Scarborough ExpressRail

Technical Memo

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Table of Contents

I. Introduction

This memo provides an overview of the technical issues involved in the operational feasibility and constructability of the Scarborough ExpressRail concept (also referred to sometimes as SmartSpur) as it relates to existing transit services such as the Scarborough RT. The concept has significant overlap with, and boosts the ridership for, the SmartTrack concept currently being pursued by City Planning at the City of Toronto, and Scarborough ExpressRail provides a superior service offering to the Scarborough Subway Extension, providing more value for money and better supporting the City of Toronto's city building goals by taking higher quality rapid transit to more places and connecting these places to a network that can achieve higher speed than the subway network. This document will explore issues related to:

- Signal systems
- Uxbridge subdivision capacity south of Ellesmere Rd
- Kingston subdivision capacity west of Midland Ave
- Union Station
- Scarborough ExpressRail on top of SmartTrack
- Frequencies, design and speed of service
- Stations
- Interlockings
- Construction staging

II. Signal Systems

The proposals associated with Metrolinx's RER programme include an upgraded signal system to accommodate more aggressive service levels per track. The current signal system, Centralized Traffic Control (CTC), is designed with the aim of accommodating the very long lengths of trains associated with freight rail traffic, but this is fine for less aggressive passenger rail operations as well. For passenger rail services that are more aggressive and in line with what is expected of rapid transit service, a more powerful signal system is required.

Already mandated in the United States by law, which affects cross-border CN and CP equipment, the Positive Train Control (PTC) signaling system is a system that can be built on top of the existing CTC system to augment the capabilities of that signal system. Among other things, PTC adds an on-board component that allows the signal system to dynamically communicate with the engineer driving the train, and the PTC system itself can take corrective action if the engineer fails to respond to the provided signals and risks creation of a dangerous situation. PTC provides an effective, automatically enforced collision-avoidance regime for railway traffic control that provides a high level of enhanced safety that enables trains to travel more closely together on the same track.

The PTC system monitors the locations of the trains in relation to each other by GPS in real time, as well as the speed of the trains on the system. The PTC system also knows the length of the trains and their braking profiles to enforce safe separation between trains across all operating speeds. This creates a moving block system to automatically protect trains in high-density traffic environments. The PTC system can also enforce temporary slow orders and work zones where railway contractors may be actively working on or alongside the line requiring reduced speed.

PTC is a system that will be required for managing traffic on the RER system that Metrolinx is pursuing and so would be available, at a minimum, on all electric Metrolinx vehicles and along all of the Lakeshore corridor (with the possible exception of Hamilton) and the Weston subdivision portion of the Kitchener corridor, where traffic volumes are highest. That comprises a significant proportion of the SmartTrack proposal. It is not known if the Uxbridge subdivision, the remaining piece for the SmartTrack proposal, would have the wayside components of the PTC system implemented as part of the RER programme given the original service plan for the Stouffville corridor that was announced prior to SmartTrack.

Analysis work was undertaken as part of the report published in 2013, GTHA Regional Rapid Rail, which was one of the influencing documents that led to the SmartTrack proposal from a technology perspective (GTHA Regional Rapid Rail never included any route to the Mississauga Airport Corporate Centre (MACC)). The analysis tested the possible headways based on length of train (e.g. 200m for an 8-car train), braking distance required for a train during regular operations (varies by speed), and an additional safety buffer for ensuring safe separation (250m). The calculation is conservative because the regular braking distance was used in this analysis, not the emergency braking distance. While there are other factors beyond the signal system that influence the achievable headway per track, the analysis found that headways of three minutes would be achievable in a PTC environment.

III. Uxbridge Subdivision Constraints South of Ellesmere Rd

The Uxbridge subdivision hosts the Stouffville corridor after it leaves the Lakeshore corridor at the Scarborough junction. It is inconsistent in width, but ranges between 50 and 90 feet wide. Most of the stretch between Lawrence Ave E and Ellesmere Rd along the Uxbridge subdivision has the footprint of the Scarborough RT's northbound track occupying a part of the 50-foot right of way for the Metrolinx tracks, while the southbound Scarborough RT track has its own property allowance (which was previously part of the original rail corridor).

For expansion in the corridor, two tracks are achievable within its existing 50-foot right of way, although it could be reasonably argued that three tracks would fit at added cost. With the removal of the Scarborough RT after its replacement transit service is operational, the Uxbridge subdivision can widened to 90 feet between Eglinton Ave E and Lawrence Ave E, and to 66 feet or wider (inconsistent width) between Lawrence Ave E and Ellesmere Rd. These widths are capable of accommodating a four-track corridor, although the 66-foot implementation will be more expensive than the 90-foot implementation due to differences in the drainage solutions required. Cross-sections in Appendix A illustrate how the railway corridor expansion can be achieved within these right-of-way allowances.

The corridor is 66 feet wide between Eglinton Ave E and St Clair Ave E except alongside the TTC lands at the Kennedy subway station which would presumably be included in design discussions for the new Kennedy station solution associated with the Eglinton-Crosstown LRT in addition to SmartTrack itself. At St Clair Ave E is the Scarborough junction, where the Uxbridge subdivision joins the Kingston subdivision that hosts Metrolinx's Lakeshore East corridor.

Where to transition the four-track corridor to a two-track corridor would be influenced by future service plans. This transition could be done anywhere between the Scarborough junction and immediately south of the Ellesmere station, but the most cost-effective approach is that the transition be immediately south of the Ellesmere station.

IV. Kingston Subdivision Constraints West of Midland Ave

The Kingston subdivision hosts both the Lakeshore East and Stouffville corridors between the Scarborough junction (at St Clair Ave E and Midland Ave) and the Union Station Rail Corridor. It also hosts Toronto-Ottawa and Toronto-Montreal VIA Rail service. Its width is inconsistent through Toronto but is sufficiently wide to accommodate five tracks. There are immediate plans to add a fourth track to this part of the corridor, but it is not known if there are any plans to go to five tracks.

V. Union Station Rebalancing

Union Station traffic pressures are unbalanced; the Union Station Rail Corridor traffic pressure is west-side-heavy as the combined ridership of the Kitchener, Lakeshore West, and Barrie lines exceed that of the Stouffville and Lakeshore East lines (the Milton and Richmond Hill lines are omitted as they are not slated for electrification in the current RER programme). Depending on the specifics of the operating plan for integrating SmartTrack service with the electrified Kitchener service to the Bramalea station (or possibly the airport subject to future study of compatibility with the Pearson subdivision), SmartTrack creates opportunities to reduce the imbalance of traffic volumes between the east and west sides of Union Station, increasing capacity at Union Station by using trains in service that otherwise would have turned around or gone out of service at Union Station. A network that also includes Scarborough ExpressRail further reduces the Union Station traffic imbalance, further increasing capacity at Union Station.

VI. Scarborough ExpressRail on Top of SmartTrack

The Scarborough ExpressRail concept would provide alternate termini at the east end of the SmartTrack line. Scarborough Centre and points further northeast would be added to the existing SmartTrack proposal's terminus at Unionville by the new downtown of Markham. The frequencies of the two lines combined becomes a constraining factor southwest of the Scarborough junction (at Midland Ave/St Clair Ave E).

Based on ridership models from the Univeristy of Toronto Transportation Research Institute (UTTRI), there is a significant fall-off of ridership as the line heads north through Scarborough. Ridership is extremely strong southbound leaving Kennedy station, at just over 17,000 passengers per hour per direction, but at Unionville the ridership is underwhelming, at just under 4,000 passengers per hour per direction, a difference of over 13,000. Only the MACC area had lower ridership than at Unionville, and while cost was certainly a major consideration, the MACC portion has been removed from the proposal and replaced with the Eglinton-Crosstown LRT Phase Two. Given the significance of Kennedy station in the transit network, as one of the larger bus terminals in the TTC system, a large jump at Kennedy would be expected for SmartTrack. It can be reasonably assumed that several thousand passengers per hour get on at Kennedy given the Scarborough Subway Extension's inclusion in the network model in addition to bus traffic.

The ridership at Sheppard, Finch, and Steeles would still be well-served by a ten-minute network, given that today these stations have either peak period peak direction service only or, in the case of Finch, no service at all. With Scarborough ExpressRail added to SmartTrack, there is still a Sheppard East LRT connection with the five-minute service through the McCowan branch LRT route from Sheppard Ave to Scarborough Centre proposed by City Planning at the City of Toronto. While boardings at Sheppard, Finch, and Steeles would be affected by a move to the fifteen-minute SmartTrack service along the Unionville branch instead of five-minute service, it may be worth considering the move to fifteen-minute service along this branch due to the number of level crossings that exist north of Ellesmere.

Ridership will be higher on the SmartTrack service with Scarborough ExpressRail added to the SmartTrack concept as it puts the urban growth centre at Scarborough Centre on the SmartTrack system, thereby increasing the alleviating function SmartTrack provides to not only the Yonge St half of Line 1, but also to the Danforth Ave half of Line 2. Prior to the release of the UTTRI ridership model results for the Relief Line, the estimated ridership from Scarborough Centre to downtown that would be captured by Scarborough ExpressRail was 2,000 passengers per hour per direction in the peak hour in 2021 and 3,000 passengers per hour per direction in 2031. That estimate was based on Transportation Tomorrow Survey 2011 data that indicated the percentage of riders in the Scarborough RT corridor (30%) that were bound for the financial district, scaled up to demand projections from the Metrolinx Scarborough RT Benefits Case Analysis published in 2009. These estimated demand numbers are in a similar range as the UTTRI model's Relief Line numbers, or higher than the Relief Line depending on the Relief Line alignment (UTTRI modeled four different alignments for the Relief Line). Scarborough ExpressRail would also improve the reverse-peak demand on the corridor, which would appear to be lowest through Scarborough if linearly extrapolated from Union Station to Unionville, the only reverse-peak numbers available (2,700 passengers per hour per direction at Union Station and only 812 passengers per hour at Unionville, for the 5-minute network). The west half of the SmartTrack corridor had much stronger reverse-peak ridership, and Scarborough ExpressRail mitigates this east end reverse-peak weakness, especially with service to the Centennial College Progress Campus included.

VII. Frequencies of Service

Recognizing the constraints between Scarborough Junction and Union Station as they relate to Scarborough ExpressRail, the following service combinations are presented for consideration:

Option	Average Frequency to Unionville	Average Frequency to Scarborough Centre
4-14	15'00"	4'17"
4-15	15'00"	4'00"
4-16	15'00"	3'45"
5-14	12'00"	4'17"
5-15	12'00"	4'00"
6-14	10'00"	4'17"

All options provide service to Scarborough Centre better than that currently provided by the Scarborough RT, which runs every 4’30” during peak periods. All also limit the combined throughput at Scarborough Junction to 20 trains per hour or fewer, which fits with the three-minute headway capability of the PTC signal system and the constraints of the Kingston subdivision. All options to Scarborough Centre operate at a more aggressive service level than the modeled SmartTrack frequency of 5’00”, although differences in frequencies in this aggressive range of service levels would not be expected to have any meaningful impact on ridership unless significant crowding differences were at play (which it is not according to the UTTRI models).

VIII. Design & Speed of Service of Scarborough ExpressRail

Between Ellesmere and the Centennial College Progress Campus, the horizontal and vertical geometry has been worked out to determine the viability of the corridor and also to determine what speeds may be realistically achievable on this service.

The horizontal alignment has the most significant influence on speed due to the curves required for navigating through the existing built form of the broader Scarborough Centre area. There are nine curves between the Ellesmere and Progress Campus stations, with details as follows:

Curve	Ellesmere	Highland	Brimley	B.Harrison	McCowan	Grangeway	Bellamy	Production	Markham
Degree	6	2	7	7	5	5	4.5	4.5	6
Super.	4.5	1	4.5	4.5	5	5	5	5	4.5
Imbal.	2.2	2.5	3.3	3.3	3.8	3.8	2.9	2.9	2.2
km/h	70	85	65	65	80	80	85	85	70

The above table rows identify the curve by name (Curve), which is typically its nearest crossing street or creek; the degree of curve (Degree); the applied superelevation or banking in inches along the curve (Super.); the imbalance in inches for the design speed along the curve (Imbal.); and the design speed along the curve (km/h). While higher speeds are available along the Lakeshore corridor, and to a lesser extent along the Stouffville corridor north of the Scarborough junction as well, these speeds between the Ellesmere and Progress Campus stations are in the same range as subway and LRT, which both have a maximum design speed of 80 km/h. The sharper curves along Scarborough Express Rail are near stations and do not have a measurable impact on average travel speed since trains would be accelerating or decelerating in these areas. Sketches of the horizontal alignment are provided in Appendix B, and more detailed analyses of curve design alternatives are provided in Appendix C.

The vertical alignment for the line between the Ellesmere and Scarborough Centre stations has a surface portion and an underground portion. The surface portion starts at the Ellesmere station and consists of an underpass at Midland Ave using momentum grades of 2% entering and leaving the underpass. East of the underpass is a new bridge over Highland Creek beside the existing Scarborough RT bridge. Immediately after the bridge, the grade changes from the 2% leaving the underpass to -1% approaching the portal just west of Brimley Rd to the underground portion.

The underground portion maintains the -1% gradient from the portal near Brimley Rd until it nears the Scarborough Centre station, shortly west of which it changes to -0.3%, which it maintains through the station and beyond until Grangeway Ave, where the underground portion ends. The underground portion maintains 3 m of cover above the box tunnel structure throughout its 1.1 km length, including the Scarborough Centre station box structure. The Scarborough Centre station would provide exits near Albert Campbell Square at its west end, which is very close to the main exit of the existing Scarborough RT station, and to the intersection of Town Centre Crt and Borough Dr (near McCowan Rd) at its east end. The mezzanine level of the Scarborough Centre station includes an integrated underground bus terminal off Triton Rd.

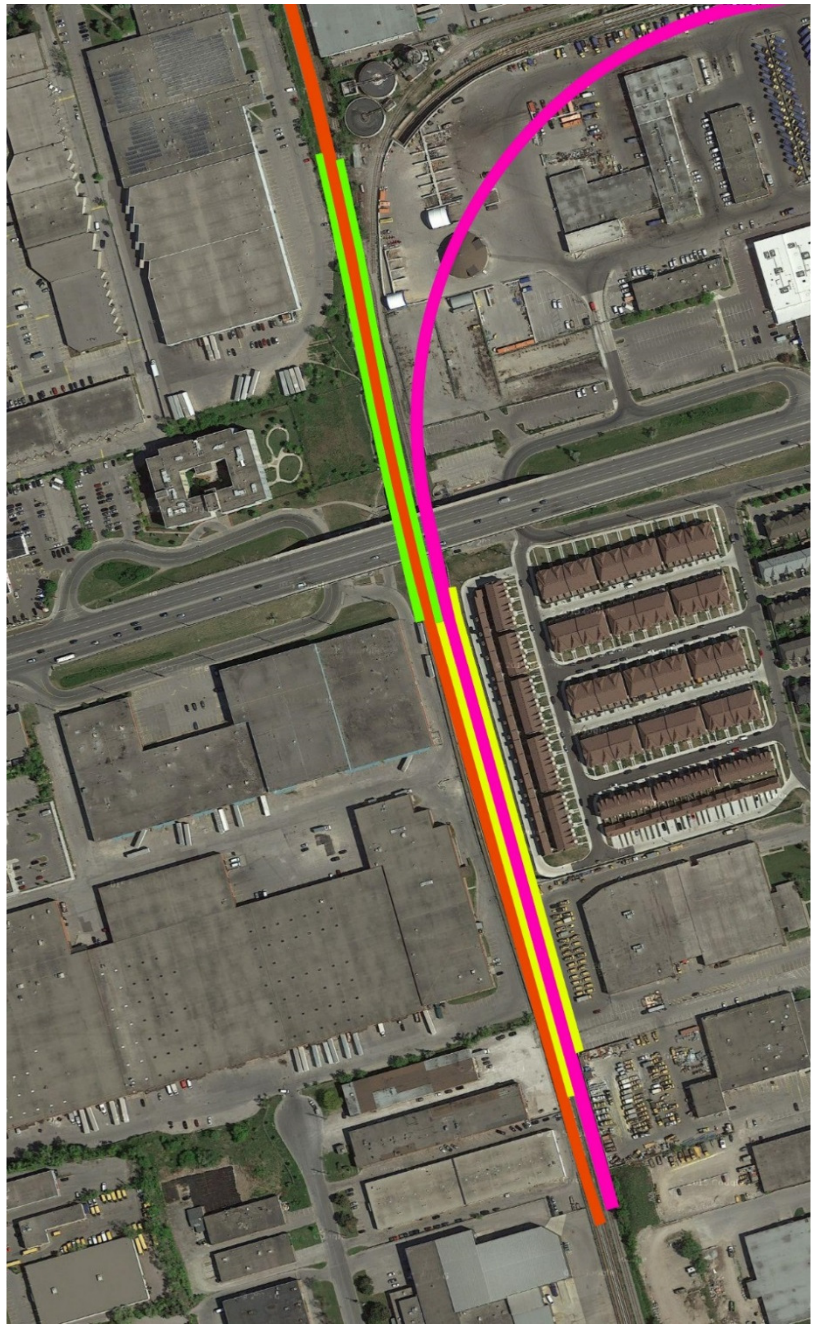
East of the underground portion, the line would climb at a 1.7% gradient towards Bellamy Rd, flying over the road. East of Bellamy Rd, the vertical design proceeds at a -1.5% gradient towards the Progress Campus station, shortly before which the gradient changes to 0.3%. Progress Campus is an underground station beneath Highway 401, envisioned as being constructed in the same fashion as Osaka Business Park station in Osaka, Japan, which utilized a three-face tunnel boring machine to bore the station. This allows the station to be constructed without disruption to Highway 401 above. The Progress Campus station would provide exits to both the south and north sides of the highway, serving the educational institution to the south and the underdeveloped business park to the north.

All vertical curves' lengths would be set to accommodate speeds that reflect the horizontal alignment constraints in the same area.

The vertical alignment of the line between Ellesmere Rd and Grangeway Ave is provided in Appendix D.

IX. Ellesmere Station

Ellesmere is the most challenging station to accommodate due to the real estate challenges at this particular location, compounded by the fact that it is a junction location for Scarborough ExpressRail. As a junction point, the Ellesmere station also functions as a transfer node for people coming from Agincourt and points further north along the Stouffville corridor that wish to reach the Scarborough Centre or Progress Campus stations for work or school. The transfer node function of this station makes the station's inclusion in the network important as transit riders are known to prefer the most direct travel paths, which in turn result in the highest ridership.



The least expensive solution to the space constraints at this location is a staggered station layout where the Scarborough ExpressRail platforms are south of Ellesmere Rd and the Stouffville/SmartTrack platforms are mostly north of Ellesmere Rd (per image at right). While the Scarborough ExpressRail tracks would be straight, the Stouffville/SmartTrack would have a very minor bend to them, but no superelevation, along a half-degree curve (radius of about 3.5 kilometres). The southbound Scarborough ExpressRail platform and the northbound Stouffville/SmartTrack platform would be the "same" platform but would have fencing along one side of the platform at all times because it can only load from one side at a time due to its constrained width that is only suitable for one-track loading. The "compound-platform" length would be at least 630 metres long assuming both lines will be designed to accommodate twelve-car trains (expected to be required at peak periods).

While it can be restricted to land that is only used for landscaping, surface parking/storage, or a separation buffer from residential areas (used for platforms only, not track), some property acquisition is unavoidable for accommodating this station. The platform for northbound Scarborough ExpressRail service can have its northernmost two coaches placed on the spiral to minimize property requirements for the northbound platform footprint. There are redevelopment proposals that are currently being assessed by the City of Toronto for 1001-1025 Ellesmere Rd, which shares a property line with the Uxbridge subdivision and could perhaps involve a joint-development opportunity that could bring the southbound Stouffville/SmartTrack platform further south by about 100 metres.

The existing pedestrian underpass at this station is expected to be recycled for the new station design.

Other design alternatives at higher cost may also be possible for this station.

X. Lawrence East Station

The Lawrence East station should not require more than a two-track cross-section. If using minimum platform widths, which can be accommodated within the existing right of way of 50 feet, this station could have its “full build” built prior to the shutdown of the Scarborough RT. Demand at this station is expected to be relatively light. If more tracks and/or platforms are desired, a phased approach would be required to accommodate the full build.

It is assumed that in order to be along a straight segment of track that the station will be entirely on the south side of Lawerence Ave E. The existing pedestrian underpass that forms part of the Scarborough RT station may not be practical to recycle into this station due to the southerly location. A northerly location for the station could be considered if some of the lands could be acquired for a minor railway realignment from 2440-2444 Lawrence Ave E, which are government-owned lands used jointly for Toronto Police Services and Ministry of Community Safety and Correctional Services. That realignment would render practical the repurposing of the existing pedestrian underpass from the Scarborough RT station by shifting the station approximately 100 metres further north.

XI. Kennedy Station

Kennedy station is a major interchange station in the network that includes connections between the Crosstown LRT and Line 2 on the subway network, in addition to being a major hub for bus traffic. It is unclear without a model projecting the transfer movements between the different services at this station what the requirements at this station would be for the Uxbridge subdivision services, as the dwell times need to be well understood if the headways are going to be very aggressive. It is known from the SmartTrack model run by UTTRI that there may be a significant number of peak hour boardings at this station. If demands are high with longer dwell times projected, consideration may be given to having a four-track station area while the corridor is otherwise two tracks. This would allow longer dwells to avoid disrupting the aggressive headways on the Uxbridge subdivision. As the lands on the west side of the Uxbridge subdivision in the Kennedy station area are TTC-owned lands, including lands used for the Scarborough RT that will later become obsolete and available for repurposing, there should not be any property requirements not already under public ownership to accommodate a larger station. If the model demonstrates that a two-track station will be sufficient without unreasonable dwell times, such a station can be built while the Scarborough RT is still operational.

There have been repeated proposals to rebuild the Stouffville corridor's Kennedy station as part of an expansion of the mobility hub at Kennedy. Among the other options, but especially relevant in the discussion of the Crosstown East LRT recently proposed by City Planning at the City of Toronto, is the option of lowering the Uxbridge subdivision tracks to have them function as a bridge over the subway instead of having the three-plus metres of cover that it currently has as a "non-bridge" condition. What the lowering of the Uxbridge subdivision would achieve is the opportunity to re-profile the design of the bridge for Eglinton Ave E to have the west embankment accommodate a gradient of 2% instead of its current 5% so that it can meet design standards for an LRT platform near the peak height of the modestly-lowered bridge. This requires a reconstruction of the Eglinton Ave E bridge but avoids significant underground LRT construction. The Scarborough RT must be shut down prior to the reconstruction of the bridge as the lowered bridge will not provide the clearance required for Scarborough RT operation.

XII. Scarborough Junction Station

The existing Scarborough station, which with the addition of a Scarborough Centre station is suggested be renamed to "Scarborough Junction" to minimize confusion, would require some minor modifications to accommodate expanded service. This is related to the frequency of service coming from the Uxbridge subdivision, regardless of which service or services contribute to that frequency.

An additional track and platform are required on the north [northwest] side of the station to accommodate the expanded service along the Uxbridge subdivision without causing regular displacement of Lakeshore East service at this station. Due to property constraints, this expansion requires a shift of at least the existing north platform, but in order to better integrate service with buses along St Clair Ave E, there is a benefit to shifting the south platform as well. The platform shift is 70 to 75 metres, or about three GO coaches, to the east, and includes moving the accessible mini-platform to be right beside the overpass of St Clair Ave E. The shift also allows convenient access to the north side of St Clair Ave E, improving the convenience of station access to those transferring to/from the westbound TTC buses.

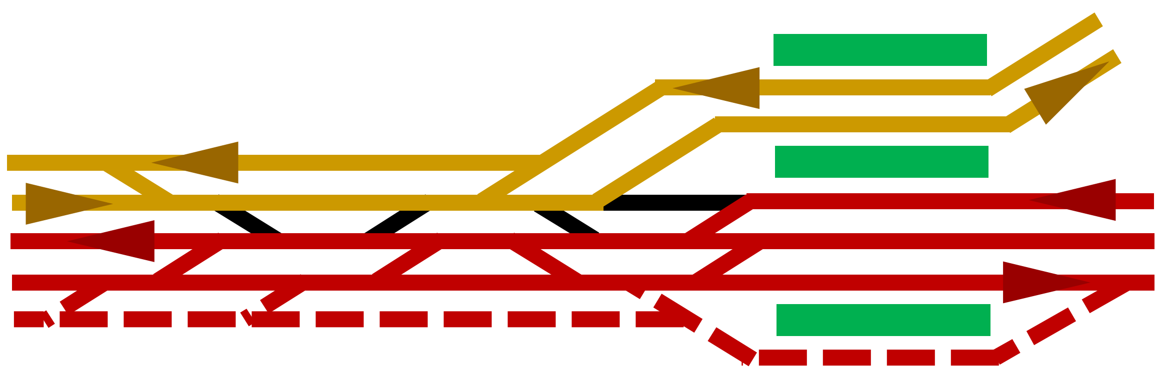
The property issue forcing the platform shift is the Uxbridge subdivision track and its proximity to 3595 St Clair Ave E. The shift in platform allows the second Uxbridge subdivision track to be added south of the existing track at this specific location because it is along the flaring of tracks to accommodate the island platform. Without the modest shift in platform location, the second track would be on the north at this location just like it is on the north elsewhere in the Scarborough junction area, which would be outside the right of way. All pedestrian tunnels and associated access stairways would remain active in their current locations with this platform shift.

This would provide two tracks for Uxbridge subdivision service and two tracks for Kingston subdivision service plus an express track along the Kingston subdivision which has no platform access. A fourth track along the Kingston subdivision on the south side of the corridor can be added in the future and would serve the opposite side of the existing south platform, for which provision already exists.

XIII. Interlockings

There are two interlockings that are vital to the smooth operations of Scarborough ExpressRail. One is an expansion of the interlocking that facilitates the Scarborough junction, which spans between Kennedy Rd and the west end of the Scarborough Junction station, the other is a new interlocking, that facilitates the junction with Scarborough ExpressRail between the Lawrence East and Ellesmere stations.

The Scarborough junction interlocking needs to be expanded to the west to accommodate the new Uxbridge subdivision track, which should also extend along the Lakeshore East corridor, presumably on the north side. This would involve additional crossovers being added for both directions of travel to access the new track, and also additional crossovers between Kingston subdivision tracks to allow parallel crossover movements of two trains at the same time. It is important to note that SmartTrack, with or without Scarborough ExpressRail, is positioning the Kingston subdivision between the Scarborough junction and the Union Station Rail Corridor (USRC) to be the busiest segment of rail corridor after the USRC in all of Canada. The requirement of a fifth track in this part of the Kingston subdivision would need to be seriously considered for this volume of traffic.



The diagram above illustrates the expanded interlocking concept. Tan represents services using the Uxbridge subdivision. Red represents services using the Kingston subdivision (mostly Lakeshore East services, but VIA Rail services also use the corridor). The fifth track between the USRC and the Scarborough junction is shown as a dashed red line. Black represents existing track that may see regular use during off-peak periods but would see minimal (if any) regular use during peak periods, except possibly by non-revenue equipment moves (e.g. to/from the yard). Green blocks represent platforms at the Scarborough Junction station – the north platform is conceptual, while the others are existing.

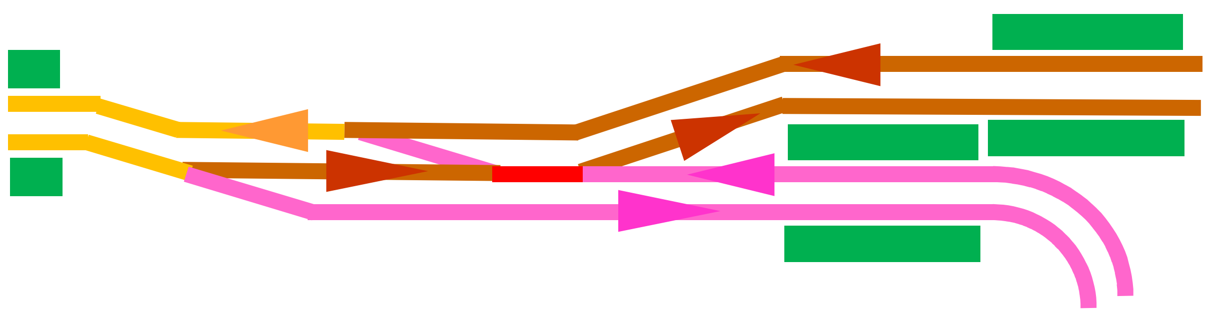
The new interlocking between the Lawerence and Ellesmere stations involves one two-track corridor splitting into two two-track corridors. This needs to be achieved in a way that allows service to operate at a high frequency but still accommodate a very short stretch of a conflicting path of movement. During normal operations, southbound Stouffville/SmartTrack service and northbound Scarborough ExpressRail service would be free from any conflicting movements with trains in opposite directions. Southbound

Scarborough ExpressRail and northbound Stouffville/SmartTrack service would have a brief but still manageable arrangement where trains in opposite directions will very briefly cross one another's paths.

There needs to be a priority sequence between the following pairs of trains:

- Southbound Scarborough ExpressRail has priority over southbound Stouffville/SmartTrack
- Southbound Scarborough ExpressRail has priority over northbound Stouffville/SmartTrack

Scarborough ExpressRail southbound gets the priority because it has the more aggressive schedule to maintain compared with southbound Stouffville/SmartTrack service; Stouffville/SmartTrack southbound at Ellesmere is not going to cause domino effects from a 45-second hold at Ellesmere. Same applies for northbound traffic from Lawerence East, but it is important to note the phased layout of the interlocking, as there is a "pocket" where a Stouffville/SmartTrack train can "hold" between turnouts if necessary, without impeding northbound Scarborough ExpressRail traffic right behind it.



The diagram above illustrates the interlocking layout concept. Orange represents shared operation between Stouffville/SmartTrack and Scarborough ExpressRail. Brown represents Stouffville/SmartTrack operations only. Magenta represents Scarborough ExpressRail operations only. Red represents where northbound and southbound operations share a common piece of track in the interlocking. Green blocks represent platforms; Lawrence East is at the left end and Ellesmere is at the right end.

XIV. Construction Staging

The Scarborough RT carries a number of passengers per hour that well exceeds that of a mixed-traffic bus operation. The Scarborough RT therefore must be kept operational until its replacement is in operation and able to carry the passenger demand that already exists on it before it is shut down and removed. Some parts of the Scarborough ExpressRail concept require the Scarborough RT's removal in order to reach the "full build" concept and so construction staging is vital to the viability of Scarborough ExpressRail.

The east-west running portion of the Scarborough RT from the Ellesmere tunnel beneath the Uxbridge subdivision to the McCowan yard is not affected by the "full build" of phase 1A of Scarborough ExpressRail to Scarborough Centre (phase 1B is Scarborough Centre to Progress Campus).

The north-south running portion of the Scarborough RT has three stations along it, Kennedy, Lawrence East, and Ellesmere. If the Lawrence East station is built as a two-track station, as is believed to be sufficient, its full build can be implemented without shutting down the RT. However, if the existing pedestrian underpass is to be recycled in the new station by acquiring some of the government-owned lands at 2440-2444 Lawrence Ave E, this would happen after the RT is shut down.

The situation with the Kennedy station is similar to that of Lawrence East, but it is less clear if a two-track station is sufficient for Kennedy given its higher demand. However, whether Kennedy requires a four-track layout or a two-track layout may not affect construction staging decisions. The reason for this is that if Kennedy were to be a four-track station, a double-island configuration would be the most passenger-friendly and would also be the easiest to stage construction for; the east island including tracks serving the east island can be built prior to the removal of the RT. If a two-track station is sufficient for Kennedy, the east island of the four-track model can be the "full build" of Kennedy, without needing to shut down the RT. However, the previously discussed lowering of the tracks to accommodate a better Crosstown (East) LRT interface on the bridge at Kennedy needs to be considered as part of the construction staging scheme.

The Lawrence East to Ellesmere segment is the most constrained as only about eleven metres of right-of-way is available for Stouffville corridor tracks (whereas elsewhere upwards of 15 metres is available). However, two tracks can be laid in this segment (with subdrain(s)) prior to the shutting down of the RT. An interim arrangement at Ellesmere is required, and for the interim, one platform would be available for each of the Stouffville/SmartTrack and Scarborough ExpressRail services, with both directions of each service using their respective single platforms. Inherent in this arrangement is an inability to provide aggressive frequencies, but this is only to enable a service to be operational between the time the Scarborough RT is shut down for removal and the additional tracks laid in the RT's footprint go live. While it constrains the frequencies to Scarborough Centre on one hand, it can be argued it simplifies turn-around operations on the other hand. The interim single-track operation through the Ellesmere curve and

Midland underpass would see a turnout to two-track operation immediately east of the new Highland Creek crossing, with two-track operation through the underground portion, but with both tracks being bi-directional for phase 1A. This eliminates the previously-identified need for a cross-over at Scarborough Centre station, allowing the "full build" station to be built in phase 1A rather than phase 1B. That in turn allows higher capacity to be provided to Scarborough Centre by running longer trains while frequencies are constrained by the presence of the Scarborough RT, as there would not be an interim eight-car restriction on Scarborough ExpressRail train length at the Scarborough Centre station. Such an operation would offer capacity that is many times the 4,000 passengers per hour per direction the Scarborough RT is able to provide, as each twelve-car EMU train would provide 1,700 passengers per hour, so from a capacity perspective, this more than satisfies requirements.

Departures from the Scarborough Centre and Ellesmere stations could be coordinated to have the inbound Scarborough Centre trains clear the turnout between one-track and two-track service shortly before the outbound train traverses the turnout, thereby maximizing frequency in the constrained interim arrangement. Similar could be done between the Lawerence East and Ellesmere stations for both the Scarborough ExpressRail and Stouffville/SmartTrack services. The Stouffville/SmartTrack service may, if necessary, do the same between the Ellesmere and Agincourt stations.

After the Scarborough RT is shut down and removed, the realigned Uxbridge subdivision through the Ellesmere station area can be built, including its platforms. The platform that was being used for both directions of Stouffville/SmartTrack service would then become the southbound Scarborough ExpressRail platform after the Stouffville/SmartTrack realignment is in service, and the second track for Scarborough ExpressRail completed, along with the final interlocking arrangement implemented.

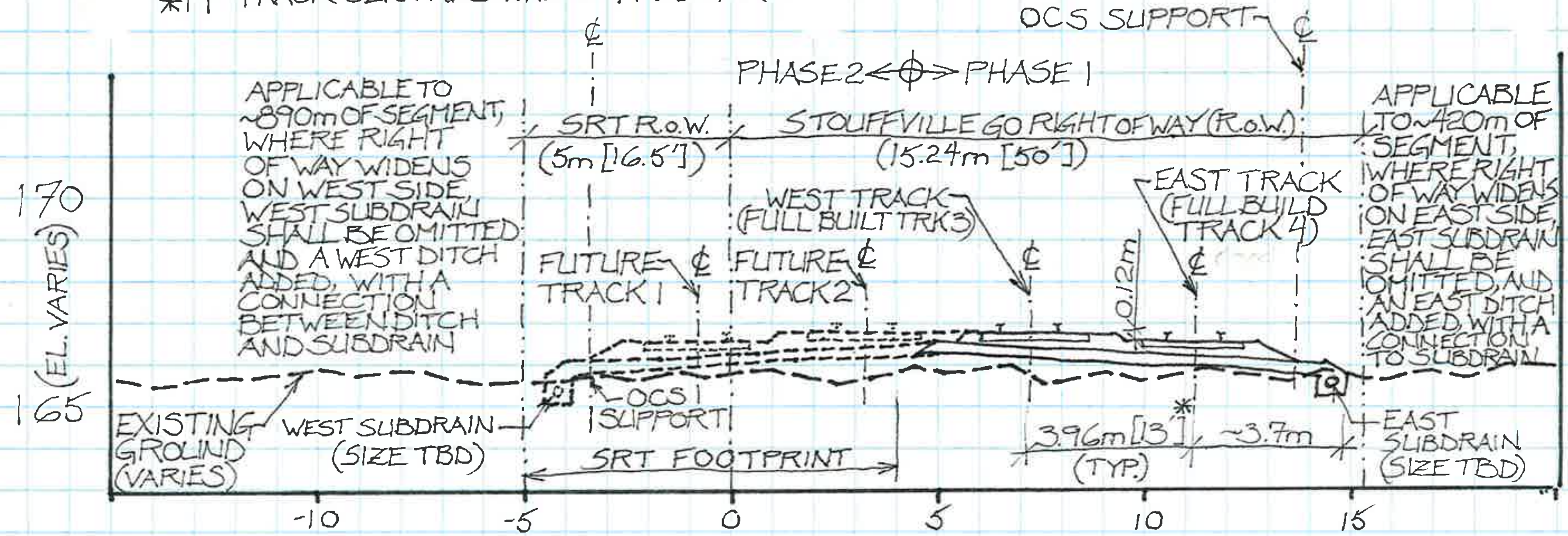
XV. In Closing

Scarborough ExpressRail is constructible and feasible, providing significant improvements to the capacity of service on the Scarborough RT corridor while still operating very competitive frequencies, and also providing all-day service in the Stouffville/SmartTrack corridor at ten- to fifteen-minute frequencies to Unionville. It is a viable alternative to the Scarborough Subway Extension, offering better value for money and a stronger network given the added relief it provides to the subway system. The money saved by implementing Scarborough ExpressRail instead of the Scarborough Subway Extension would be enough to extend service to the Centennial College Progress Campus, which is currently left out of the transit plan put forward in January, 2016 by the City of Toronto. It can also be extended to other areas in the northeastern area of Scarborough including Malvern and eventually connecting with the Havelock subdivision that goes through southeastern Markham. The long-term extension potential for Scarborough ExpressRail also opens up yard expansion opportunities for the RER network as it inherently provides convenient access to the CP Toronto Yard that is being partially sold by CP Rail, which could provide additional storage and maintenance capacity for the RER network's long-term growth needs.

XVI. Appendices

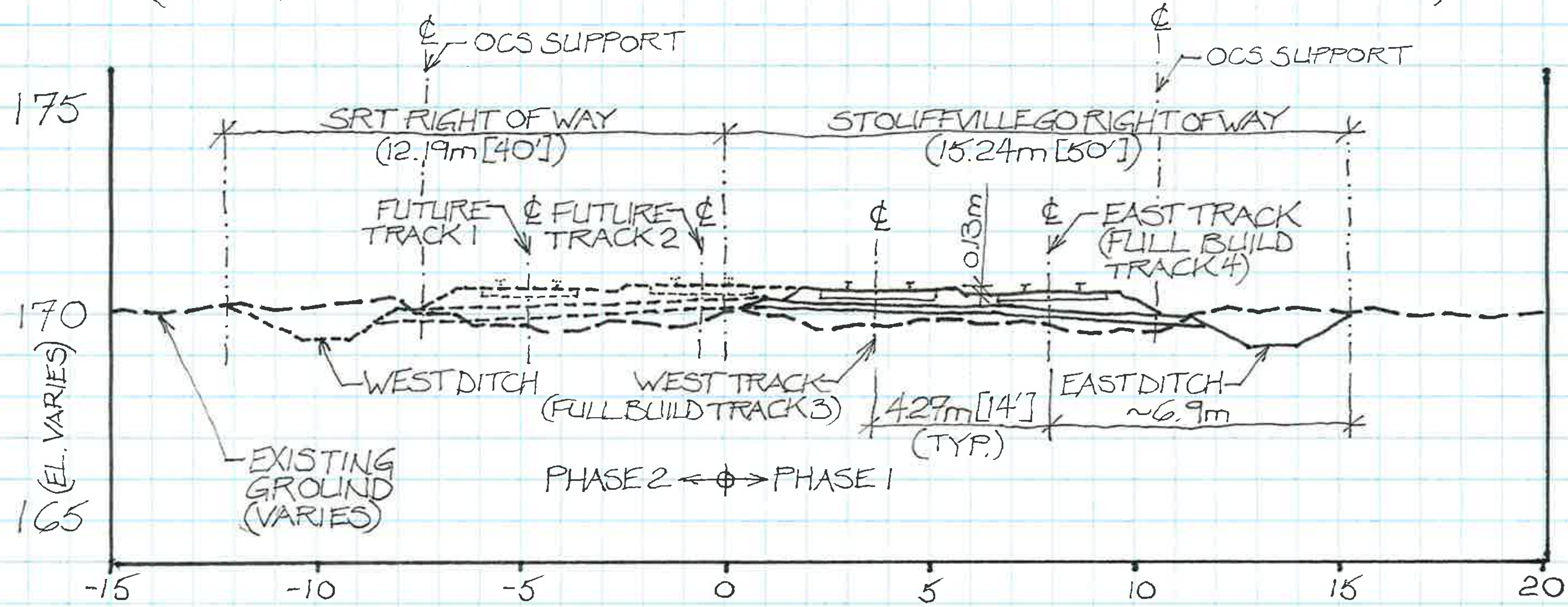
Appendix A

*14' TRACK CENTRES WHERE PRACTICAL



TYPICAL CROSS-SECTION FOR 4-TRACK UXBRIDGE SUB.: ~20m WIDE SEGMENT
(NOT SHOWN: REQUIRED RETENTION STRUCTURE SOUTH OF DANFORTH RD.)

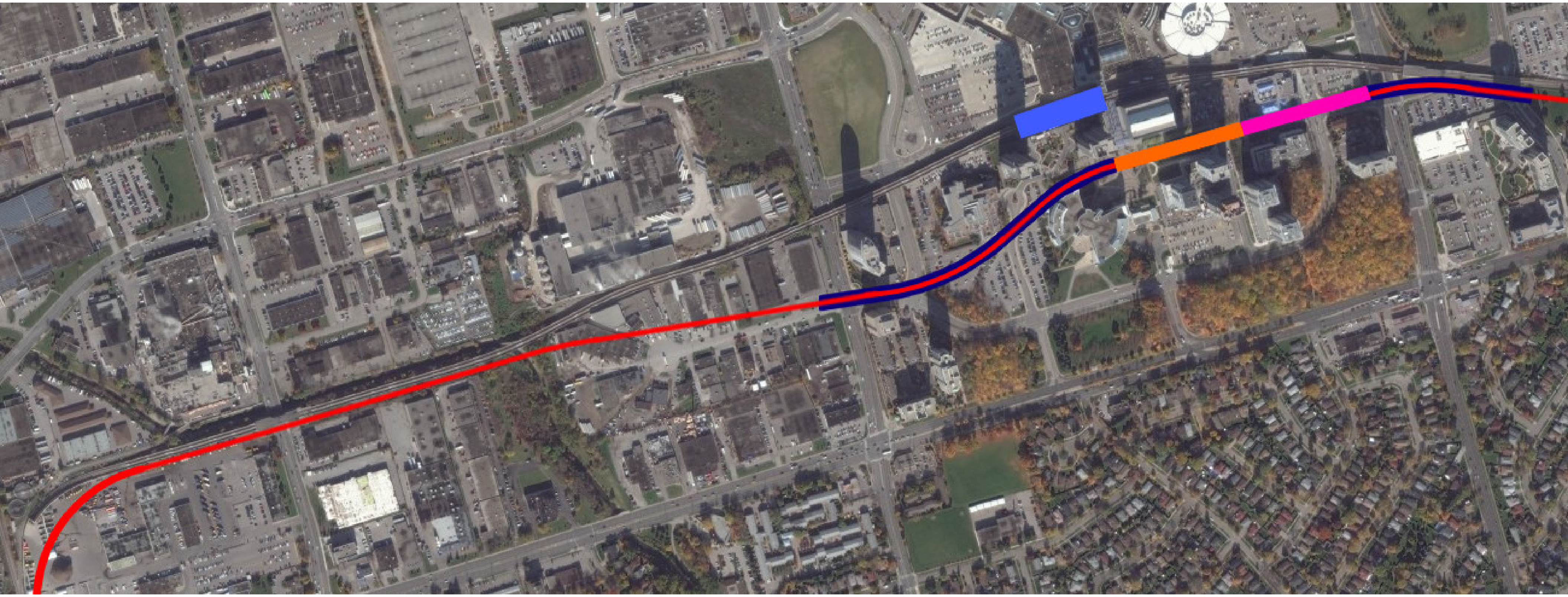
CONCEPTUAL - NOT FOR CONSTRUCTION



TYPICAL CROSS-SECTION FOR 4-TRACK UXBRIDGE SUB.: 27.4m WIDE SEGMENT

CONCEPTUAL - NOT FOR CONSTRUCTION

Appendix B



Appendix C

ELLESMERE CURVE DESIGN OPTIONS

GO Transit geometry standards based on CN due to previous ownership and CN running rights of GO Transit-owned rail corridors (except Milton).
CN geometry standards are based on AREMA.
AREMA is the industry guideline (not a standard) for North American railroading, and widely used.
The formula from AREMA for curve speed is:

$(Ea + Eu) = DV^2 0.0007$

D.C.	Degree of Curve (degrees)
R	Radius (metres)
Ea	Actual Superelevation (inches)
Eu	Underbalance (inches)
V	Velocity (miles/hour)
S	Speed (kilometres/hour)
(init.)	Initial value
(round)	Rounded value to multiple of 5

OPTION	D.C.	R	Ea	Eu (init.)	V (init.)	V (round)	S (round)	Eu (round)	Spiral (m)
1	6	291.1	4.5	2.5	40.82	40	65	2.22	85.0
2	6	291.1	4.5	3	42.26	40	65	2.22	85.0
3	6	291.1	4.5	3.5	43.64	40	70	2.22	85.0
4	6	291.1	4.5	4	44.99	40	70	2.22	85.0
5	6	291.1	5	2.5	42.26	40	65	1.72	94.5
6	6	291.1	5	3	43.64	40	70	1.72	94.5
7	6	291.1	5	3.5	44.99	40	70	1.72	94.5
8	6	291.1	5	4	46.29	45	70	3.51	94.5

HIGHLAND CREEK CURVE DESIGN OPTIONS

GO Transit geometry standards based on CN due to previous ownership and CN running rights of GO Transit-owned rail corridors (except Milton). CN geometry standards are based on AREMA. AREMA is the industry guideline (not a standard) for North American railroading, and widely used. The formula from AREMA for curve speed is:

$(Ea + Eu) = DV^2 0.0007$

D.C.	Degree of Curve (degrees)
R	Radius (metres)
Ea	Actual Superelevation (inches)
Eu	Underbalance (inches)
V	Velocity (miles/hour)
S	Speed (kilometres/hour)
(init.)	Initial value
(round)	Rounded value to multiple of 5

OPTION	D.C.	R	Ea	Eu (init.)	V (init.)	V (round)	S (round)	Eu (round)	Spiral (m)
1	2	873.2	1	2.5	50.00	50	80	2.50	62.1
2	2	873.2	1	3	53.45	50	85	2.50	62.1
3	2	873.2	2	2.5	56.69	55	90	2.24	61.1
4	2	873.2	2	3	59.76	55	95	2.24	61.1
5	2	873.2	2.5	2.5	59.76	55	95	1.74	47.4
6	2	873.2	2.5	3	62.68	60	100	2.54	75.7
7	2	873.2	3	2.5	62.68	60	100	2.04	60.8
8	2	873.2	3	3	65.47	65	105	2.92	94.1

BRIMLEY CURVE DESIGN OPTIONS

GO Transit geometry standards based on CN due to previous ownership and CN running rights of GO Transit-owned rail corridors (except Milton). CN geometry standards are based on AREMA. AREMA is the industry guideline (not a standard) for North American railroading, and widely used. The formula from AREMA for curve speed is:

$(Ea + Eu) = DV^2 0.0007$

D.C.	Degree of Curve (degrees)
R	Radius (metres)
Ea	Actual Superelevation (inches)
Eu	Underbalance (inches)
V	Velocity (miles/hour)
S	Speed (kilometres/hour)
(init.)	Initial value
(round)	Rounded value to multiple of 5

OPTION	D.C.	R	Ea	Eu (init.)	V (init.)	V (round)	S (round)	Eu (round)	Spiral (m)
1	7	249.5	4.5	2.5	37.80	35	60	1.50	85.0
2	7	249.5	4.5	3	39.12	35	60	1.50	85.0
3	7	249.5	4.5	3.5	40.41	40	65	3.34	85.0
4	7	249.5	4.5	4	41.65	40	65	3.34	85.0
5	7	249.5	5	2.5	39.12	35	60	1.00	94.5
6	7	249.5	5	3	40.41	40	65	2.84	94.5
7	7	249.5	5	3.5	41.65	40	65	2.84	94.5
8	7	249.5	5	4	42.86	40	65	2.84	94.5

BRIAN HARRISON CURVE DESIGN OPTIONS

GO Transit geometry standards based on CN
due to previous ownership and CN running rights
of GO Transit-owned rail corridors (except Milton).
CN geometry standards are based on AREMA.
AREMA is the industry guideline (not a standard)
for North American railroading, and widely used.
The formula from AREMA for curve speed is:
$(Ea + Eu) = DV^2 0.0007$

D.C.	Degree of Curve (degrees)
R	Radius (metres)
Ea	Actual Superelevation (inches)
Eu	Underbalance (inches)
V	Velocity (miles/hour)
S	Speed (kilometres/hour)
(init.)	Initial value
(round)	Rounded value to multiple of 5

OPTION	D.C.	R	Ea	Eu (init.)	V (init.)	V (round)	S (round)	Eu (round)	Spiral (m)
1	7	249.5	4.5	2.5	37.80	35	60	1.50	85.0
2	7	249.5	4.5	3	39.12	35	60	1.50	85.0
3	7	249.5	4.5	3.5	40.41	40	65	3.34	85.0
4	7	249.5	4.5	4	41.65	40	65	3.34	85.0
5	7	249.5	5	2.5	39.12	35	60	1.00	94.5
6	7	249.5	5	3	40.41	40	65	2.84	94.5
7	7	249.5	5	3.5	41.65	40	65	2.84	94.5
8	7	249.5	5	4	42.86	40	65	2.84	94.5

McCOWAN CURVE DESIGN OPTIONS

GO Transit geometry standards based on CN
due to previous ownership and CN running rights
of GO Transit-owned rail corridors (except Milton).
CN geometry standards are based on AREMA.
AREMA is the industry guideline (not a standard)
for North American railroading, and widely used.
The formula from AREMA for curve speed is:
$(Ea + Eu) = DV^2 0.0007$

D.C.	Degree of Curve (degrees)
R	Radius (metres)
Ea	Actual Superelevation (inches)
Eu	Underbalance (inches)
V	Velocity (miles/hour)
S	Speed (kilometres/hour)
(init.)	Initial value
(round)	Rounded value to multiple of 5

OPTION	D.C.	R	Ea	Eu (init.)	V (init.)	V (round)	S (round)	Eu (round)	Spiral (m)
1	5	349.3	4.5	2.5	44.72	40	70	1.10	85.0
2	5	349.3	4.5	3	46.29	45	70	2.59	85.0
3	5	349.3	4.5	3.5	47.81	45	75	2.59	85.0
4	5	349.3	4.5	4	49.28	45	75	2.59	85.0
5	5	349.3	5	2.5	46.29	45	70	2.09	94.5
6	5	349.3	5	3	47.81	45	75	2.09	94.5
7	5	349.3	5	3.5	49.28	45	75	2.09	94.5
8	5	349.3	5	4	50.71	50	80	3.75	94.5

GRANGEWAY CURVE DESIGN OPTIONS

GO Transit geometry standards based on CN
due to previous ownership and CN running rights
of GO Transit-owned rail corridors (except Milton).
CN geometry standards are based on AREMA.
AREMA is the industry guideline (not a standard)
for North American railroading, and widely used.
The formula from AREMA for curve speed is:
$(Ea + Eu) = DV^2 0.0007$

D.C.	Degree of Curve (degrees)
R	Radius (metres)
Ea	Actual Superelevation (inches)
Eu	Underbalance (inches)
V	Velocity (miles/hour)
S	Speed (kilometres/hour)
(init.)	Initial value
(round)	Rounded value to multiple of 5

OPTION	D.C.	R	Ea	Eu (init.)	V (init.)	V (round)	S (round)	Eu (round)	Spiral (m)
1	5	349.3	4.5	2.5	44.72	40	70	1.10	85.0
2	5	349.3	4.5	3	46.29	45	70	2.59	85.0
3	5	349.3	4.5	3.5	47.81	45	75	2.59	85.0
4	5	349.3	4.5	4	49.28	45	75	2.59	85.0
5	5	349.3	5	2.5	46.29	45	70	2.09	94.5
6	5	349.3	5	3	47.81	45	75	2.09	94.5
7	5	349.3	5	3.5	49.28	45	75	2.09	94.5
8	5	349.3	5	4	50.71	50	80	3.75	94.5

BELLAMY CURVE DESIGN OPTIONS

GO Transit geometry standards based on CN due to previous ownership and CN running rights of GO Transit-owned rail corridors (except Milton).
CN geometry standards are based on AREMA.
AREMA is the industry guideline (not a standard) for North American railroading, and widely used.
The formula from AREMA for curve speed is:
$(Ea + Eu) = DV^2 0.0007$

D.C.	Degree of Curve (degrees)
R	Radius (metres)
Ea	Actual Superelevation (inches)
Eu	Underbalance (inches)
V	Velocity (miles/hour)
S	Speed (kilometres/hour)
(init.)	Initial value
(round)	Rounded value to multiple of 5

OPTION	D.C.	R	Ea	Eu (init.)	V (init.)	V (round)	S (round)	Eu (round)	Spiral (m)
1	4.5	388.1	4.5	2.5	47.14	45	75	1.88	85.0
2	4.5	388.1	4.5	3	48.80	45	75	1.88	85.0
3	4.5	388.1	4.5	3.5	50.40	50	80	3.38	85.0
4	4.5	388.1	4.5	4	51.95	50	80	3.38	85.0
5	4.5	388.1	5	2.5	48.80	45	75	1.38	94.5
6	4.5	388.1	5	3	50.40	50	80	2.88	94.5
7	4.5	388.1	5	3.5	51.95	50	80	2.88	94.5
8	4.5	388.1	5	4	53.45	50	85	2.88	94.5

PRODUCTION DR CURVE DESIGN OPTIONS

GO Transit geometry standards based on CN
due to previous ownership and CN running rights
of GO Transit-owned rail corridors (except Milton).
CN geometry standards are based on AREMA.
AREMA is the industry guideline (not a standard)
for North American railroading, and widely used.
The formula from AREMA for curve speed is:
$(Ea + Eu) = DV^2 0.0007$

D.C.	Degree of Curve (degrees)
R	Radius (metres)
Ea	Actual Superelevation (inches)
Eu	Underbalance (inches)
V	Velocity (miles/hour)
S	Speed (kilometres/hour)
(init.)	Initial value
(round)	Rounded value to multiple of 5

OPTION	D.C.	R	Ea	Eu (init.)	V (init.)	V (round)	S (round)	Eu (round)	Spiral (m)
1	4.5	388.1	4.5	2.5	47.14	45	75	1.88	85.0
2	4.5	388.1	4.5	3	48.80	45	75	1.88	85.0
3	4.5	388.1	4.5	3.5	50.40	50	80	3.38	85.0
4	4.5	388.1	4.5	4	51.95	50	80	3.38	85.0
5	4.5	388.1	5	2.5	48.80	45	75	1.38	94.5
6	4.5	388.1	5	3	50.40	50	80	2.88	94.5
7	4.5	388.1	5	3.5	51.95	50	80	2.88	94.5
8	4.5	388.1	5	4	53.45	50	85	2.88	94.5

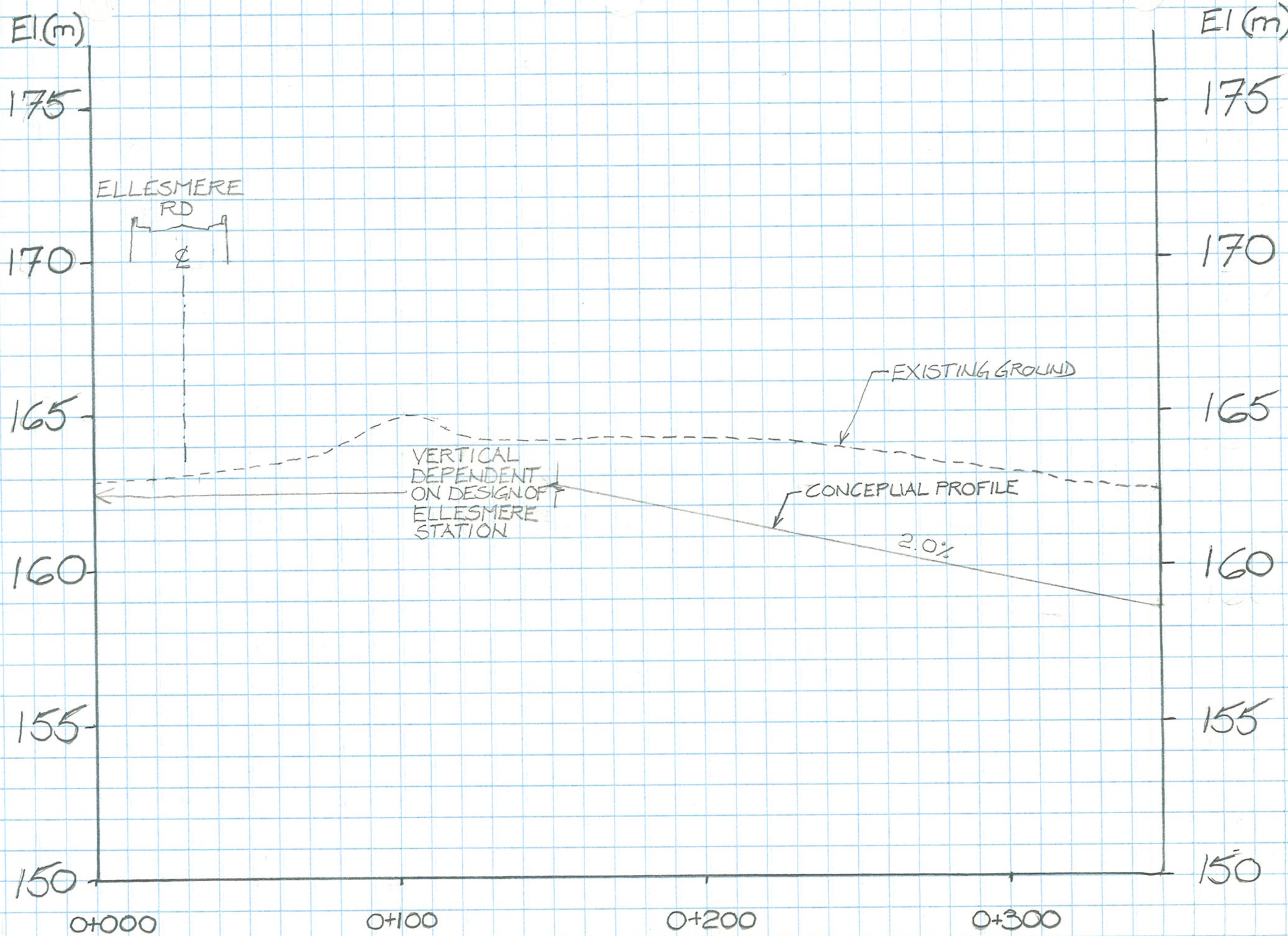
MARKHAM RD CURVE DESIGN OPTIONS

GO Transit geometry standards based on CN
due to previous ownership and CN running rights
of GO Transit-owned rail corridors (except Milton).
CN geometry standards are based on AREMA.
AREMA is the industry guideline (not a standard)
for North American railroading, and widely used.
The formula from AREMA for curve speed is:
$(Ea + Eu) = DV^2 0.0007$

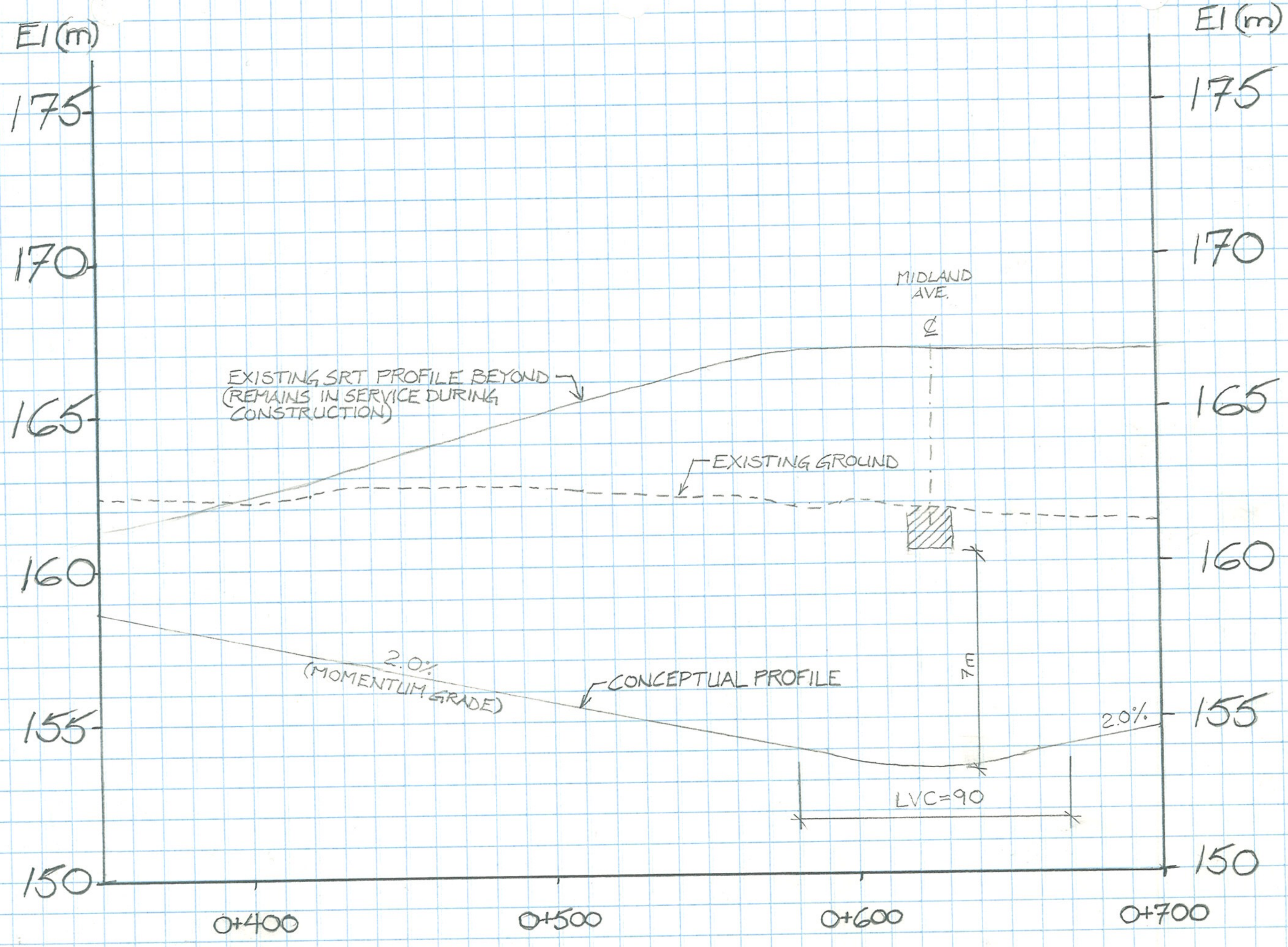
D.C.	Degree of Curve (degrees)
R	Radius (metres)
Ea	Actual Superelevation (inches)
Eu	Underbalance (inches)
V	Velocity (miles/hour)
S	Speed (kilometres/hour)
(init.)	Initial value
(round)	Rounded value to multiple of 5

OPTION	D.C.	R	Ea	Eu (init.)	V (init.)	V (round)	S (round)	Eu (round)	Spiral (m)
1	6	291.1	4.5	2.5	40.82	40	65	2.22	85.0
2	6	291.1	4.5	3	42.26	40	65	2.22	85.0
3	6	291.1	4.5	3.5	43.64	40	70	2.22	85.0
4	6	291.1	4.5	4	44.99	40	70	2.22	85.0
5	6	291.1	5	2.5	42.26	40	65	1.72	94.5
6	6	291.1	5	3	43.64	40	70	1.72	94.5
7	6	291.1	5	3.5	44.99	40	70	1.72	94.5
8	6	291.1	5	4	46.29	45	70	3.51	94.5

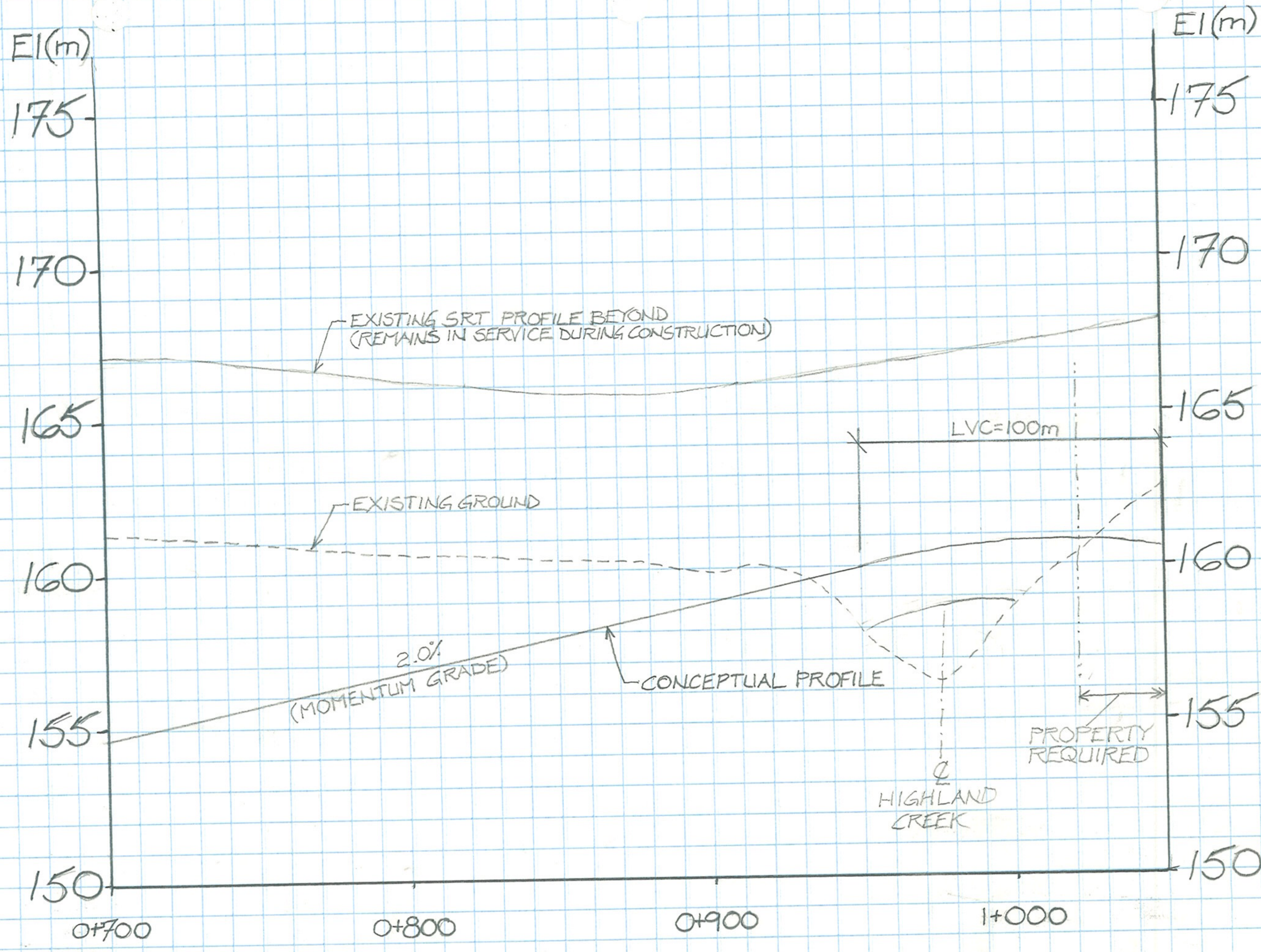
Appendix D

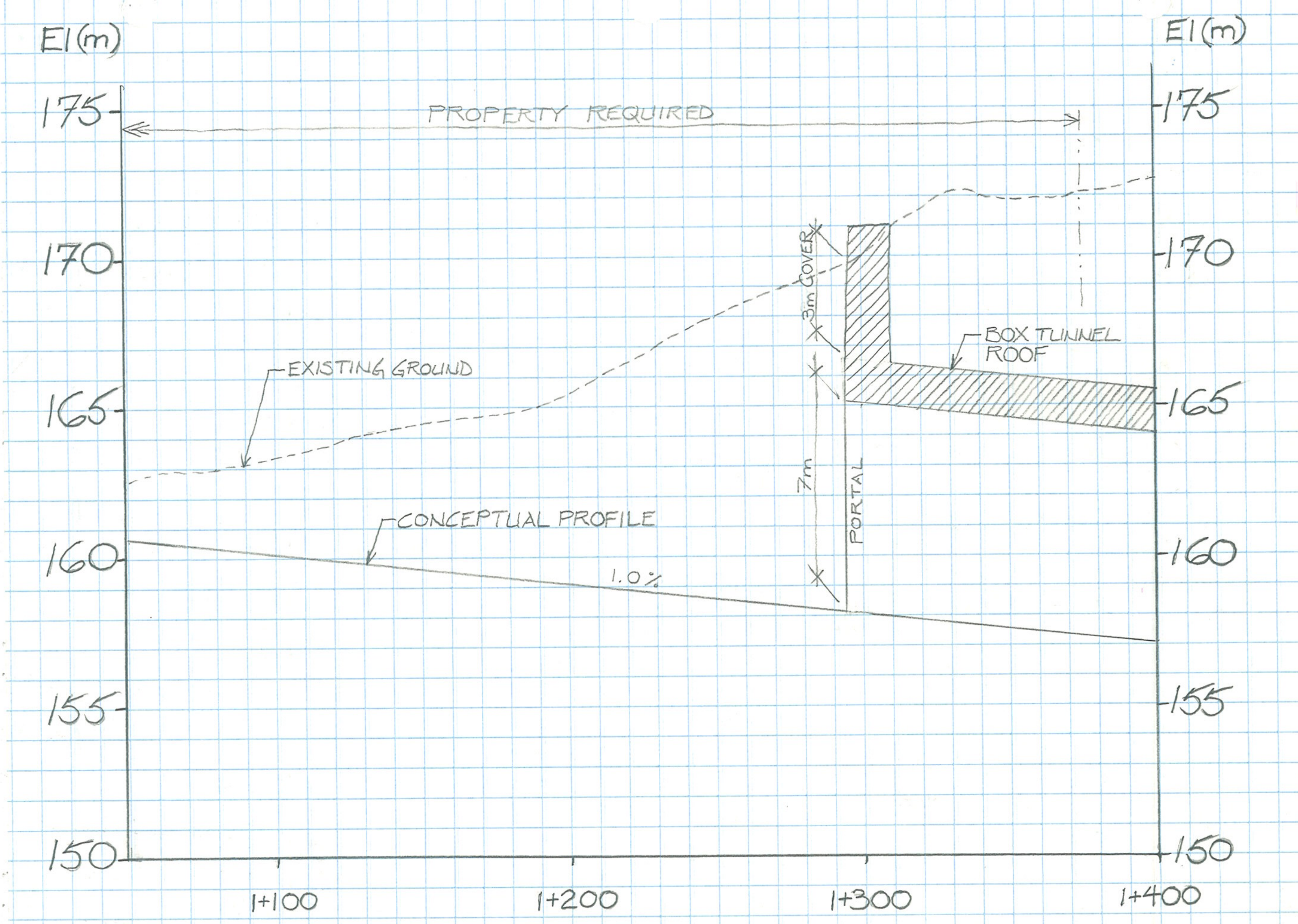


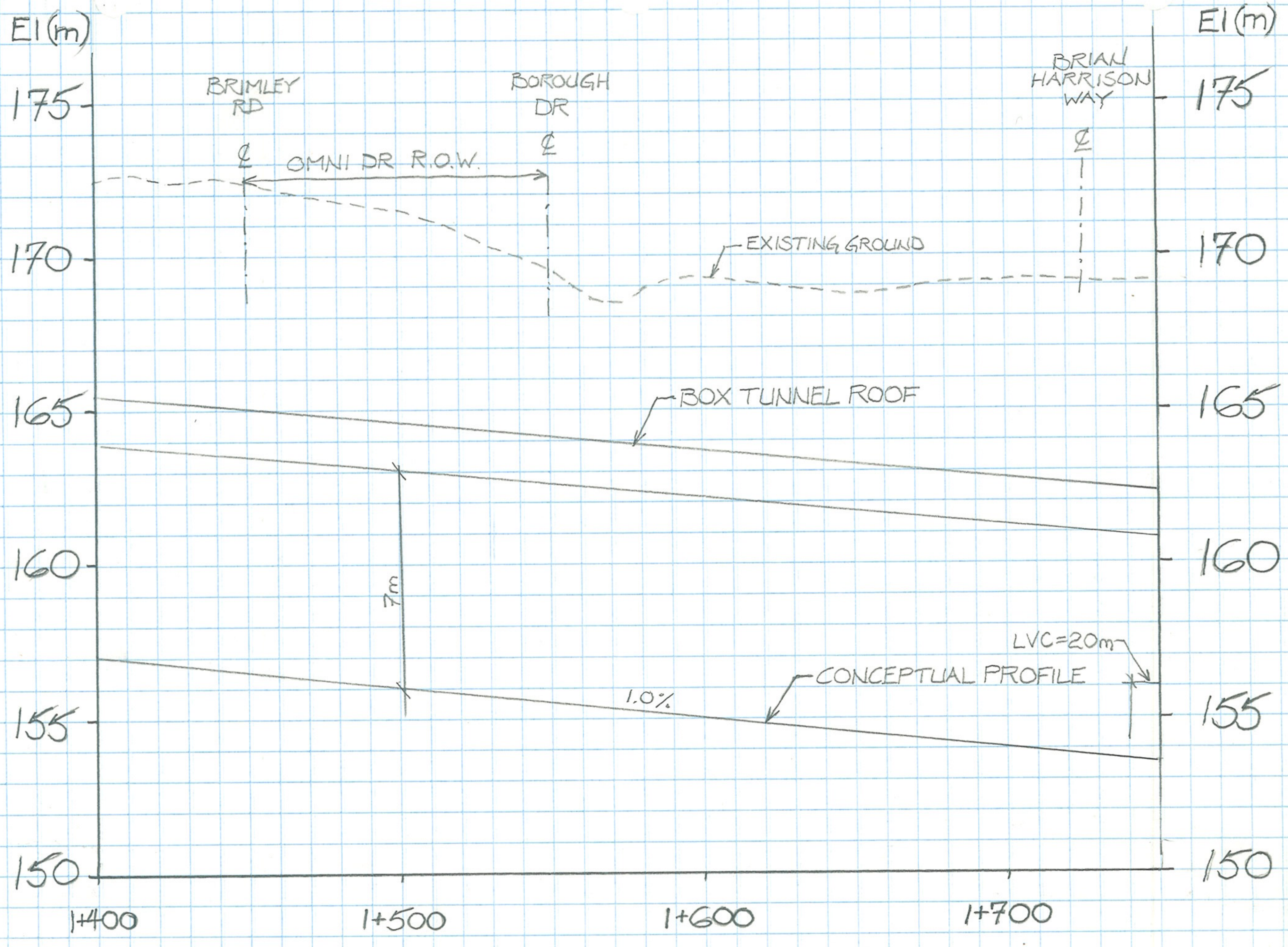
El (m)
175
170
165
160
155
150
ELLESMERE RD
℄
EXISTING GROUND
VERTICAL DEPENDENT ON DESIGN OF ELLESMERE STATION
CONCEPUAL PROFILE
2.0%
0+000
0+100
0+200
0+300



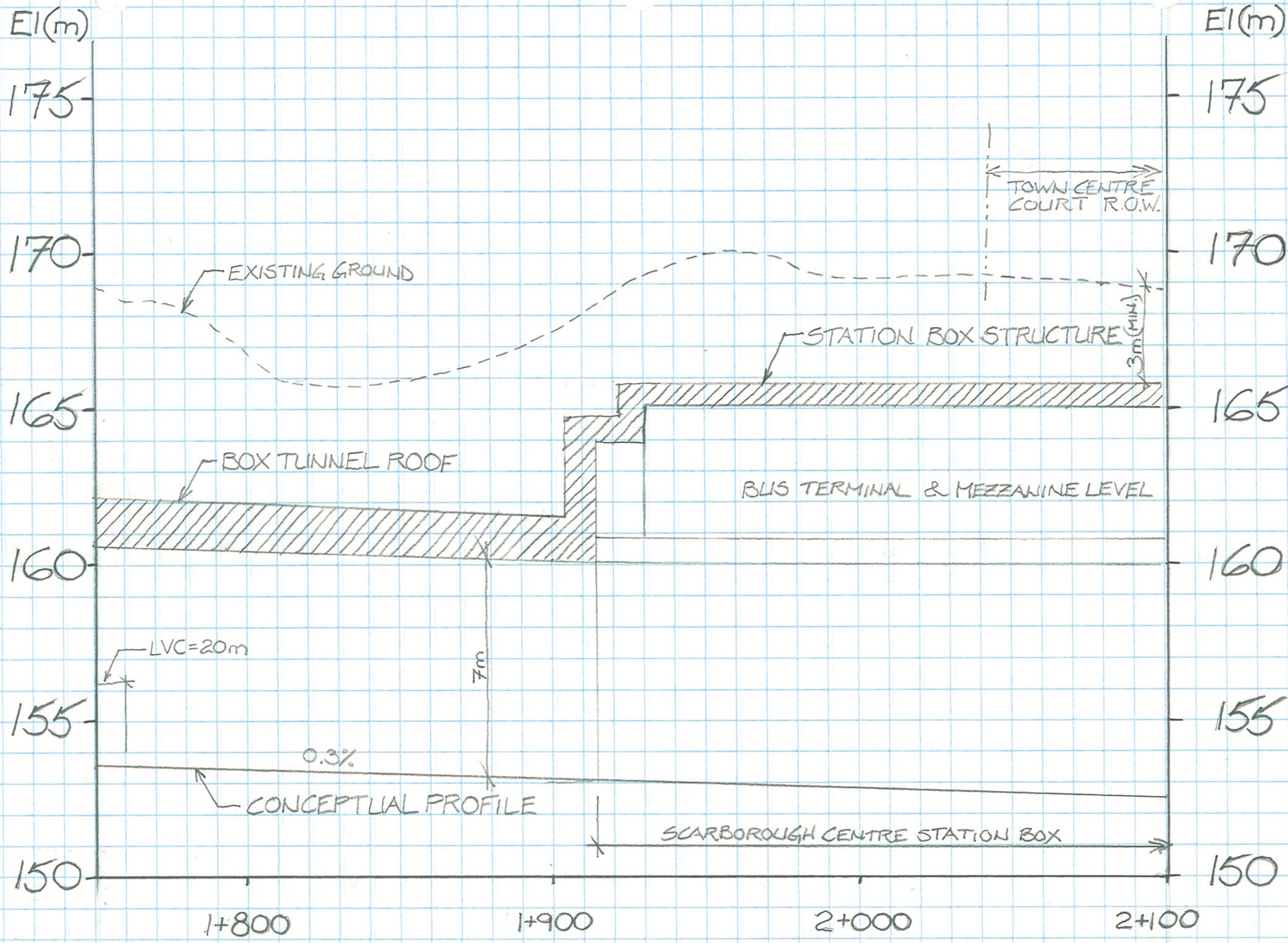
El (m)
El (m)
175
170
165
160
155
150
MIDLAND AVE.
℄
EXISTING SRT PROFILE BEYOND (REMAINS IN SERVICE DURING CONSTRUCTION)
EXISTING GROUND
2.0% (MOMENTUM GRADE)
CONCEPTUAL PROFILE
7m
2.0%
LVC=90
0+400
0+500
0+600
0+700

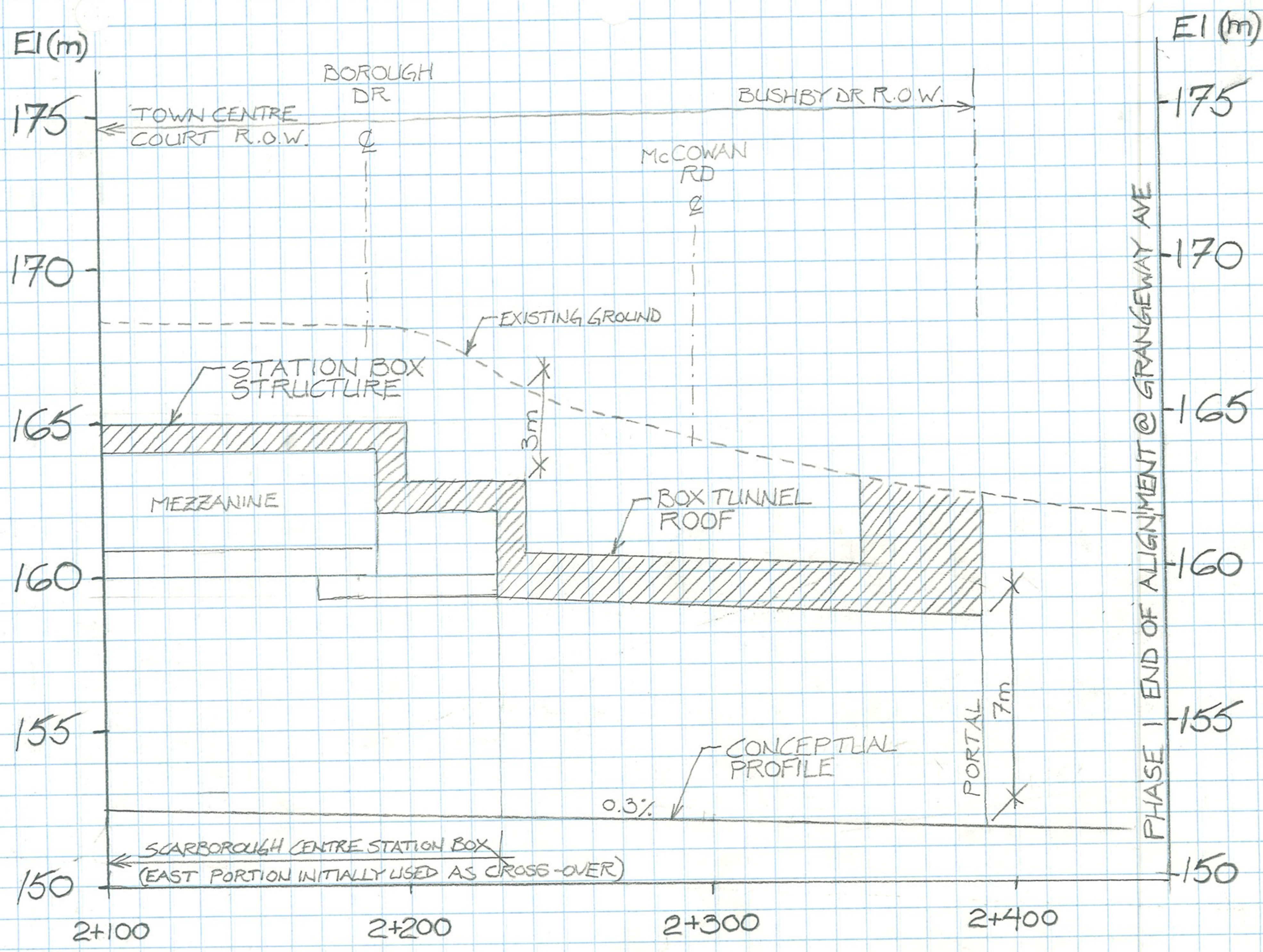

El(m)
175
170
165
160
155
150
EXISTING SRT PROFILE BEYOND
(REMAINS IN SERVICE DURING CONSTRUCTION)
LVC=100m
EXISTING GROUND
2.0%
(MOMENTUM GRADE)
CONCEPTUAL PROFILE
PROPERTY REQUIRED
℄ HIGHLAND CREEK
0+700
0+800
0+900
1+000


El(m)
El(m)
175
170
165
160
155
150
PROPERTY REQUIRED
3m COVER
BOX TUNNEL
ROOF
EXISTING GROUND
7m
PORTAL
CONCEPTUAL PROFILE
1.0%
1+100
1+200
1+300
1+400



El (m)
El (m)
175
170
165
160
155
150
BRIMLEY RD
BOROUGH DR
BRIAN HARRISON WAY
℄
℄
℄
OMNI DR R.O.W.
EXISTING GROUND
BOX TUNNEL ROOF
7m
LVC=20m
CONCEPTUAL PROFILE
1.0%
1+400
1+500
1+600
1+700


El(m)
El(m)
175
175
170
170
165
165
160
160
155
155
150
150
TOWN CENTRE
COURT R.O.W.
EXISTING GROUND
STATION BOX STRUCTURE
3m (MIN.)
BOX TUNNEL ROOF
BUS TERMINAL & MEZZANINE LEVEL
LVC=20m
7m
0.3%
CONCEPTUAL PROFILE
SCARBOROUGH CENTRE STATION BOX
1+800
1+900
2+000
2+100



El (m)
175
170
165
160
155
150
BOROUGH DR
℄
TOWN CENTRE COURT R.O.W.
BUSHBY DR R.O.W.
McCOWAN RD
℄
EXISTING GROUND
STATION BOX STRUCTURE
3m
MEZZANINE
BOX TUNNEL ROOF
PORTAL
7m
CONCEPTUAL PROFILE
0.3%
SCARBOROUGH CENTRE STATION BOX
(EAST PORTION INITIALLY USED AS CROSS-OVER)
PHASE 1 END OF ALIGNMENT @ GRANGEWAY AVE
2+100
2+200
2+300
2+400