Structure Type and Alternatives Assessment Report for S/E-N Ramp Flyover

McLaughlin Road and Spine Road Class EA
Project # TPB166090; Town of Caledon

Prepared for:

Town of Caledon

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1.0 Introduction

The Town of Caledon (Town) has initiated a Municipal Class Environmental Assessment (Class EA) Schedule 'C' for the widening of McLaughlin Road and construction of the new East-West Spine Road (Mayfield West Phase 2). The improvements are required to meet the Town's development needs considering satisfactory level of service and safe driving conditions within the study area. Wood Environment & Infrastructure Solutions was retained by the Town to complete the study.

Part of the works includes connection of the new Spine Road to the Highway 410 / Valleywood Boulevard / Hurontario Street interchange. Through assessment of alternatives and in consultation with the Ministry of Transportation, extensive modifications to the interchange have been identified to facilitate this connection.

A key element of the modifications is to construct a new northbound on-ramp from Hurontario Street / Spine Road to Highway 410. The new northbound on-ramp, known as the S/E-N Ramp, will cross over Highway 410 and connect to the northbound lanes approximately 600m north of the existing interchange. The crossing of Highway 410 will require a grade separated overpass to support the movement of traffic over the mainline. This report was completed to document the assessment completed and the specifics of the grade separation for the new ramp.

2.0 Design Criteria and Functional Requirements

2.1 Existing Condition of Highway 410 and Future Widening

Under existing conditions, Highway 410 is transitioning from an east-west roadway to a north-south roadway as the highway crosses under Valleywood Boulevard. The mainline consists of wide left and right paved shoulders, 2 lanes in each direction, and a speed change lane for the existing S-N Ramp. The widths of these elements are as follows:

<u>Westbound/Northbound</u>

- 3.40m wide left shoulder (paved);
- 2 x 3.75m wide travel lanes;
- 3.50m wide speed change lane, and
- 3.00m wide right shoulder (paved).

<u>Eastbound/Southbound</u>

- 6.80m wide left shoulder (paved);
- 2 x 3.75m wide travel lanes;
- 3.00m wide right shoulder (paved);

The MTO has indicated that there are no plans to widen Highway 410 at the study location. However, in order to ensure the new flyover can accommodate future widening without significant modification to the superstructure / substructure, it has been assumed that one additional lane in each direction will be constructed. The future lanes are identified on the general arrangement drawing accordingly. The flyover structure will consist of a two-span bridge with a centre pier located at the median of Highway 410.

2.2 Geometric Design Requirements for the Flyover

For the design of the S/E-N Ramp, the following design parameters have been applied:

Ramp: S/E-N (from Hurontario Street / Spine Road / Valleywood Boulevard to Highway 410)

S/E-N Ramp		DESIGN STANDARDS	PROPOSED STANDARDS
Crossing Road Design Speed (Highway 410)		100 km/h	100 km/h
Ramp Design Speed		60 km/h	60 km/h
Sight Distance Requirement for Stopping, Crossing And Turning Movements at the Crossing Road		N/A	N/A
Equivalent Minimum "K" Factor	**Crest**	11	20
	SAG	8 – 9(1)	20
Grades Maximum		6 %	4.25 %
Radius Minimum		120	230
Pavement Width		4.75 m	4.75 m
Shoulder Width		1.0m LT 2.5m RT	1.0 / 2.5m LT(4) 1.0 / 2.5m RT
Shoulder Rounding		0.5 m	0.5 m(2)
Superelevation Maximum Rate		0.06 m/m	0.06 m/m
Sight Distance at Exit Terminal		N/A	N/A
Exit Terminal Speed-Change Lane Length		N/A	N/A
Sight Distance at Entrance Terminal		205m	>205m
Entrance Terminal Speed-Change Lane Length		140 - 325 m(3)	390 m

Notes:

(1) Assumed that the ramp will be illuminated
(2) Shoulder rounding to increase to 1.0m where steel beam guide rail is required
(3) From TAC GDGCR (2017) - Table 10.6.5
(4) Wider left (inside) shoulder to ensure sight distance is achieved (only where sight lines are obstructed by the concrete barrier / parapet wall).

Traffic data for the proposed ramp is as follows:

Location	AADT 2021	SADT 2021	DHV	% Comm (2031)	% Long Trucks (2031)	AADT 2031	SADT 2031
Proposed On-Ramp from NB Hurontario St to NB Hwy 410	5,830	5,830	10%	2.50%	4.00%	6,880	6,880

2.3 Future Rehabilitation

With proper maintenance, bridges built to current standard are expected to provide a service life of 75 years without major works, except the expansion joints and waterproofing which would require replacement every 25 to 30 years. During future rehabilitations, although the bridge could possibly accommodate the unsymmetrical live load effects on the deck, the deck width has not been designed to allow for staged construction with one live lane on the bridge during rehabilitation. If the flyover needs to be closed for future rehabilitation, the current loop ramp is planned to be maintained and will serve as an alternative route to divert the northbound traffic from Hurontario Street.

3.0 Structure Alternatives

3.1 Alternative 1: Cast in Place Post-Tensioned Deck

This type of structure is very robust and is most suitable for medium span (>30m) and curved bridges. MTO started building this type of bridge in the 1960s but it was only after 1974 that transverse post-tensioning became a mandatory requirement. The implementation of transverse post-tensioning essentially eliminated the concerns of longitudinal cracking due to shear lag effect and longitudinal cracking due to stress concentration over the voids; those constructed after 1974 are all performing very well with minimal maintenance requirements. The only drawback with this type of bridge is that during construction, the formwork/falsework system has to span over the existing highway to provide adequate vertical and horizontal clearances for safety; this would often require raising the profile of the roadway above the highway in order to accommodate the temporary clearance envelope, which is not always feasible due to physical constraints and property issues.

The minimum vertical clearance to the underside of formwork during construction according to the MTO standard is 4.5 m; it would be prudent for the ministry to review whether this minimum requirement is acceptable at this site due to the high speed and truck traffic volume. In order to meet this minimum vertical clearance during construction, the vertical profile of the flyover would have to be raised by approximately 0.75m compared with the other alternatives.

3.2 Alternative 2: Slab on Steel Plate Girders

This type of bridge is very suitable for the proposed span arrangement and plate girders can be fabricated in a curve to match the curvature of the roadway. However, plate girders have drawbacks from a durability and maintenance point of view since the bottom flange tends to hold debris and moisture, which could lead to premature corrosion of uncoated weathering steel, and therefore necessitating a protective coating system. The current MTO policy for use of plate girders over highways requires that the vertical clearance be increased to 6.0 m for a posted speed up to 90 km/hr as opposed to the standard minimum of 5.1m for girders, and that the girders shall be hot-dipped galvanized or metallized. Since the girder segments are likely longer than the maximum length that the galvanizing tank can handle, metallizing would be the only coating option and it has a service life of 30 to 40 years; the girders therefore have to be recoated at least once within their design life of 75 years.

3.3 Alternative 3: Slab on Steel Box Girders

Steel box girders are very suitable for curved bridges due to their inherent high torsional stiffness. They do not have the same durability concern related to the bottom flange of plate girders. Hence, according to the current MTO policy, they do not require protective coating except for 3.0m at the ends under expansion joints. The fabrication cost could be somewhat higher than plate girders but for longer spans the thickness of the bottom flange could be within preferred thicknesses while plate girders might require much thicker plates. The ministry has constructed many curved bridges with steel box girders, including those in the 407 East, and they are performing well.

There are however two drawbacks of box girders:

(i) The inside space is considered to be a confined space, hence any inspection task in the future has to be conducted following proper health and safety protocols accordingly, and the minimum depth of girder to allow such inspection according to MTO policy is 1.2m; the proposed depth of girders for this site is around 1.5m.

(ii) For very large skew angles (>30 degree), the detailing of the end diaphragms could become complex and the distribution of bearing reactions could become quite uneven within the same box. For this particular site, it is proposed that the abutments should be perpendicular to the alignment of the flyover thus eliminating the skew effect on the bearing reactions and simplifying the diaphragm details.

3.4 Alternative 4: Slab on Precast Concrete Girders

Since precast girders cannot be cast and prestressed in a curved shape, straight girders will be used with a kink at the pier. Due to the abrupt change in direction at the pier, there is an unbalanced force in the transverse direction that needs to be taken care of in the design. It is also aesthetically not pleasing due to the varying deck cantilever width resulting from the mismatch of the curved deck edge and the straight girder. In general, the horizontal radius of curvature has to be larger than 300m for this to be feasible; the radius for this site is around 230m and therefore this alternative would not be recommended.

3.5 Comparison of Alternatives and Recommendation

Table 1 in Appendix A shows the comparison of the four alternatives noted above. The first preferred alternative from a structural performance point of view is the cast in place post-tensioned deck (Alternative 1); however, due to the vertical clearance issue during construction and the risk involved, we would recommend moving forward with the slab on steel box girders (Alternative 3).

4.0 Performance Level of Barrier Wall

Due to the relatively low design speed and the low AADT, the calculated exposure index according to CHBDC only requires a TL4 barrier. We would however propose a TL5 concrete barrier wall without the top handrail to minimize long term maintenance requirement and to enhance safety.

5.0 Foundation

As revealed by the geotechnical investigation, soil stratum within reasonable depth from the existing grade would not provide sufficient bearing capacity for the anticipated loading, hence, it is recommended that the abutments and pier be supported on driven steel H-piles, and since bedrock is at a great depth at this site, the piles shall be driven to achieve the specified capacity with estimated toe elevations.

6.0 Expansion Joint Versus Integral Abutment

Due to the curvature and skew of the bridge, integral abutment or semi-integral would generate an unbalanced earth pressure load that could cause lateral bending and planar displacement of the deck. The actual point of zero movement in relation to the supports at abutment is also difficult to assess accurately. Hence, we would recommend conventional Type A expansion joints at both abutments. In order to enhance durability of the ballast wall, bearing seat and the front face of abutments, premium reinforcement could be considered in these locations.

7.0 Durability and Corrosion Protection Strategy

The corrosion protection strategy, including the type of reinforcement in the deck, barrier wall, substructure, and coating of the structural steel, shall be according to the MTO corrosion protection policy as stipulated in the Structural Manual (2016).

8.0 Cost Comparison

All the girder type bridges considered in this report should be budgeted for a benchmark cost of $4000 per sq.m, of deck area plus 15% contingency, for a total cost of $3.3M. As for the post-tensioned deck, since there have been very few of them constructed in the recent past, it is difficult to provide an accurate estimate, but for comparison with the other alternatives, we would recommend a benchmark cost of $4500 per sq.m plus 15% contingency, for a total cost of $3.7M. There is therefore not a significant difference in initial capital cost between the alternatives.

As for life-cycle cost, the only alternative that would incur significant future maintenance/rehabilitation cost relative to the others is Alternative 2 (slab on steel plate girders), since the plate girders would have to be recoated in around year 30 for a capital cost of $500,000 and a present value cost of $125,000.

9.0 Constructability

All the girder type bridges could be constructed using conventional methods and equipment. Lifting of the girders would likely be by cranes set on Highway 410 during off-peak hours with short term lane closures.

The plate girders might have to be lifted in pairs for stability while the box girders could possibly be lifted individually.

As mentioned in subsection 3.1, temporary falsework has to span over Highway 410 during construction of the post-tensioned deck with 4.5m vertical clearance, and with TCB on each side protecting the shoring towers; erection of the falsework beams would also require temporary lane closures during off peak hours. This alternative therefore has a higher risk from an operational safety perspective. This alternative would also take longer time to construct compared with the girder alternatives since the girders could be fabricated in advance, possibly during the winter months if the contract is awarded early.

For all the alternatives, a center pier that coincides with the center line of the median would be required. Currently the distances from the edge of the NBL and SBL roadway to the center of median is 3.4m and 6.8m respectively. In order to install piles and construct the pier footing, a clear work zone of around 6m on each side of the median would likely be required with TCB protection. While this would have minimal impact to the SBL due to the wider shoulder, a temporary shift in lanes for the NBL would be required.

To facilitate the construction of the median pier, the northbound lanes need to be shifted to provide a 6m wide work zone. Additionally, a temporary concrete barrier and 0.5m left shoulder will need to be placed in order to protect the work zone. Given this, a total work zone of 7.15m between the median pier and the edge of travel lanes is required.

At the new pier location, the following lane configuration occurs: 3.40m left shoulder, 2 x 3.75m travel lanes, 1 x 3.50m speed change lane, and a 2.50m right shoulder. Assuming the above noted lane widths are maintained, the right shoulder is reduced to 0.5m, and the paved shoulder can be used to carry traffic, temporary widening of 2.0m will be required to facilitate the pier construction. It is noted that based on the design drawings provided by MTO for Highway 410, the right shoulder is paved with 40mm SP 12.5 FC2 + 50mm SP 19.0. A pavement investigation will need to be conducted to ensure the right shoulder has sufficient strength to carry the expected traffic loads created by the lane shift onto the paved shoulder.

10.0 Conclusion

We recommend that the flyover at this site be constructed as a 2-span slab on steel box girder bridge; the box girders will utilize uncoated weathering steel except the end 3.0m under expansion joint will be coated. The vertical clearance provided is around 5.2m and is controlled by the future widening of Highway 410 at the right shoulder of the NBL. The General Arrangement of the proposed bridge is included in Appendix B.

Appendix A: Alternative Assessment Table

Table 1

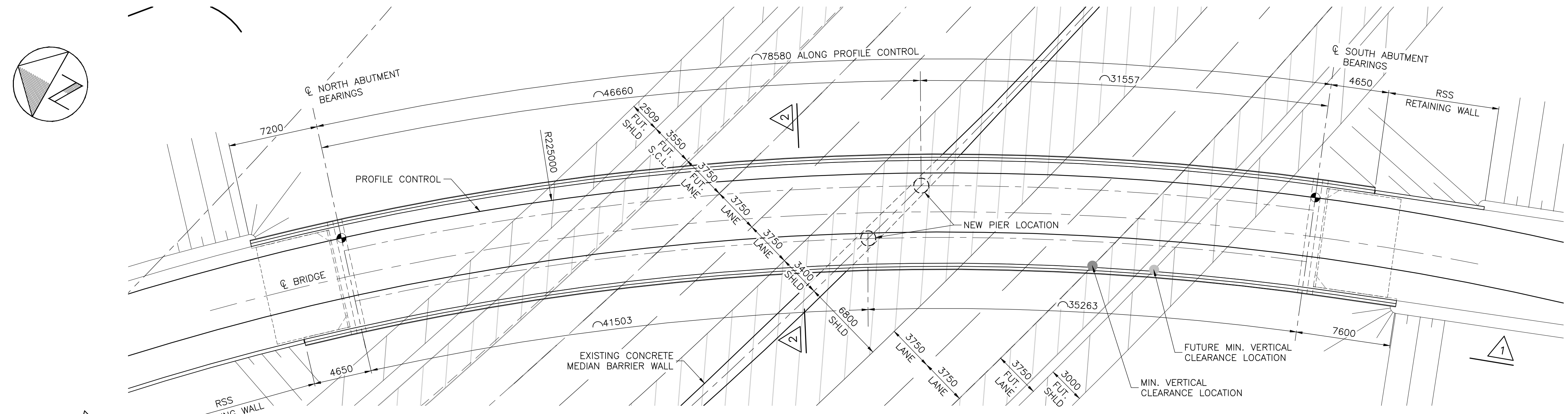
Type of structure	Pros	Cons	Durability and maintenance	Design complexity
Post-tensioned deck (solid up to 28m, voided when span > 28m)	• Most suitable for curved bridges with sharp radius • Can be supported on single pier column if deck width < 14m • Smaller super-structure depth compared with other types of structures • Most robust type of structure against potential impact and therefore requires only 4.65m vertical clearance in service.	• Requires falsework to span over highway, depth of formwork assembly has to be added to vertical clearance required for temporary condition, typically min 900mm for 2 lanes and 1200mm for 3 lanes. • TCB is required to protect falsework towers from traffic impact with 1m offset. • Longer construction duration than girders. • Heavier superstructure than slab on girders so higher load on foundation	• High durability with minimal maintenance	• Requires 3D analysis with expertise in post-tensioned design
Uncoated weathering steel box girders	• Girders can be curved with closer spacing of diaphragms to resist torsion. • More stable than plate girders during erection	• Small radius of curvature would cause fabrication and stability issues during construction that needs special attention	• Based on MTO's recent observations, soffit of uncoated weathering steel box girders over highways may have corrosion issues requiring	• Requires sophisticated 3D analysis to assess torsional effect, uneven bearing reactions, single versus double bearings for

Type of structure	Pros	Cons	Durability and maintenance	Design complexity
	• No collection of debris, bird droppings and nesting on bottom flange	• Vertical clearance inside boxes should be >1200mm to allow for inspection, therefore not commonly used for spans < 30m unless depth is oversized. • Requires inspection of inside of boxes as confined space in the future • Girders need 5.0m vertical clearance from highway below	ongoing maintenance, but there is no policy yet to coat bottom of box girders.	each box and skew effect
Galvanized or metallized steel plate girders	• Can be used for larger range of spans compared with box girders • Easier to fabricate than box girders • Girders can be curved with closer spacing of diaphragms to resist torsion. • Erection by crane at off peak hours with minimal impact to traffic below	• Require min 6.0m vertical clearance from highway below according to MTO policy • More difficult to erect a curved bridge due to torsional effect • Max length of galvanizing tank is 18m; longer girder segments can possibly be double dipped, but field splices require more bolting for slip critical connections. Metallizing has no length limit, but more susceptible to	• Requires maintenance and multiple cycles of coating during life time of bridge	• Requires sophisticated 3D analysis to assess torsional effect, uneven bearing reactions, skew effect and out of plane bending of diaphragms

Type of structure	Pros	Cons	Durability and maintenance	Design complexity
		damage during handling and transportation. • Bottom flanges tend to collect debris, moisture, bird droppings and nesting etc.		
Precast concrete girders	• Simple construction no different than a straight bridge • Standardized girder sections • Erection by crane at off peak hours with minimal impact to traffic below	• Radius of curvature has to be > 300m, otherwise the variation in deck cantilever width is too much • Aesthetically not very pleasing due to varying deck cantilever and kink at pier • Girders need 5.0m vertical clearance from highway below	• High durability with minimal maintenance	• 3D analysis may still be required depending on radius and kink angle

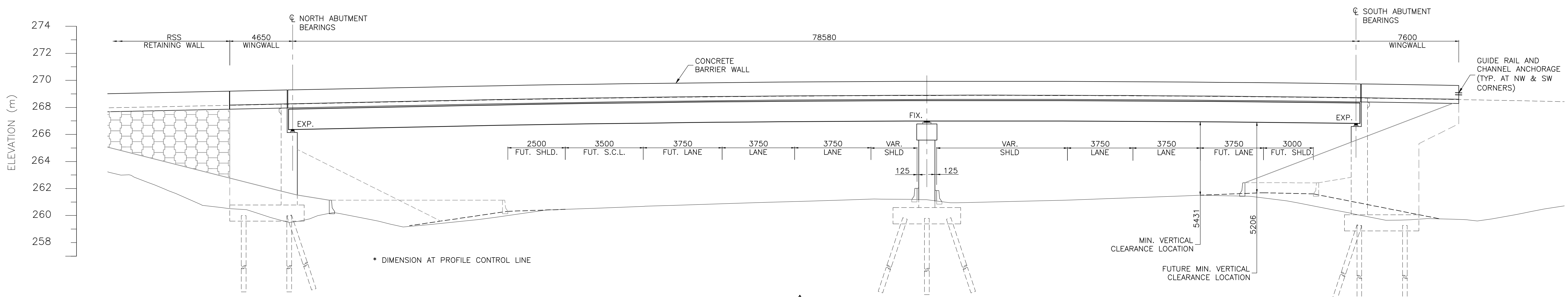
First Preferred option: post-tensioned deck if the vertical and horizontal clearances during construction can work.
2nd preferred option: Uncoated weathering steel box girder.

Appendix B: General Arrangement Drawing



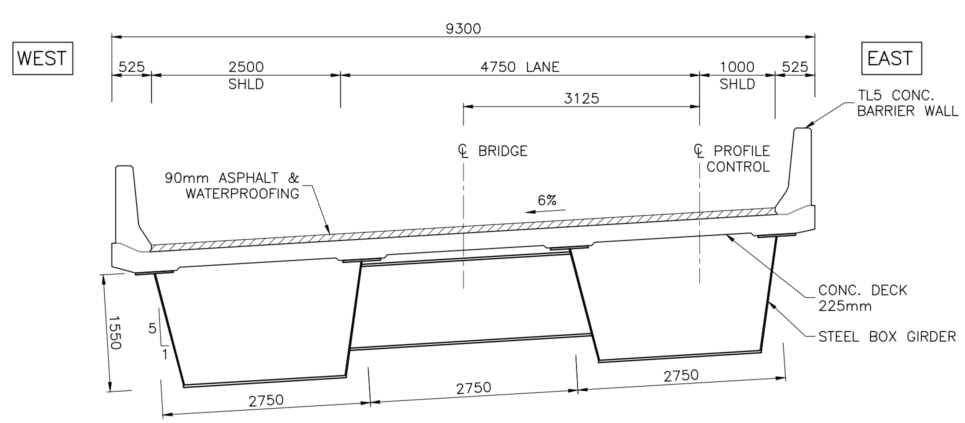
PLAN

SCALE 1:200



ELEVATION 1

SCALE 1:150



SECTION 2

SCALE 1:50

GENERAL NOTES

1. CONCRETE:
   - CONCRETE SHALL BE CLASS 30 MPa UNLESS NOTED OTHERWISE.
2. CLEAR COVER TO REINFORCING STEEL:

– FOOTING	100 ± 25
– ABUTMENTS & WINGWALLS	70 ± 20
– DECK TOP	70 ± 20
– DECK BOTTOM	40 ± 10
– PIER CAPS	70 ± 20
– REMAINDER	70 ± 20 UNLESS OTHERWISE NOTED

3. REINFORCING STEEL:
   - REINFORCING STEEL SHALL BE GRADE 400W UNLESS OTHERWISE SPECIFIED.
   - UNLESS SHOWN OTHERWISE, TENSION LAP SPLICES FOR BLACK OR STAINLESS REINFORCING STEEL BARS SHALL BE CLASS B.
   - STAINLESS REINFORCING STEEL SHALL BE TYPE 316LN OR DUPLEX 2205 AND HAVE A MINIMUM YIELD STRENGTH OF 500 MPa, UNLESS OTHERWISE SPECIFIED.
   - BAR MARKS WITH PREFIX 'S' DENOTE STAINLESS STEEL BARS.
   - GLASS FIBRE REINFORCED POLYMER REINFORCING BARS SHALL BE GRADE III AS SPECIFIED IN THE CONTRACT DRAWINGS. THE NOMINAL DIAMETER, TENSILE MODULUS OF ELASTICITY AND GUARANTEED MINIMUM TENSILE STRENGTH SHALL BE AS SPECIFIED IN THE CONTRACT DOCUMENTS.
   - BAR MARKS WITH THE PREFIX GIII DENOTE GRADE III GLASS FIBRE REINFORCED POLYMER BARS.
   - BAR HOOKS SHALL HAVE STANDARD HOOK DIMENSIONS USING MINIMUM BEND DIAMETERS, WHILE STIRRUPS AND TIES SHALL HAVE MINIMUM HOOK DIMENSIONS. ALL HOOKS SHALL BE IN ACCORDANCE WITH THE STRUCTURAL STANDARD DRAWINGS SS12-1, UNLESS INDICATED OTHERWISE.

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Plotted By: dante.shawil
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Last Saved: 2019-05-17

No	Date	Drawn	Appr'd	Revisions

APPROVALS

Design		Checked	
Drawn		Checked	
Scale	AS SHOWN		
Date	NOVEMBER 2018		

PRELIMINARY
NOT TO BE USED FOR CONSTRUCTION

McLAUGHLIN RD. & SPINE RD. CLASS EA
E/W-N RAMP FLYOVER

GENERAL ARRANGEMENT

wood.

Contract No.

Consultant File No. TPB166090

Drawing No.

SHEET OF