of excavating combines ancient methods of mining with modern methods for immediately supporting the soils at the exposed heading. The tunnel structure is designed to benefit from soil/structure interaction, and instrumentation is employed to monitor geologic reactions to the work. If observations indicate unexpected geologic behavior, the design and construction procedure may be modified quickly to adapt to geologic conditions with modest construction cost implications. It has been in use for more than 50 years. It utilizes small tools and light equipment for excavation, which proceeds in discretely sized increments. In soft ground with seams of sand, the heading may be previously stabilized by piling support, ground improvement grouting prior to excavation, and then with concrete by means of shotcreting the exposed surfaces, providing rapid initial support. Since stabilization of the heading immediately follows excavation, there is usually only minimal surface subsidence caused by this method. As the initial tunnel progresses and the incrementally excavated headings develop into the final shape, the final lining is constructed. Waterproofing liners may be installed readily between the initial and final linings. Progress must be deliberate due to the sequential method being used, however the investment in tunneling equipment and time required for mobilization is minimal. Progress may be improved when multiple headings are opened from station cut-and-cover sites. This method is ideal for short lengths of tunnel or for tunnels with changing or irregular shapes and profiles. There are no proposed applications of this approach for the SSE project.

3.3.2 Jacking Pre-cast Tunnel Sections

This method consists of building a complete tunnel structure in a pit, then forcing it by means of powerful jacks into its design position. It may only be suitable for short segments of tunnel, as the resistance to jacking forces increases as the length of tunnel increases. It has been used in a few cases where special surface conditions made other tunnel construction methods untenable. The material ahead of the tunnel as it is jacked forward is removed by mining techniques. This material usually must be treated to obtain sufficient "stand-up" time using ground freezing or grouting methods. There are no proposed applications of this approach for the SSE project.

4. Site Specific Issues

4.1 YORK UNIVERSITY

An initial horizontal plan alignment for the Spadina subway extension has been selected. A portion of the new subway will be located below the existing campus of York University at their Keele Street location. As illustrated in Exhibit 2, the recommended alignment of the new subway is oriented in a northwest/southeast direction through the campus.

The construction of a new subway and station is a major undertaking in terms of cost and magnitude of surface activity, but much of this activity can be controlled by specific design detailing and related contract requirements. The two specific areas of concern at York University are:

- 1) General tunneling activities under existing buildings and utilities. Specifically, the depth of tunneling (1.5 to 2 tunnel diameters) below the footings and foundations.
- 2) As identified previously, the York University station may be deep. Added depth to a station significantly increases the construction cost (estimated at \$1.9 to 2.2M per metre of extra depth). This technical memo explores means to reduce the depth of the York University Station.

Exhibit 2: Recommended Alignment within York University



4.1.1 General Site overview:

The overall terrain is relatively flat with the grade rising from an elevation of 197.5 m at Keele St and Pond Road to 200 m at Steeles Avenue.

Prevailing soil types and ground water levels are mentioned in Appendix D

The majority of the affected site is open space and comprises walkways, roads, parking lots. There are several buildings and utilities that may be affected by the undertaking.

4.1.2 Key Buildings:

As illustrated in Exhibit 1, the subway tunnels, are located below several buildings on campus, including the following:

Schulich School of Business:

- Houses the lecture halls, auditorium, meeting rooms and hotel. This building has provisions for connection into the future York University station from its basement.
- Built in 2002.
- The foundations of the building are a combination of spread footings for columns, strip footing for walls and mat footing at the sub basement level. It is approximately 8m below existing ground.

York Lanes:

- This building houses retail outlets, book stores and serves as the common area in the campus with a covered walkway in front of the building.
- Constructed in 1998
- The foundations of this building are about 5m below existing ground.

York Lanes Parking Garage:

- This is a 3-storey parking facility north of the York lanes building.
- Constructed in 1998
- The foundations consists of spread footings are at about 4m below grade

Metro Toronto Track and Field Centre:

- This is a sports facility in the York University Campus.
- Constructed in 1980
- The foundations consists of concrete strip footings are at about 1.25m below grade

4.1.3 Utilities

- Two storm sewers 1500mm, 8m deep and 1200mm, 5m deep and a 525mm, 7m deep sanitary sewer are in conflict with the proposed York University station. These utility crossings have to be relocated over to the tunneled portion of the subway. Relocating the utilities will also facilitate the faster construction of the station structure.
- There are two service tunnels crossing the subway alignment. They include telecommunication and fibre optic cables which service York University, and are approximately 3m deep. The service tunnel along York Blvd. Crosses the alignment on top of the station structure. The service tunnels are shallow and the one one along York Blvd. will need to be protected during construction of York University station.

4.2 COST PREMIUM FOR DEEPER STATION AT YORK UNIVERSITY STATION

This report gives an approximate magnitude of the cost estimate per unit depth for open cut subway station construction with regards to certain range of depth increase from standard 15m to deepest 30m for the station rail track level.

Subway project experience has illustrated that tunneling method for station construction is more economical than open cut if the depth of track invert level is more than 30 m below grade.

The major cost elements of civil and structural for open cut subway station are

1. shoring -retaining walls
2. struts and waling or tie back (soil/rock anchors)
3. intermediate piles /columns for traffic deck
4. traffic deck for major road traffic
5. utility services relocation/support and protection
6. excavation and soil disposal
7. ground water control
8. property protection and monitoring
9. structural wall and slab of the station box
10. passageways/stairwells, vent shafts
11. contract administration

The other costs involved are system-wide equipment contracts and architectural works. These will also be increased for greater depth, especially cost of additional units of escalators are required to keep the vertical travel distance between each landing level not more than 10 m for TTC standard.

Direct /Substantial Cost Increase due to Increasing Depth are:

- Shoring-retaining wall
- Struts and waling and removal
- Intermediate piles/columns for traffic deck support
- Deep excavation
- Ground water control
- Structural main walls and slabs
- Backfill to roof slab

Factors affecting construction:

Shoring - Retaining wall

Lateral pressure and load will increase in greater excavation depth. Thus stiffer retaining wall or timber lagging soldier piles are necessary.

To provide proper water level control and minimizing external water level drawn down and subsoil soil settlement, the retaining wall should be designed and constructed to perform a certain degree of water- tightness and lesser lateral deflection.

In general, deeper excavation of more than 15 m below grade, contiguous pile walls are applied for better water level drawn control and better stiffness for lesser strut layers.

Deeper pile wall toe level is required to cope with water level control (soil boiling at the invert level)

Cut off depth varies from 5 m to 10m below station invert level.

Overall, it is understood that the total cost of retaining wall is not just only linearly proportional to the depth increase, but depending on geo-technical factors such as water level, types of subsoil.

For the cost estimate, contiguous pile wall (pile diameter- 1 m) is used.

Strut and waling

The cross sectional area and weight of strut and waling and bracing are increased in greater excavation depth. Tie back system may not be applied in urban area because of adjacent property right.

For construction cost estimate, strut layer (level) spacing of 2.75m and horizontal spacing 4m are used.

Intermediate pile column for traffic deck

Spacing of column will be assumed as 4m with 2 rows of columns to facilitate the standard size of either timber deck section or pre-cast concrete deck slab panel of not more than of 3m long.

Longitudinal Channel soldier girders will be fixed onto the column to support the transverse secondary deck beams.

5 to 10m effective pile socket length below the invert level is assumed for construction cost estimate depending on subsoil strength.

Deep excavation

The production rate of a mucking out opening depends on the local road traffic conditions and truck turn round trip time.

For general conditions of strut layer installation time, excavation efficiency below grade and hoisting speed by crane, 350 m3 /day(10 hour shift) production rate is used for excavation mucking out/disposal under urban area condition .

Backfill

Backfill more than 5 m will have certain concerns of long term consolidation settlement in main road area.

Non shrinkage fill or lean mix plus hollow structural concrete box will possibly be used as backfill to achieve ultimate road restoration sub-grade performance and cost effectiveness.

Station main wall and slab

Due to greater depth combined with more hydrostatic pressure, thicker main wall, roof and base slab are generally required to cope with more earth pressure and providing floatation resistance.

For approximate estimate, the solid cross section of station main structure and the solid backfill should be more than cross section of space.

The following table is the summary of unit cost per meter depth for additional depth of a standard cut and cover subway station with bottom up construction in urban area where strutting and traffic deck structure are required. The unit rate built-up is illustrated in the appendix.

Direct Cost Elements	(\$Million/ m depth)	Remark
Shoring-retaining wall	0.25	Refer to Rate built up
Strut and waling and removal	0.26	And allow 10% contingency
Intermediate column and removal	0.07	Vent shaft and stairwell passageway not included
Deep excavation	0.21	
Ground water control	0.02	
Backfill	0.18	
Station main structure	0.70	

Total \$1.69 million per m depth increase

Based on a 15-25% contingency the increase rate will possibly be in the range \$ 1.9 to 2.2 million per meter depth increase if M&E, vent shafts/stair wells and additional escalator running units are included.

To reduce the cost due to the increased depth of the tunnel in the vicinity of the York University station the following methods can be employed to avoid the foundations of the surrounding buildings.

The excavations for the running tunnels will be performed by a TBM. The tunnel excavation begins immediately at the end of the station rooms. The TBM excavation does not cause groundwater drawdown but it does cause a slight subsidence of surface soils immediately above the bored hole.

- At locations where the TBM passes below light foundations or spread footings, it is recommended that the soils below the affected foundations be conditioned to resist the effect of subsidence, by use of grouting the soils.
- At locations where the TBM will cut through piles or caissons, it is recommended that the affected foundations be underpinned before tunneling commences This technique is used when the underground structure must cut through any existing piles or caissons that are supporting building columns. Its purpose is to replace the deep foundation with a new foundation that is out of the path of the new subway. It is also used to replace a shallow foundation with a deep foundation, when necessary.

4.3 THE CN / GO BRADFORD RAIL EMBANKMENT

The Sheppard West subway station is proposed to be located immediately west of the existing railroad embankment, so that it may be possible to build a future transfer interchange for passengers between the Spadina subway and a future passenger station on the GO system at this location. As observed earlier, the elevation of the top of transit rail at this location is about 185.0m. It is estimated that the top of rail of the CN railroad is about El. 204.0m. The total difference between top of rail elevations is about 19.0 m.

The existing embankment supports the operating track of the CN railroad with GO service. And an additional siding track is located on this embankment.

An operating railroad track is very sensitive to subsidence. The tunneling operation below this embankment must be carefully specified so that the risk of subsidence is absolutely minimized, and steps to remedy any movement are proposed.

4.3.1 Construction Methodology

The construction procedure that will be used at the embankment is affected by the type of construction that is occurring on either side of it, to the east and west. The portion of the subway to the west is the new station site, and it is usually constructed by the cut-and-cover method involving a large open excavation. The portion of the subway to the east consists of running tunnels, but the construction method to be used in the open field will most likely be cut and cover, with no support of excavation required. The following procedure has been used at similar situations where subsidence of an existing railroad track or roadway must be negligible or very minimal: (See Exhibit 3)

1. It is given that the difference between top of rail elevations is about 19.0 m and that since the tracks are approaching a station, the distance between subway track centers is 13.6 m. The excavated diameter of a single track tube is about 5.7 m. On this basis, the unexcavated distance between tubes is about 7.9 m and the unexcavated region above a tube to the base of the CN/GO track is about 7.8 m.
2. The design is based on two separate excavations being made through the subsurface soils that support the embankment.
3. Since existing surface grades on either side of the track embankment are about El. 198.0 m, and the new subway track grade will be at about El. 185.0 m, large deep cuts are required on both sides of the embankment. It is estimated that after these excavations are made, the remaining width of the CN/GO embankment will be about 65 m, or somewhat less if a temporary sheeting system is installed. This is the length that must be excavated below the track for the subway tracks.
4. Using a horizontally mounted auger drill, the builder will drill an overlapping pattern of temporarily cased holes centered on each subway track alignment (inbound and outbound), each approximately 0.7 m to 1.3 m in diameter as required by detailed design analysis, filling each with concrete when it is drilled through from end to end. This pattern of overlapping concrete-filled holes will form a structural arch with an intrados diameter roughly equal to

the outer dimension of the subway tube. It is necessary to assure that each end of the drilled-hole arch is based on firm bearing material, possible pre-grouted soil if necessary, so that the arch thrust may be supported.

5. With the embankment supported on these cast-in-situ arches, the soils below and within the arches may be excavated for the subway track structure using light equipment, with little disturbance to the track above. These arches would remain in place.

Significant research and analysis are required to confirm the ultimate construction methodology, which will be finalized in consultation with CN and GO during the design phase.

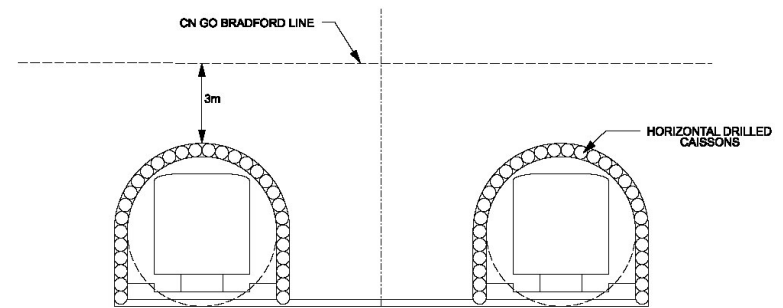


Exhibit 3: CN / GO Bradford Rail Embankment

4.4 THREE TRACK STRUTURE NORTH OF DOWNSVIEW STATION

The operational requirements for the proposed new Spadina subway extension in the area immediately outbound from the existing Downsview Station call for a double-ended tail track between the inbound and outbound tracks. The result of this directive is that the new section of subway that will connect to the existing tracks at Downsview will comprise an array of three parallel tracks, with a new double cross-over at the outbound end of the center tail track near Sta. 0+600. In a normal multiple track section of subway it is common to provide a wall between each track, however, the area at the track cross-overs cannot be obstructed with walls or columns. This would require the roof slab of the tunnel to be a long span structure of about 17.0 m at those locations.

During the later part of the study the proposed three track structure was excluded from the scope of the study and therefore the discussions with regard to the 3-tack structure in this section are no longer applicable.

4.4.1 Potential Impact of Project Construction – N/A

The Toronto Transit Commission recognizes the difficulty in economically tunneling the three-track curved structure under most of the buildings in the Keele industrial area and is planning to purchase most of these properties to allow for demolition as necessary to allow construction of the three-track subway section using a cut-and-cover method. The impact of the project on most of these properties is therefore resolved.

One industrial/commercial building commonly known to be a condominium will not be acquired. A special construction procedure will be used to tunnel below this structure and to extend the two track subway section below adjacent Sheppard Avenue.

Construction impacts on the nearby community and the environment would be temporary and can be minimized with careful planning and by specifying restraints on selected contributing factors during construction.

In general, the following table outlines several impacts resulting from such construction activities and development in the region.

4.4.2 Impact to Surface Structures– N/A

Within this section of the subway, several existing features must be protected during construction. They are described as follows.

Existing Condominium Industrial Building located on Sheppard Avenue: – N/A

Tunneling underneath this building with shallow cover between the top of tunnel and bottom of footing is feasible but must be designed to avoid the following impacts:

- Minor (local) cracking on walls due to settlement.
- Major (local) cracking on walls or slab due to significant differential settlement of foundation or heaving of ground.
- Structural failure in terms of serviceability and usage.

The type of existing building foundations is an important factor in the assessment of the impact of underground excavation on structural behavior. The types of foundations found at this building are spread footings or strip footings, and slabs-on-grade. The zone of influence below the footings is a gradually widening region within a line of 2:1 slope from the edge of the footings. Soil within this zone is assumed to provide direct support to the foundation, and loading stress increases in this region with increasing depth. The effects of underground excavation within this zone of influence must be carefully considered and examined. In addition, lowering the groundwater table may reduce the shear strength of the soil and weaken the soil considerably, resulting in subsidence.

Sheppard Avenue with existing underground utilities– N/A

This road is heavily traveled with vehicles at significant speeds. Underground utilities like gas, sewage, and water supply pipelines are essential to daily operation and occupancy of buildings. Surface subsidence would result in potential damage to these utilities. Information on existing underground utilities shall be obtained before construction commences and included in the plan, and they shall be diverted or protected if encountered during excavation. Decking is undesirable to minimize the impact on traffic flow.

4.4.3 Mitigation Methods– N/A

Condominium Industrial Building – N/A

The proposed subway structure that is to be located below the existing condominium industrial building will consist of a two-track structure, lying outbound of the three-track cross-over section. It is proposed to tunnel this short section using the New Austrian Tunneling Method (NATM). The design for the NATM tunnel will specify methods to pre-treat the subsurface soils that support the building foundations to prevent building damage. The most common technique used for this is permeation grouting.

Permeation grouting: The tunneler injects grout into undisturbed soils at a low pressure. The purpose of permeation grouting is to allow grout material to fill the voids within the soil particles. This method is more effective in coarse-grained sandy material where porosity (ratio of volume of voids to sample total volume) is higher. It requires “lighter” equipment set-up than jet grouting and has a lower tendency of ground heaving and surface leakage. The end result is that most of the soil mass becomes a cemented block with much higher in-situ strength.

NATM construction: This type of tunneling involves many stages of construction and is very complex for design, instrumentation and construction – not a common practice in soft ground tunnels in the North American market. The excavation is performed with light equipment, excavating in short increments and using shotcrete to provide rapid placement of an initial support lining.

Sheppard Avenue- N/A

This section of subway under a road would usually be constructed by cut and cover methods (where a TBM is not involved) using decking to allow maintenance of traffic. However, if NATM is used to excavate the twin tunnels under the condo building, it is advisable and feasible to extend the tunnels across Sheppard Avenue using the same method, thereby avoiding support of excavation walls and decking.

While cut and cover construction is generally less expensive than tunneled solutions, the incremental cost of extending the tunnel across the road using NATM is very cost-effective since this cost need not consider the mobilization of heavy equipment or the tunnel labor to the site but simply considers the unit cost of tunneling over the additional length. This approach also provides the benefits of eliminating surface impacts and the need for traffic control on Sheppard Avenue. The NATM tunnels will terminate in the open cut excavation within Downsview Park.