NOVEMBER 2019

GEORGE MASSEY CROSSING – FEASIBILITY ASSESSMENT FOR ONGOING USE

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GEORGE MASSEY CROSSING STUDY – FEASIBILITY ASSESSMENT FOR ONGOING USE

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1 Introduction

The George Massey tunnel (the Tunnel), constructed between 1957 and 1959, is a 630-meter long immersed tube tunnel crossing the Fraser River (Figure 1). It has 550 m and 335 m long approaches on the north and south ends, respectively. The Tunnel design was the "State of the Art" at the time, and among the first pre-fabricated rectangular concrete tunnels in the world to be installed using immersed tube technology. The Tunnel is owned and operated by the Province of British Columbia (the Province). The 4-lanes tunnel suffers from congestion and reliability issues; in addition, potential liquefiable soil increases its seismic vulnerability and the mechanical and electrical systems require upgrades.

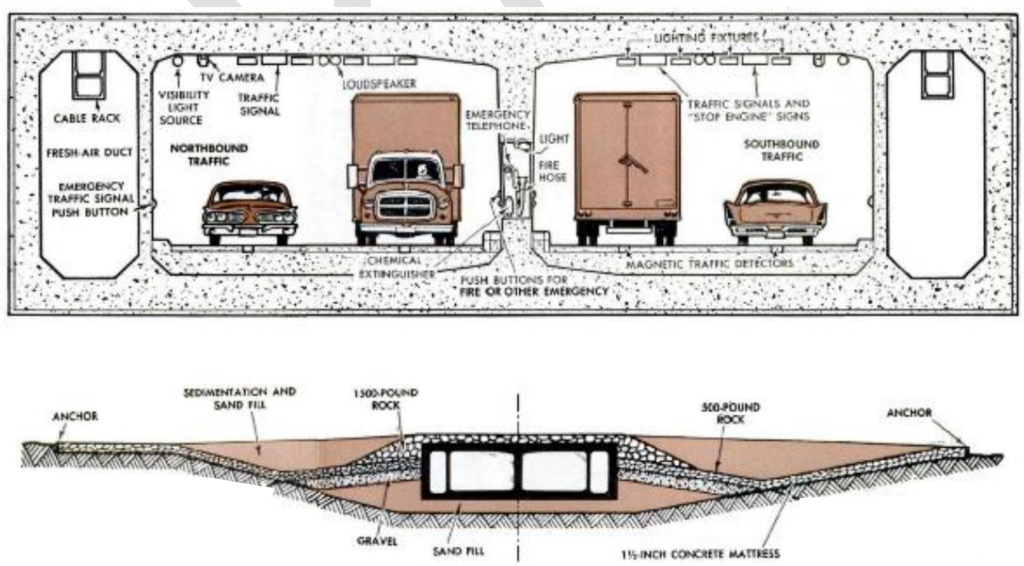

Figure 1: Typical Cross Section of the George Massey Tunnel as originally constructed (extracted from [1])

Based on a 2001 seismic vulnerability assessment, a structural seismic retrofit, and mechanical and electrical systems upgrades were completed in 2006 as the first part of the seismic retrofit design, while the second part, which comprises ground improvement, was cancelled.

This report aims to establish the feasibility of ongoing use of the Tunnel for the following four configurations:

- Option A – One tube used for active transportation only, one tube closed. Utilities are present.
- Option B – One tube used for active transportation and one tube used for bus transit. Utilities are present.
- Option C – Both tubes used for bus transit only. Active transportation is not accommodated in this configuration. Utilities are present.
- Option D - Utility corridor only. No public access would be allowed in the tunnel, but it would be used as a utility corridor for existing, and possibly new utilities.

For each configuration, the feasibility assessment will evaluate the following upgrade considerations:

- Seismic retrofit: the feasibility of completing the previously designed seismic retrofit works and comment on the environmental implications and interruptions to traffic in the Tunnel as a result of these works.
- Fire protection and life safety systems.
- Electrical and mechanical installations and systems including drainage and operation procedures.
- Security.
- Pavement, barriers, clearances, and lane widths.
- Visual appearance.
- Concrete repairs.
- Traffic Management during construction and in the final configuration.
- Navigation Channel Corridor.

The main consideration for the ongoing use of the Tunnel by the public is the seismic vulnerability of the tunnel at its current condition and the substandard dimensions by today's standards. This memo presents in Section 2 an overview of studies and work performed to enhance the seismic performance of the Tunnel. A brief overview on service life and life safety items are presented in Section 2.

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2 Background Information

2.1 Seismic Design and Retrofit

The original design of the Tunnel considered differential pressures associated with 5 m high moving riverbed sand dunes, scour to 14 m below the riverbed, and a seismic load assuming a peak ground acceleration of 0.21g (that is 21% of gravity in the horizontal direction) [1]. The original design dealt with the scour risk by adding rip rap protection over the tunnel but did not consider the effects of soil liquefaction that may occur during an earthquake and the post liquefaction settlements as these were not well understood at the time.

Table 1 lists reports that investigated seismic loading, soil liquefaction, and seismic retrofit Options. Information in this table is based on publicly available information[1].

Table 1: List of Seismic Reports Produced

Year	Report Title and Author	Purpose and Main Conclusion
1989	George Massey Tunnel no.1509 Response to Earthquakes [3] By Ker, Priestman and Associates Ltd.	Approximate evaluation of the Tunnel's response to shaking caused by an earthquake with a return period of 475 years. Tunnel does not have sufficient strength to prevent collapse under the 475 year earthquake. Potential risk for liquefaction is high.
1991	George Massey Tunnel Site Investigation Project No.07780 [4] By BC MoTi	Determine the need for structural analysis that also included a liquefied soil condition. Results show liquefiable soils up to 20 m deep.
1996	Seismic Response of the George Massey Tunnel [5] By Surinder Singh Puar, University of British Columbia	Determine post-liquefaction deformation of the tunnel as a result of a 475 year earthquake. Results show displacements beyond tolerances. Soil densification adjacent to the tunnel was identified as the most effective and economically feasible solution to limit displacements.

[1] https://engage.gov.bc.ca/masseytunnel/archiveddocuments/

2001	George Massey Tunnel No.1509 Seismic Safety Retrofit and Rehabilitation – Final Strategy Report [6] By COWI (formerly Buckland and Taylor Ltd.)	Seismic assessment and identification of seismic vulnerabilities, development of retrofit solutions to address life safety during the 475 year earthquake and restrict damage to a repairable level. A structural retrofit and ground improvement works were recommended to improve the safety of the tunnel.
2002	George Massey Tunnel Seismic Safety Retrofit Final Design RPI Centrifuge Test Results [7] By Adalier et al., Rensselaer Polytechnic Institute (RPI)	Centrifuge tests on tunnel models in accordance with the specifications from the 2001 COWI report to provide data which may serve as a basis for calibration and validation of design and computational modeling of the Tunnel.
2004	Value Engineering Study George Massey Tunnel Seismic Safety Retrofit and Rehabilitation Project [8] By Jacobs (formerly CH2MHill)	Value engineering for the detail design of the seismic structural retrofit and ground improvement designed by COWI.
2007	Value Engineering Study George Massey Tunnel Seismic Densification [9] By EVM Project Services Ltd.	Value engineering for the detail design of the seismic ground improvement designed by COWI. The study highlighted the uncertainty of the effectiveness for the ground improvements designed by COWI.
2009	Prediction of Tunnel Performance with No Ground Improvement [10] By COWI (formerly Buckland and Taylor Ltd.)	Estimate the level of earthquake that the structurally retrofitted Tunnel can tolerate without life safety damage, under the current ground and soil conditions without any ground improvement. The Tunnel with the structural seismic retrofit and no ground improvement can meet the performance criteria for an earthquake with a return period of approximately 150 to 240 years.
2016	George Massey Tunnel Replacement Project [11]	Memorandum presenting a chronology of the seismic studies and works.

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	From Engage BC	The memorandum states that the Tunnel can tolerate a 275 year seismic event.
2018	Independent Technical Review of the George Massey Crossing [1]	Appendix E (Tunnel History) and Appendix F (Tunnel Seismic Retrofitting) provide a description of the original design and a history of the seismic retrofit. The Review Team proposed a concept to improve the seismic performance of the Tunnel in a 475-year event, based on order of magnitude calculations.

The objectives of the George Massey Tunnel study of 2001 by COWI was to prevent the loss of life and restrict damage to a repairable level for a 475-year return period earthquake. These objectives were achieved with the following retrofit strategy:

- **Stage 1 - Structural retrofit and mechanical and electrical systems upgrades**: The structural retrofit objective is to improve section ductility to prevent large cracking which means that the retrofitted structure will have a smeared pattern of small cracks and less water ingress. Repairs to seal the cracks can be done on an ongoing basis as they occur, and water leakage is likely to be manageable. The structural retrofit work includes installing steel plates and reinforced concrete through the full length of the Tunnel and additional steel at each joint. Pumping and drain pipes upgrades are recommended to increase the available time for the evacuation after a seismic event. An emergency power supply is also needed to ensure that the pumping and the lighting systems will stay functioning even if the main power supply is lost.

- **Stage 2 - Ground improvement:** The ground improvement objective is to reduce the risk of floatation during the seismic event. Two different sections are recommended as described below:

  - **Along the tunnel and approaches:** Ground densification using vibro-replacement stone columns on each side of the tunnel and provide seismic gravel drains adjacent to the densified zones.

  - **At the riverbank**: Densifying the riverbanks with stone columns.

By 2006, the Stage 1 retrofit work was completed, while no ground improvement has been performed to date. As a result, the Tunnel does not have the level of safety intended in the original 2001 COWI study as the risk of tunnel floatation during the seismic event still exists. The 2009 COWI study estimates the level of earthquake that the structurally retrofitted tunnel could tolerate without ground improvement to be a 150 to 240 years return period earthquake. It is not clear where reference [11] based its statement that the Tunnel could withstand a 275 year return period earthquake as this is not consistent with analysis by COWI.

The early warning system (Emergency Road Closure System) installed in 2008 comprised sensors at each end of the tunnel and designed to detect seismic motions and activate signage to allow traffic in the tunnel to safely exit while preventing new traffic from entering. The system is meant to limit the Tunnel use for seismic events greater than 275 year return period [11].

2.2 Service Life and Life Safety

The Tunnel is 60 years old and in the Tunnel approaches, the concrete wall shows signs of deterioration and concrete has spalled from the portal cross beams; this deterioration is considered to be repairable [1]. A detailed condition survey was performed in 2000 that identified that long-term alkali-aggregate reaction distress could be expected [6].

The existing tunnel dimensions are below current standards and do not provide the level of safety for the amount and type of vehicles using the tunnel [12].

The following upgrades and repair work to the following items has been identified [12]: upgrade ventilation and electrical systems, replace lightning, management of water ingress, repair of surfaces showing significant wear, other less significant upgrades.

Additional upgrades to the fire life and safety system and high voltage system have been identified previously [14,15].

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3 Possible Configurations for Continued Use

Four configurations of the exiting tunnel are considered in the present feasibility study:

- **Option A** – **One tube used for active transportation only**. This configuration suggests utilizing one tube for active transportation accommodation and close the other tube (Figure 2). No other users would be permitted in the second tube, except in the case of emergencies. Both tubes could be used for utilities as required.

- **Option B** – **One tube used for active transportation and one tube used for local traffic and/or bus transit.** This configuration separate pedestrian and bicycles from roadway traffic, two unidirectional travel lanes are proposed (Figure 3). Traffic may alternate directions, i.e. traveling North in the morning and South in the afternoon to alleviate congestion on the new crossing. Both tubes could be used for utilities as required.

- **Option C** – **Both tubes used for bus transit only.** Active transportation is not accommodated in this configuration. One travel lane is proposed in each tube (Figure 4). Both tubes could be used for utilities as required.

- **Option D - Utility corridor only.** No public access would be allowed in the tunnel, but it would be used as a utility corridor for existing, and possibly new utilities.

The design criteria for pedestrian and bicycle accommodation for these options are explained in the memorandum "George Massey Crossing – Pedestrian and Bicycle Accommodation in Existing Tunnel" [2] included in Appendix A. The configurations proposed herein were identified as viable options for further consideration.

Table 2 lists proposed upgrade items that were considered and evaluated for the above options. These upgrade items are discussed further in the following section.

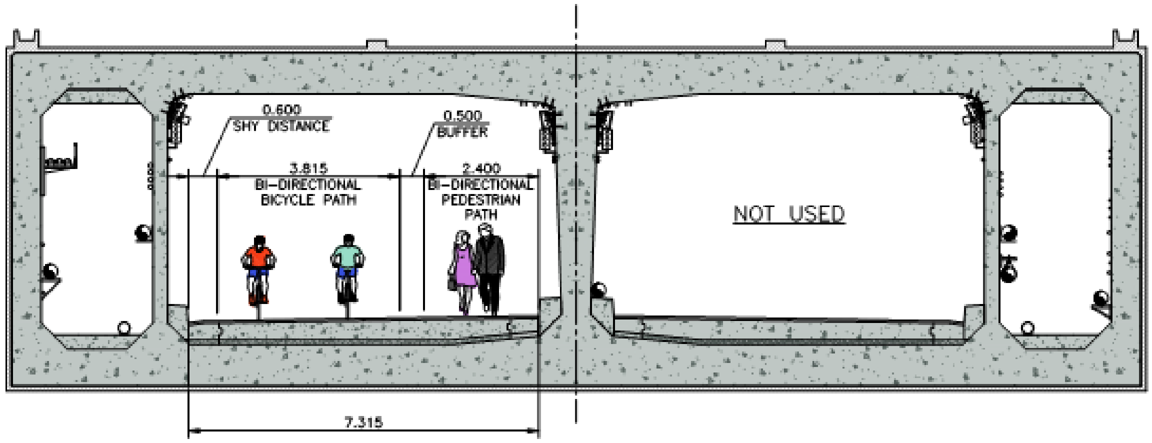

Figure 2 – Option A: One tube used for active transportation only.

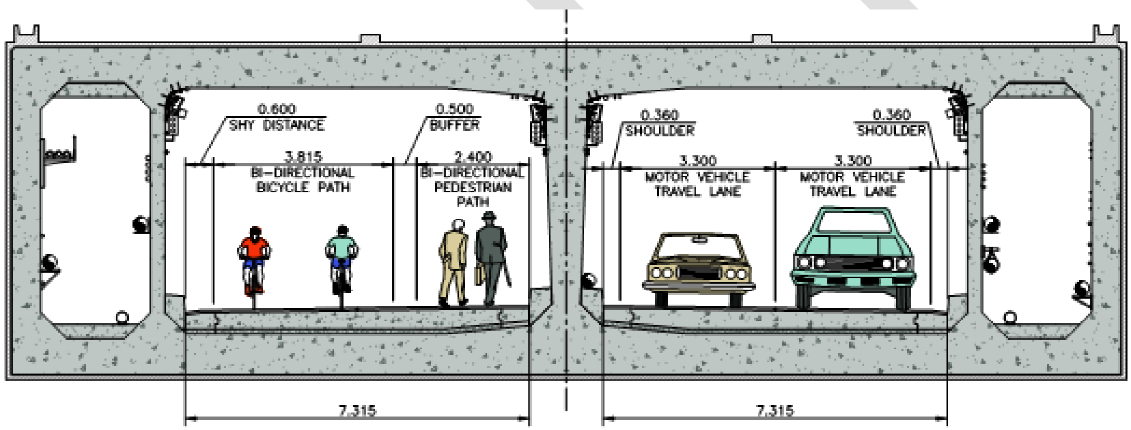

Figure 3 – Option B: One tube used for active transportation and one tube used for bus transit.

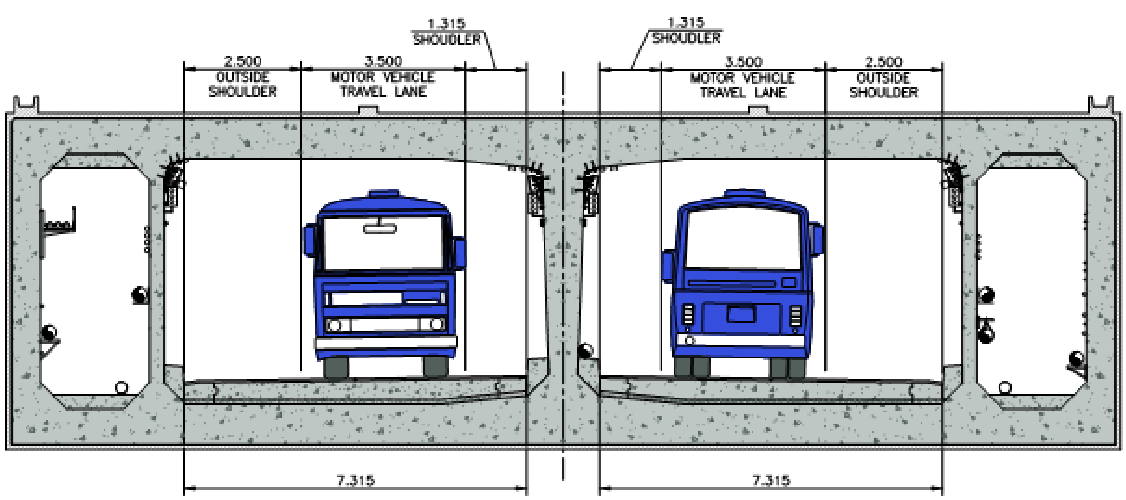

Figure 4 – Option C: Tunnel used for bus transit only.

Table 2 – Proposed Upgrades for each Option

Upgrades	**Option A Active Transportation only**	**Option B Active Transportation + Bus/Local Traffic**	**Option C Bus traffic only**	**Option D Utility Corridor only**
Seismic Retrofit	x	x	x	-
Fire and Life Safety System	x	x	x	-
Electrical and Mechanical	x	x	x	-
Security	x	x		x
Pavement, Barriers, Clearances, and Lane Widths	x	x	x	-
Improve Visual Appearance	x	x		--
Concrete Repair	x	x	x	-
Navigation Channel Depth increase	No change anticipated.	No change anticipated.	No change anticipated.	No change anticipated.

4 Proposed Upgrades

The following sections present the required retrofit work and upgrades for each of the configurations. Due to its importance, the seismic retrofit work is discussed first and include a discussion on environmental considerations and traffic management during construction. Other upgrades shown in Table 2 are presented in the subsequent sections.

4.1 Seismic Retrofit

The Tunnel does not meet seismic performance criteria defined in CSA S6-14. A seismic retrofit is required for the considered options where public use is anticipated (Option A, B, and C). The performance criteria will need to be defined at the beginning of any future seismic retrofit design, however if the public is going to continue to use the existing tunnel as part of one of the GMC options, the seismic upgrade of the existing tunnel will need to be completed.

For the purpose of this feasibility assessment, the seismic retrofit considered is the ground improvement as designed by COWI in 2001. This design is based on a design earthquake with a return period of 1 in 475 years which was the standard design earthquake at the time. The performance criteria used at the time was that the structure does not suffer irreparable damage during the design earthquake. This level of safety would be consistent with other existing major structures in the Lower Mainland – similar to "Other" structures in the current code.

4.1.1 Review of Ground Improvement Technical Feasibility

The 2001 COWI design for ground improvement consisted of densifying the granular soils and installing seismic drains along the sides of the tunnel and the approaches. The densification within the river consisted of stone columns over a width of 10 m on each side of the tunnel and extending up to 6 m below the underside of the deepest part of the tunnel (elevation -27 m) with one row of seismic drains on the outside edges. The north and south ends of the Tunnel closest to the river dyke would have varying widths of stone columns and two outer rows of seismic drains. Further inland, two to three rows of seismic drains were proposed. Figure 5 shows a cross-section of the tunnel with the proposed ground improvement.

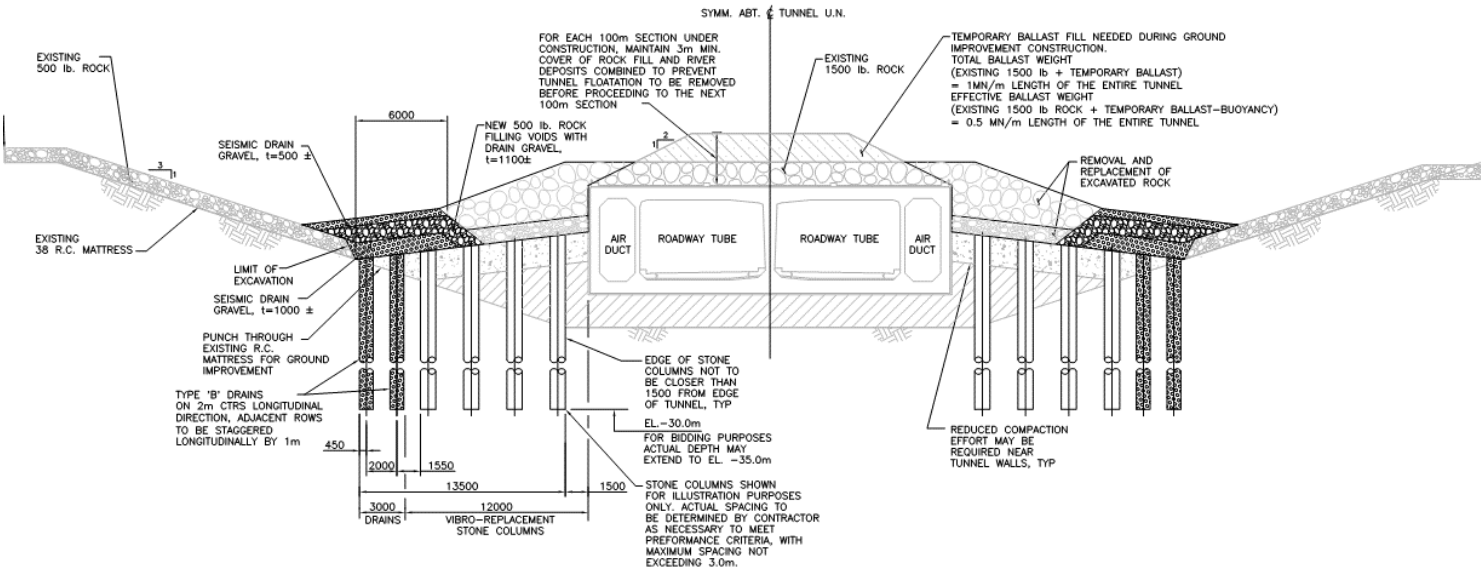

Figure 5 - Proposed ground improvement by COWI in 2001

The decision not to proceed with the ground improvement work was based on two reasons, as described in the 2018 Independent Technical Review [1]; 1) risk of settlement and related damage to the Tunnel and the external ground improvement, 2) effectiveness of the ground improvement should silty soils be encountered as silty soils cannot be densified.

It might be possible that with careful sequencing and monitoring, the settlement risk to the Tunnel during the ground improvement work could be managed. However, there is a risk that the ground improvement process will cause settlements of the existing tunnel, that could result in damage to the structure. This could lead to significant repairs, and possibly even closures of the crossing. Therefore, it would be prudent to perform the seismic retrofit of the existing tunnel after traffic is moved to the new crossing.

Stone columns were originally selected as a preferred Option for ground improvement as they are effective in creating a densified soil mass. The main disadvantage is that it may cause horizontal displacement and possibly settlement of the soil mass around the Tunnel. To mitigate the risk associated with these effects, it was recommended to install them in a carefully planned sequence and to monitor the pore pressures to prevent shifting the tunnel alignment profile [6]. In addition, prior to their installation, the riverbed sediments overlying the rockfill around the sides of the tunnel should be dredged and the rockfill temporarily removed. The removal of the rockfill must be done carefully and incrementally to prevent any movement or flotation of the tunnel. The rockfill would then be replaced after the ground improvement has been completed. A monitoring system during construction was also proposed to measure movements and rotations.

To mitigate the liquefaction effects associated with silty soils (for which the densification would not be effective), seismic drains were designed on each side of the densification area. These seismic drains consist of gravel and can accommodate the additional water should liquefaction occur.

The 2007 Value Engineering Report [9] presented 8 value engineering proposals for consideration and included using mass concrete buttresses or anchoring pipe piles to prevent floatation, further strengthen the tunnel or limit the densification of soil to localised sections along the length of the tunnel. These options have not been investigated further.

The 2018 Independent Technical Review [1] proposed an alternative design concept to address the risk of installing the stone columns adjacent to the existing tunnel and the presence of deeper potentially liquefiable soil layers. This design was based on order of magnitude calculations and no computer modeling was performed; the author recognized that additional design work was required to confirm the feasibility of this option. The design proposes pipe piles driven along each side of the tunnel, installation of low profile steel beams and/or straps and precast concrete ballast over the Tunnel instead of the existing rock ballast, scour protection rocks on either side of the Tunnel, and stone columns at a clear distance of 15 m from the Tunnel to minimize potential tunnel settlement effects.

Based on the work performed to date, it is believed that ground improvement is technically feasible and would improve the seismic performance of the Tunnel. The final solution could be improved based on information gathered since the original design was developed. The following is to be considered during the design phase of a future retrofit design:

- The performance criteria for the Tunnel needs to be defined. This may mean accepting lower performance criteria than defined by the Canadian Highway Bridge Design Code.
- The presence and location of a future crossing needs to be considered in the analysis and design as this may optimize the ground improvement for the Tunnel.
- Liquefaction depth needs to be confirmed by more detailed 1D or 2D nonlinear site response modeling. COWI recognizes that potential liquefaction in the

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marine silt/clay layer below the densified zone is a potential deficiency and need to be assessed [1].

- A larger suit of input earthquake ground motions than previously considered by COWI in the 2001 study is needed [1].

- 3D seismic modeling that may allow refinements in seismic retrofit solutions including the requirements for ground improvements is needed [1].

4.1.2 Environmental Impacts

Completion of the Stage 2 seismic retrofit program would require excavation and construction within the Fraser River channel and banks to construct and appropriately space added geotechnical stone columns around the existing tunnel. The proposed seismic retrofit would stay within the existing tunnel footprint and would not impact existing shoreline areas upstream or downstream of the tunnel. The geotechnical upgrades would not provide any additional benefits or enhancements to existing wildlife or fisheries habitats.

The construction of stone column would involve use of in-river equipment and drilling at specific locations along the tunnel within the existing river-bed. The construction activities would temporarily disturb the river-bed and generate localized changes in turbidity and water quality. The construction of stone columns is not expected to expose or disrupt any known contaminated sites.

The construction activities would be scheduled within the least risk fisheries window on the Fraser River and would implement all appropriate protective measures, mitigations and controls to avoid and limit potential impacts on water quality and wildlife and fisheries habitats. The geotechnical upgrades would require authorization under the new 2019 *Fisheries Act*, the *Navigation Protection Act* and approval under the BC *Water Sustainability Act*.

4.1.3 Traffic Management During Construction

To limit the risk to the structure and the public, the ground improvement (as well as all other upgrade work) should be delayed until after a new crossing is open to traffic. This would allow all upgrades to be performed simultaneously (or almost) and not staggered based on the different construction steps and accommodation of traffic.

4.2 Fire Protection and Life Safety System Upgrade

There are several critical safety systems in the Tunnel, including automatic sprinkler system and fire pumps, sump pumps, mechanical ventilation and emergency lighting powered by the North and South Tower high voltage substations. The emergency power system consists of a 600kW diesel stand-by generator with 480V automatic transfer switches and emergency power buses and feeders.

The design for the retrofit of the Tunnel will be based on fire protection and life safety requirements under National Fire Protection Association (NFPA) 502 [16] for a Category C tunnel. Category C tunnels are defined by NFPA 502 as those where the tunnel length equals or exceeds 300 m. Fire emergency systems as sprinklers and hydrants and emergency ventilation are not required for tunnels used only for active transportation as the fire load in these tunnels will be very limited. Based on available information [14,15] the following actions are required to meet requirements from NFPA 502.

For Options where public use is anticipated (Option A, B, and C):

- Investigate status of existing doors in the central wall to determine compliance with NFPA 80 [20], including self-closing mechanisms, opening force, and fire resistance rating.

- Upgrade of emergency lighting and exit signage.

For Option B:

- Richmond Fire Department personnel will have only one tube to use as its main route to attend emergency situations, and therefore, consideration should be given for the width to enable vehicles to 'move aside' to allow fire appliances through. An Option could be to allow fire vehicles in the active transportation.

For Option B and C:

- An engineering analysis is required to determine whether sprinkler systems, automatic fire detection systems, mechanical emergency ventilation system, emergency communication systems need to be provided.

- Investigate fire protection of existing structural elements to comply with NFPA 502 [16].

- Provisions need to be included to stop all traffic operations during a fire.

- An egress analysis is required to determine emergency exit spacing for compliance with NFPA 502 [16].

- Investigate existing portable fire extinguishers cabinets to determine compliance with NFPA 10 [19] and placement of 90m.

- Investigate tunnel drainage system for compliance with NFPA 502 [16].

- Provide foam system to protect drainage sumps station at low point and ramp.
- Provide emergency response plan and revise procedures for first responders [1].

The Fire Life Safety upgrades are considered to be feasible but need further analysis to demonstrate compliance with NFPA 502 and impact on cost and environmental impacts handling water from spillage and fire.

4.3 Electrical and Mechanical Upgrade

The electrical and mechanical system require upgrades for all options where public use is anticipated (Option A, B, and C): ventilation and electrical systems have reached the end of their useful life, and spare parts are increasingly difficult to find [11]. $40 millions are currently allocated to interim upgrades, which for the M&E systems include, tunnel lighting, alarm, pumping, ventilation, fire door, and electrical systems scheduled to be undertaken in 2019 through 2020 [23]. Extent of upgrade should be verified.

Depending of tunnel Option A, B or C and the standards of the upgrades, reuse or modification of the system might be possible. This needs to be investigated.

General considerations for lightning, power, drainage, traffic signals, and ventilation are given below.

4.3.1 Lighting

Lightning was replaced in 2006, however, power limitations limited the level of lightning upgrade possible which, as a result, is still below the level that would be provided in a new tunnel of this type [1]. It is our understanding that the Ministry is currently conducting a replacement of the current light fixtures with a new LED luminaire fixture. However, different lighting demands are required depending of the use of the tunnel (active transport, uni-directional traffic, bi-directional traffic or counter flow traffic). Changes of the lighting system will be required for options where public use is anticipated (Option A, B, and C) based on the selected tunnel Option to suit the new purpose for compliance with ANSI/IES RP-8-18 [19] and CIE 88:2004 [20].

4.3.2 Power

Fire emergency systems as sprinklers and hydrants and emergency ventilation are not required for tunnels used only for active transportation as the fire load in these tunnels will be very limited. Power and backup power shall therefore mainly serve lighting and drainage pumps for Option A.

As stated in section 4.2 it shall be investigated whether emergency ventilation and sprinklers are required for the motorized tunnels Option B and C. The requirements for ventilation and sprinklers will affect the requirements for power and power backup.

4.3.3 Drainage

Drainage will be required for options where public use is anticipated (Option A, B, and C), as required by NFPA 502 (see Section 4.2).

Required capacity of ramp drainage will be the same for all Options.

Required capacity of the low point sump and pump installations will depend on whether sprinklers and hydrants are installed in the retrofitted tunnel.

The pumping system was upgraded in 2006 [1], further upgrades in the pumping system capacity may be necessary. It is not clear if this upgrade covered drainage, standpipe or sprinkler pumps or only one type. This has to be clarified.

4.3.4 Traffic signals

Adjustments to traffic signals is required for all Options. The existing counterflow system could be removed.

4.3.5 Ventilation

As the existing ventilation system has reached the end of is useful life [11], the precise requirements for future ventilation need to be investigated. The existing ventilation system is based on ventilation galleries on each side of the tunnel. For active transportation (Option A and partly Option B) the needs for day to day ventilation is relatively limited and a retrofit of the existing ventilation system is not mandatory. Obvious solutions to improve ventilation for pedestrian and cyclists are:

- Fresh air supply from a few locations in tunnel using the existing ventilation tubes. As fresh air requirements in this case is small, it shall be investigated if change of ventilation equipment in ventilation towers will be beneficial; or

- A few smaller jet fans in the tunnel ceiling to secure a longitudinal air flow in the tunnel.

For motorized traffic (Option C and one tube of Option B) it shall be investigated if mechanical ventilation is required both for day to day traffic and for smoke control in the event of a fire. If mechanical ventilation is required, then the preferred solution needs to be investigated:

- Retrofit of the existing ventilation system to fulfil requirements; or
- Replacement of the existing system with a longitudinal ventilation system based on jet fans.

Ventilation demands of technical buildings is not known and need to be investigated.

4.4 Security Upgrade

The Tunnel was not designed to accommodate pedestrian and cyclists. Therefore, the security of the public could be improved for Option A and B through the following measures:

- Access for the public to the ventilation tubes shall be prevented. This could be achieved by revisiting the current access and as a minimum ensuring that doors are secured and locked at all time.
- Improve security of the public: provide police patrol, security cameras, and enhanced lightning (Section 4.3.1).

For Option D, should the Tunnel be used for utilities only, access to the tunnel should be restricted to protect the public. Measures to be implemented will need to be developed.

4.5 Pavement, Barriers, Clearances, and Lane Widths Upgraded

New lane configuration and lane painting is required for all options where public use is anticipated (Option A, B, and C). Roadway barriers need to be adjusted for all Options.

The following upgrade is required for Option B and C:

- Vertical clearances are low in the Tunnel and can be improved by restricting tunnel use to lower height vehicle to eliminate safety risks due to poor vertical clearances [1].

4.6 Improve Visual Appearance

The visual appearance should be improved for Option A and B when pedestrian and cyclists will use the Tunnel. This could be achieved by changing the light type and strength, colors of the walls, providing art works, and change the pavements.

4.7 Concrete Repairs

For all options where public use is anticipated (Option A, B, and C), repairs of the damaged concrete are required. This include cast-in-place concrete retraining walls and cross beams over the Tunnel entrances. These repairs can be completed using industry standards methods.

An investigation for alkali-aggregate reaction was performed in 2000 [6] and noted that some reaction was occurring at a slow rate. As recommended by [6], a detailed survey for alkali-aggregate reaction is recommended for the approaches to assess the long-term life of the concrete.

4.8 Navigation Channel Corridor

The ground improvement work as suggested in the original design does not impact the depth of the tunnel and existing river bed and the navigation channel water height would remain as existing.

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5 Conclusions

Ongoing use of the Tunnel for the following four configurations is considered technically feasible:

- Option A – One tube used for active transportation only. This configuration suggests utilizing one tube for active transportation accommodation and close the other tube. Both tubes could be used for utilities as required.

- Option B – One tube used for active transportation and one tube used for local traffic and/or bus transit. This configuration separate pedestrian and bicycles from roadway traffic, two unidirectional travel lanes are proposed. Both tubes could be used for utilities as required.

- Option C – Both tubes used for bus transit only. Active transportation is not accommodated in this configuration. One travel lane is proposed in each tube. Both tubes could be used for utilities as required.

- Option D - Utility corridor only. No public access would be allowed in the tunnel, but it would be used as a utility corridor for existing, and possibly new utilities.

Table 3 presents, for each Option, a summary of actions as presented in further details in the previous sections.

Table 3: Summary of actions required for ongoing use of the Tunnel

<table>
<tr><th>Considerations</th><th>Option A
Active Transportation only</th><th>Option B
Active Transportation +
Bus/Local Traffic</th><th>Option C
Bus traffic only</th><th>Option D
Utilities only</th></tr>
<tr><td>Seismic Retrofit</td><td colspan="3">Seismic retrofit required. Define performance criteria and location of new crossing prior to designing the seismic retrofit.</td><td>No retrofit anticipated.</td></tr>
<tr><td rowspan="2">Fire Protection and Life Safety</td><td colspan="3">Fire protection and life safety requirements are to be designed/retrofitted to meet NFPA 502 for a Category C tunnel. Investigate status of existing emergency doors in the central wall. Upgrade of emergency lighting and exit signage.</td><td>No retrofit anticipated.</td></tr>
<tr><td></td><td>Sufficient width to allow fire vehicles through vehicles tube or in the active transportation tube. Engineering analysis required for emergency systems, protection systems, and procedures related to fire protection and life safety.</td><td>Engineering analysis required for emergency systems, protection systems, and procedures related to fire protection and life safety.</td><td>No retrofit anticipated.</td></tr>
<tr><td rowspan="2">Electrical and Mechanical</td><td colspan="3">The electrical and mechanical system require upgrades, mainly lightning, power, drainage, traffic signals, and ventilation. Changes of the lighting system will be required based on the selected tunnel Option to suit the new purpose for compliance with ANSI/IES RP-8-18 [19] and CIE 88:2004 [20].</td><td rowspan="2">Traffic signals at each end of the tunnel will need adjustment.</td></tr>
<tr><td></td><td colspan="2">Requirements for ventilation and sprinklers will affect the requirements for power and power backup. Investigate if mechanical ventilation is required.</td></tr>
</table>

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Considerations	Option A Active Transportation only	Option B Active Transportation + Bus/Local Traffic	Option C Bus traffic only	Option D Utilities only
Security	Access for the public to the ventilation tubes shall be prevented. Provide police patrol, security cameras, and enhanced lightning.		No retrofit anticipated.	Retrofit anticipated to restrict public access.
Pavement, Barriers, Clearances, Lane Widths	New lane configuration, lane painting, and roadway barriers.	New lane configuration, lane painting, and roadway barriers. Improve vertical clearances by replacing ballast concrete in the roadway floor or limit heights of vehicles.		No retrofit anticipated.
Visual Appearance	Improvement required. Can be achieved by changing the light type and strength, colors of the walls, providing art works, and change the pavements.		No retrofit anticipated.	No retrofit anticipated.
Concrete Repairs	Repairs of the damaged concrete. Investigation of alkali-aggregate reaction and its long-term effects.			No retrofit anticipated.
Navigation Channel Depth Increase	No change anticipated.			

6 References

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DRAFT

Appendix A George Massey Crossing – Pedestrian and Bicycle Accommodation in Existing Tunnel

To:	Derek Drummond Stantec Consulting Ltd.	From:	Josh Workman Stantec Consulting Ltd.
File:	115819043	Date:	July 26, 2019

Reference: George Massey Crossing – Pedestrian and Bicycle Accommodation in Existing Tunnel

INTRODUCTION

The purpose of this memo is to provide recommendation on the cross-section options and preferred configurations for the accommodation of pedestrians and cyclists in the existing George Massey Tunnel. This accommodation is being considered as part of the options evaluation for the George Massey Crossing (GMC) project.

The memo is organized into the following sections:

- **Existing Tunnel Cross Section.** This section provides a brief summary of the existing tunnel configuration, and geometry that would be available for repurposing if the existing tunnels were to be maintained.
- **Design Criteria for Pedestrian and Bicycle Accommodation.** This section provides a summary of relevant design criteria for the development of pedestrian and bicycle accommodation options within the existing tunnel.
- **Existing Tunnel Repurposing.** This section provides different cross section options for three different tunnel repurposing configurations that are currently being contemplated by the project team. Recommendations are provided for the options that are suitable to advance for further consideration.

EXISTING TUNNEL CROSS SECTION

The existing crossing is made up of two 7.315m clear width tunnels, measured from inside wall to inside wall, as shown in **Figure 1**.

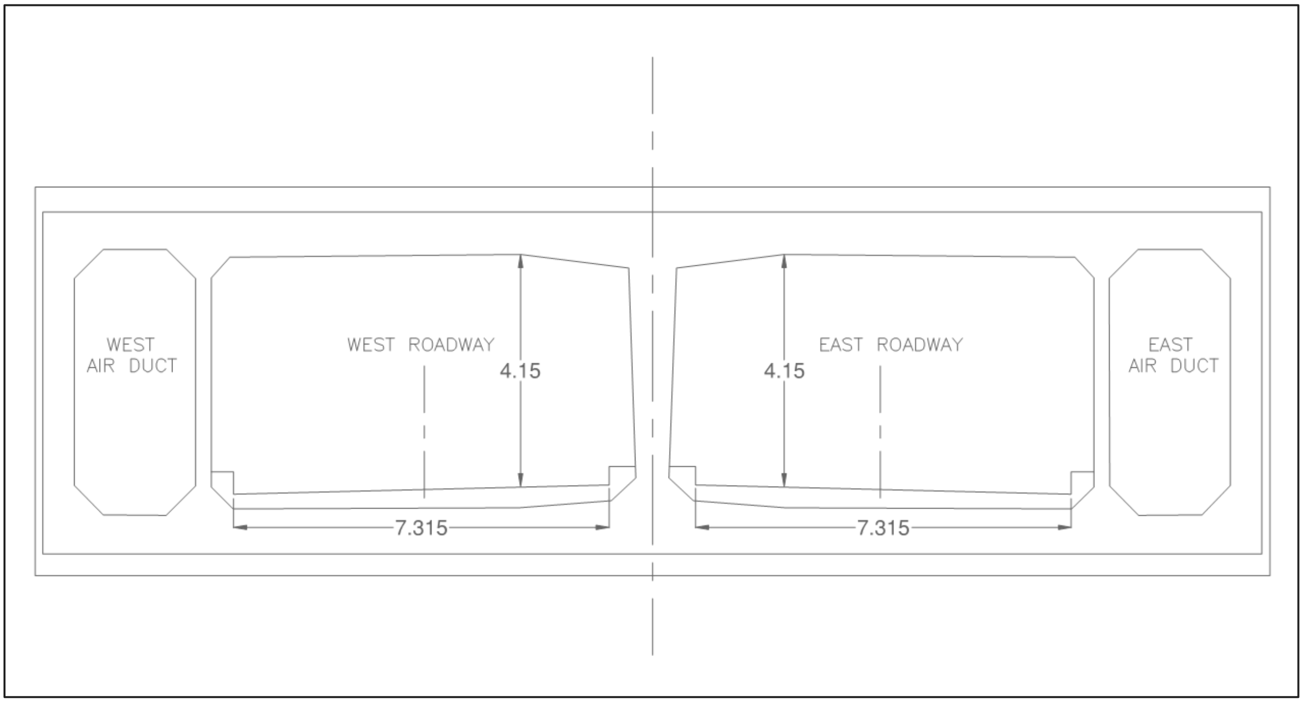


Figure 1 - Existing George Massey Tunnel Cross Section

The existing tunnel accommodates two travel lanes in the northbound direction on the east roadway and two travel lanes in the southbound direction in the west roadway during off peak hours. Reversible lanes are employed on one lane in both the east and the west roadway during peak hours.

DESIGN CRITERIA FOR PEDESTRIAN AND BICYCLE ACCOMMODATION

Design criteria for pedestrian and bicycle accommodation were gathered from the 2019 BC Active Transportation Design Guide (BCATDG) and from the 2017 Transportation Association of Canada (TAC) Geometric Design Guide (GDG). Key criteria related to the development of cross section alternatives is summarized in **Table 1**.

Reference: **George Massey Crossing – Pedestrian and Bicycle Accommodation in Existing Tunnel**

Table 1 - Pedestrian and Bicycle Cross Section Design Criteria for Existing Tunnel Repurposing

	BC Active Transportation Design Guide	2017 TAC GDG**	Recommended
Shared Pathway Width* (m)	3.0 – 4.0	3.0 – 6.0	3.0 - 4.0
Shy Distance Width to obstructions 100mm – 750mm high (m)	0.6	0.2	0.2 – 0.6
Shy Distance Width to obstructions greater than 750mm high (m)	0.6	0.5	0.6
Two-Way Bicycle Path*	3.0 – 4.0	3.0 – 3.6	3.0 – 4.0
One-Way Bicycle Path*	2.0 – 3.0	1.8 – 2.5	1.8 – 3.0
Buffer Width	0.5 – 1.0	0.3 – 0.6***	0.3 – 1.0
Pedestrian Only Path*	2.4 – 3.0	1.8 – 3.0	1.8 – 3.0

**Path width ranges identified are influenced based on the anticipated use of the facility, documented further in Table 2.*

***The range provided is the recommended lower limit to the recommended upper limit.*

****The recommended buffer width and delineator treatment is subject to consideration of adjacent use as per TAC Table 5.7.1, Delineator Based on Type and Speed of Adjacent Lane.*

The recommended design criteria is provided as a range to allow for maximization of cross section element widths in locations where space allows, and a minimum in locations where the upper range is not achievable. Upon confirmation of the preferred tunnel repurposing configuration, a more definitive design criteria can be established.

As noted above, the requirement for different pathway widths and levels of separation is informed by the anticipated pathway usage. These requirements are summarized in **Table 2**, which is based on the the BCATDG and the 2017 TAC GDG.

Table 2 - Pathway Width Functionality Limits

Pathway Width	Upper Limit of Pathway Width Functionality (Users Per Day)
3.0m Multi-Use Pathway	1,000 (more than 20% pedestrians) 1,500 (less than 20% pedestrians)
3.5 m Multi-Use Pathway	1,200 (more than 20% pedestrians) 1,750 (less than 20% pedestrians)
4.0m Multi-Use Pathway	1,400 (more than 20% pedestrians) 2,000 (less than 20% pedestrians)

It should be noted that once pathway use exceeds 1,400 users per day (with more than 20% pedestrians) or 2,000 users per day (with less than 20% pedestrians), separated pathway treatments would be justified. Further, it is noted in the BCATDG that communities such as the City of Vancouver suggest that if there are 1,500 combined users on a facility that is between 3.0 and 4.0 metres in width, and if space is available, separation of people walking and cycling is recommended.

Since there is not an existing pathway in place at this location, the following guideline was drawn from the BCATDG:

> *In locations where no pathway is currently in place, existing and future land use should be considered as well as ridership numbers on existing facilities within a similar context to obtain an understanding of projected volumes. (BCATDG, E17)*

Data on pedestrian and bicycle use is currently being gathered from other existing bridge crossings in the Lower Mainland, at which point a comparison can be made to identify anticipated daily pathway use volumes to inform a more prescriptive guideline for pathway width.

EXISTING TUNNEL REPURPOSING

As part of the GMC Project, there is a desire to consider how the existing tunnels could be repurposed. Consideration for the accommodation of transit, local traffic, pedestrians, and cyclists have been identified by the Ministry of Transportation and Infrastructure (MoTI).

Based on preliminary assessment by the project team informed by considerations for different replacement and upgrade scenarios, three different configurations for repurposing of the existing tunnel are currently under review. These are summarized as follows:

- **Configuration A – Both Tubes Used for Active Transportation.** This configuration suggests utilizing both the east and west tubes for active transportation accommodation. No other users would be permitted, except in the case of emergencies.
- **Configuration B – One Tube Used for Active Transportation, One Tube Used for Local Traffic.** This configuration suggests utilizing either the east or the west tube for active transportation and the other tube for local traffic accommodation.
- **Configuration C – Both Tubes Used for Local Traffic, No Active Transportation Accommodation.** This configuration suggests utilizing both tubes for local traffic, with no active transportation accommodation in the repurposed existing tunnel.

Additional configurations were reviewed and discarded due to feasibility issues. These are summarized as follows:

- **Pathway and roadway accommodation in one tube**. Initial assessment identified that mixing active modes with motor vehicles in a single tube would be very undesirable due to the impact of noise and vehicle exhaust in a tunnel environment on active transportation users. Further, it was determined that accommodating pedestrians, cyclists, and motor vehicles would not be feasible without using design criteria below the recommended minimum.

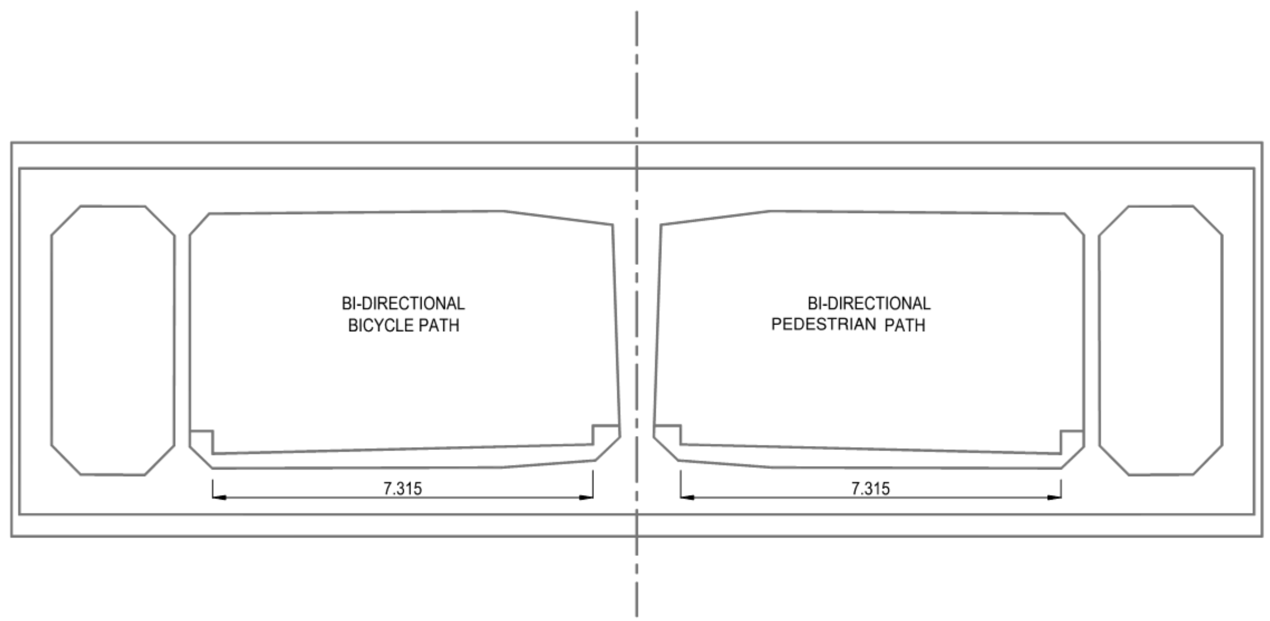
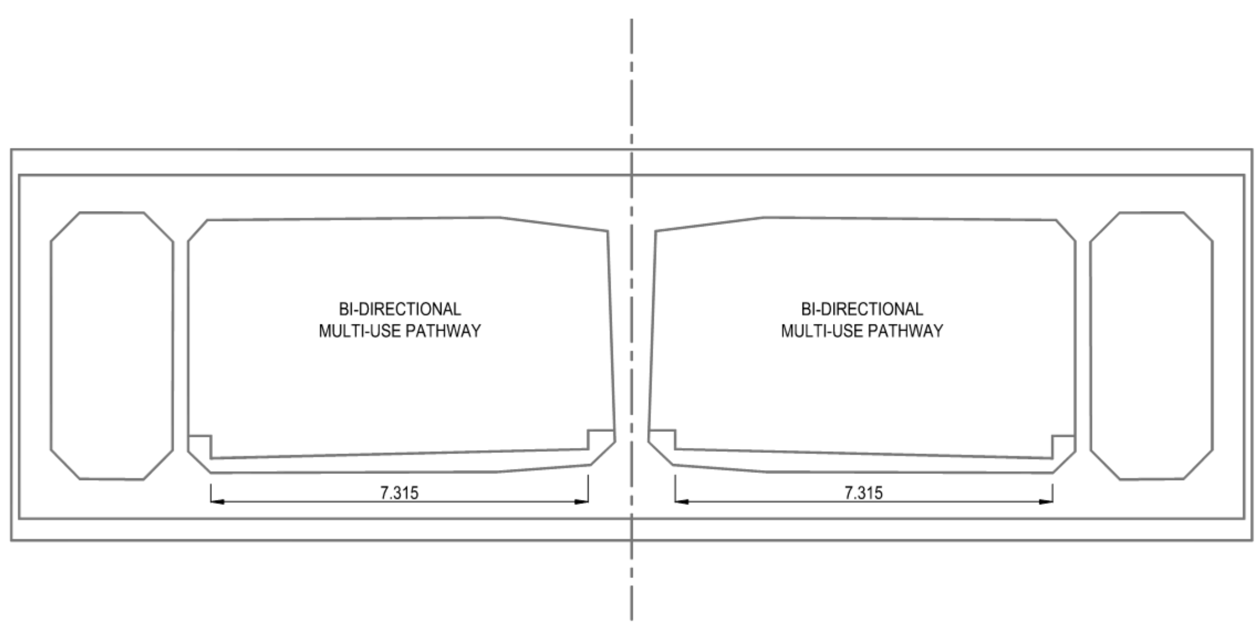
- **Bicycle and roadway accommodation in one tube**. Initial assessment identified that mixing active modes with motor vehicles in a single tube would be very undesirable due to the impact of noise and vehicle exhaust in a tunnel environment on active transportation users. Further, it was determined that accommodating cyclists and motor vehicles in one tube would not be feasible without using design criteria below the recommended minimum.
- **Pedestrian and roadway accommodation in one tube**. Initial assessment identified that mixing active modes with motor vehicles in a single tube would be very undesirable due to the impact of noise and vehicle exhaust in a tunnel environment on active transportation users. Further, it was determined that accommodating pedestrians and motor vehicles in one tube would not be feasible without using design criteria below the recommended minimum.

Reference: **George Massey Crossing – Pedestrian and Bicycle Accommodation in Existing Tunnel**

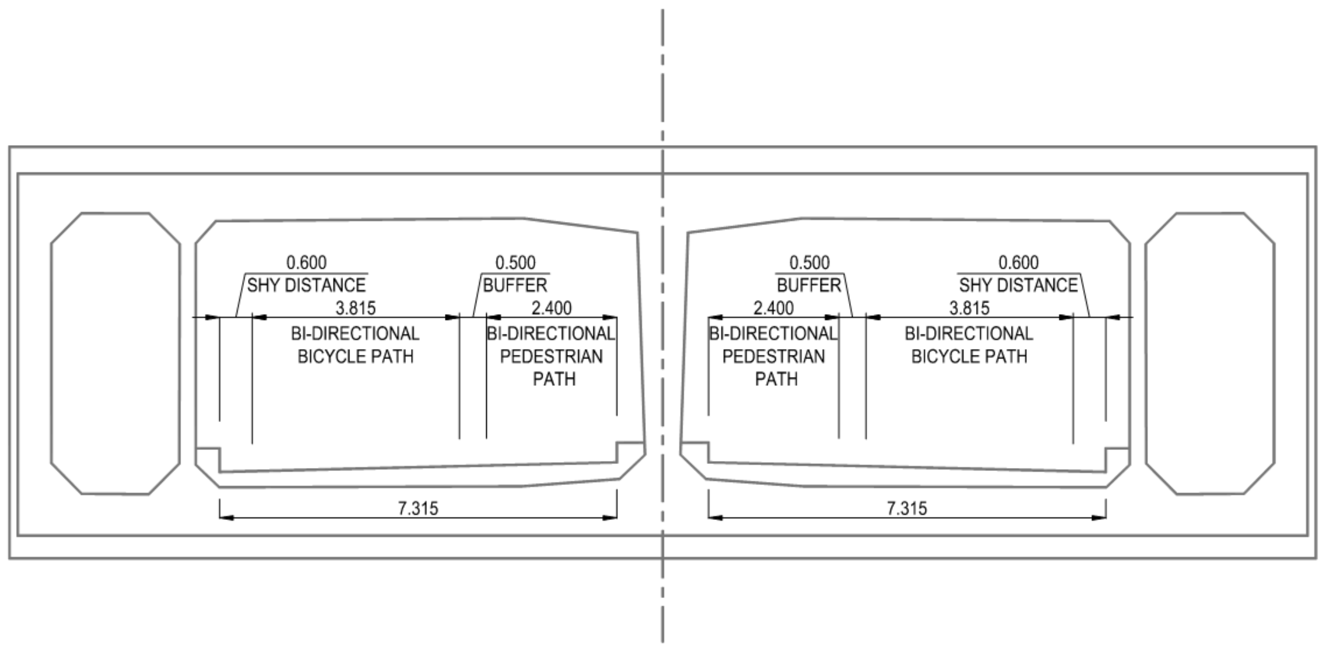
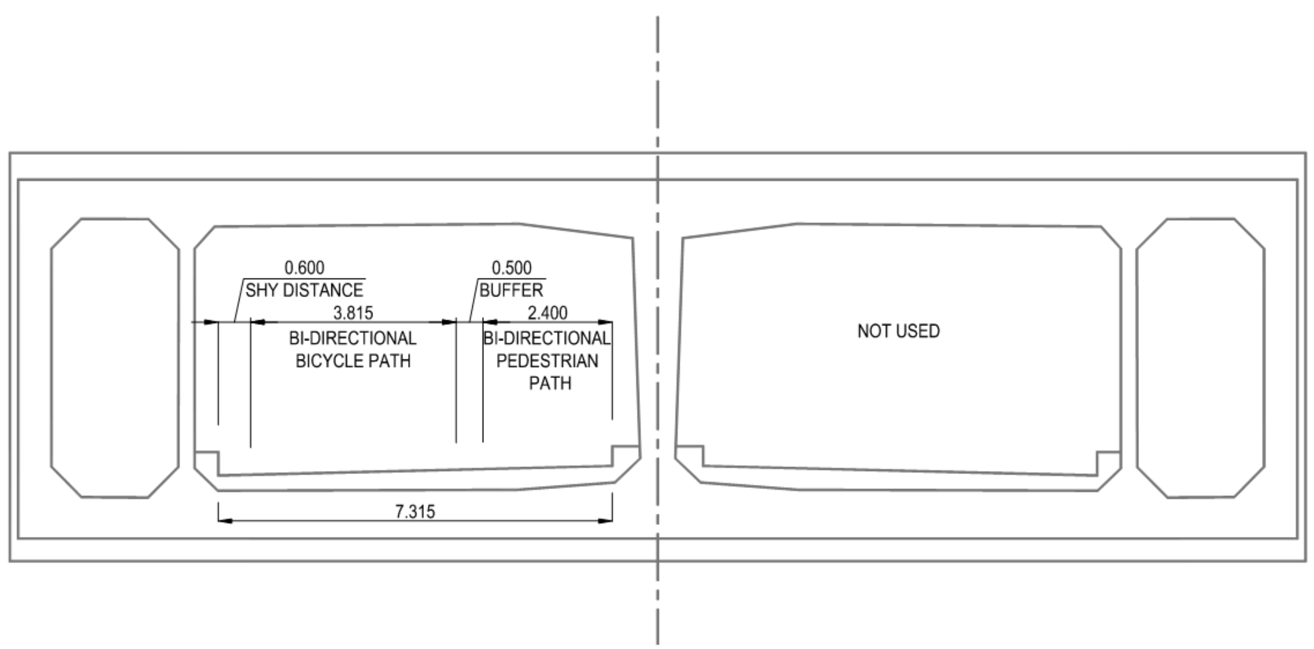
CONFIGURATION A – BOTH TUBES USED FOR ACTIVE TRANSPORTATION

Four options evaluated for Configuration A are summarized in **Table 3**, complete with recommendations for which options are recommended to advance for further consideration by the project team.

Table 3 - Configuration A Cross Section Options

Option		Cross Section	Evaluation of Option	Recommendation for Further Consideration
A1	Cycling in one tube, pedestrians in one tube		• Both pathway widths exceed the upper feasible limit of a bicycle path and a pedestrian path. • Separation of users between the two tubes may lead to more isolation and security discomfort for the tunnel crossing.	**Do not advance for further consideration.**
A2	Cycling and pedestrians in both tubes (Multi-Use Pathways)		• Both pathway widths exceed the upper feasible limit of a bicycle path and a pedestrian path. • Separation of users between the two tubes may lead to more isolation and security discomfort for the tunnel crossing. • Due to use of both tubes, may allow for additional pathway connectivity flexibility on both ends of the tunnel. (Subject to further consideration of the interchange and roadway configurations).	**Do not advance for further consideration.**

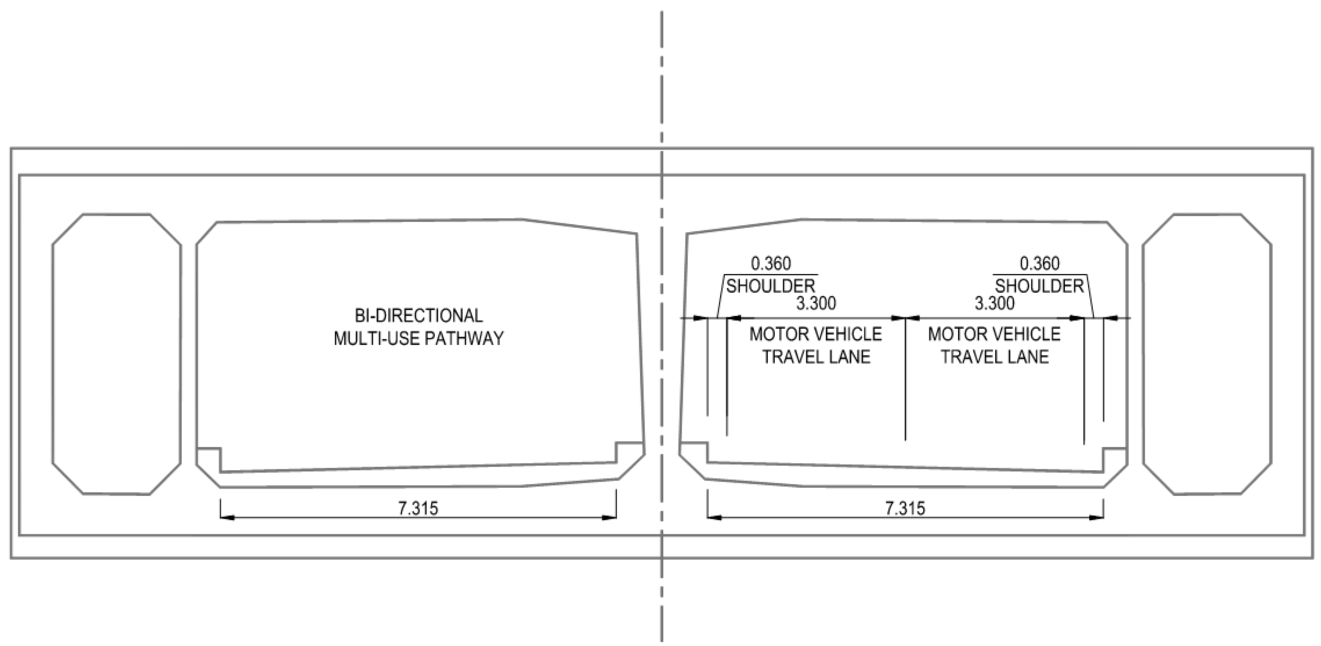
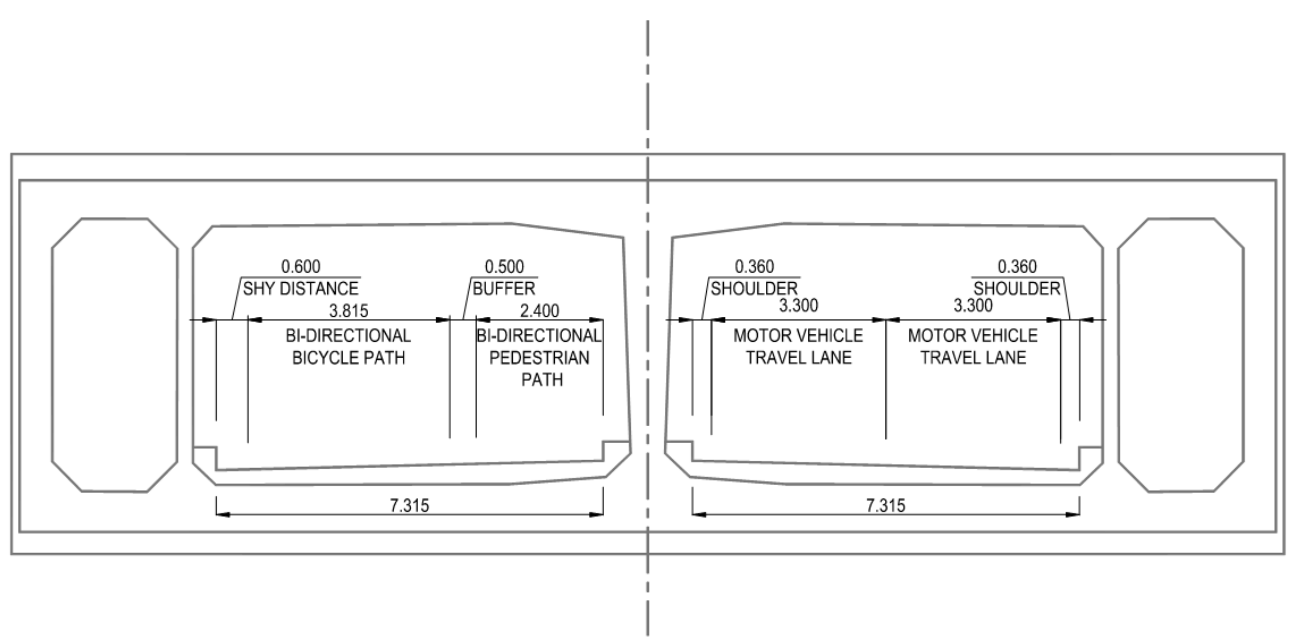
Reference: **George Massey Crossing – Pedestrian and Bicycle Accommodation in Existing Tunnel**

	Option	Cross Section	Evaluation of Option	Recommendation for Further Consideration
A3	Cycling and pedestrians in both tubes (Delineated Spaces)		• All cross-section widths fit within the recommended design criteria. • Separation of users between the two tubes may lead to more isolation and security discomfort for the tunnel crossing. • Due to use of both tubes, may allow for additional pathway connectivity flexibility on both ends of the tunnel. (Subject to further consideration of the interchange and roadway configurations).	Advance for further consideration, subject to review of anticipated pedestrian/bicycle ridership and connectivity at both ends of the tunnel.
A4	Cycling and pedestrians in one tube (Delineated Spaces), other tube not used.		• All cross-section widths fit within the recommended design criteria. • Consolidation of users in one two tubes may lead to increased perception of security by pathway users. • Use of only one tube may limit flexibility for pathway connectivity on both ends of the tunnel.	Advance for further consideration, subject to review of anticipated pedestrian/bicycle ridership and connectivity at both ends of the tunnel.

CONFIGURATION B – ONE TUBE USED FOR ACTIVE TRANSPORTATION, ONE TUBE USED FOR LOCAL TRAFFIC

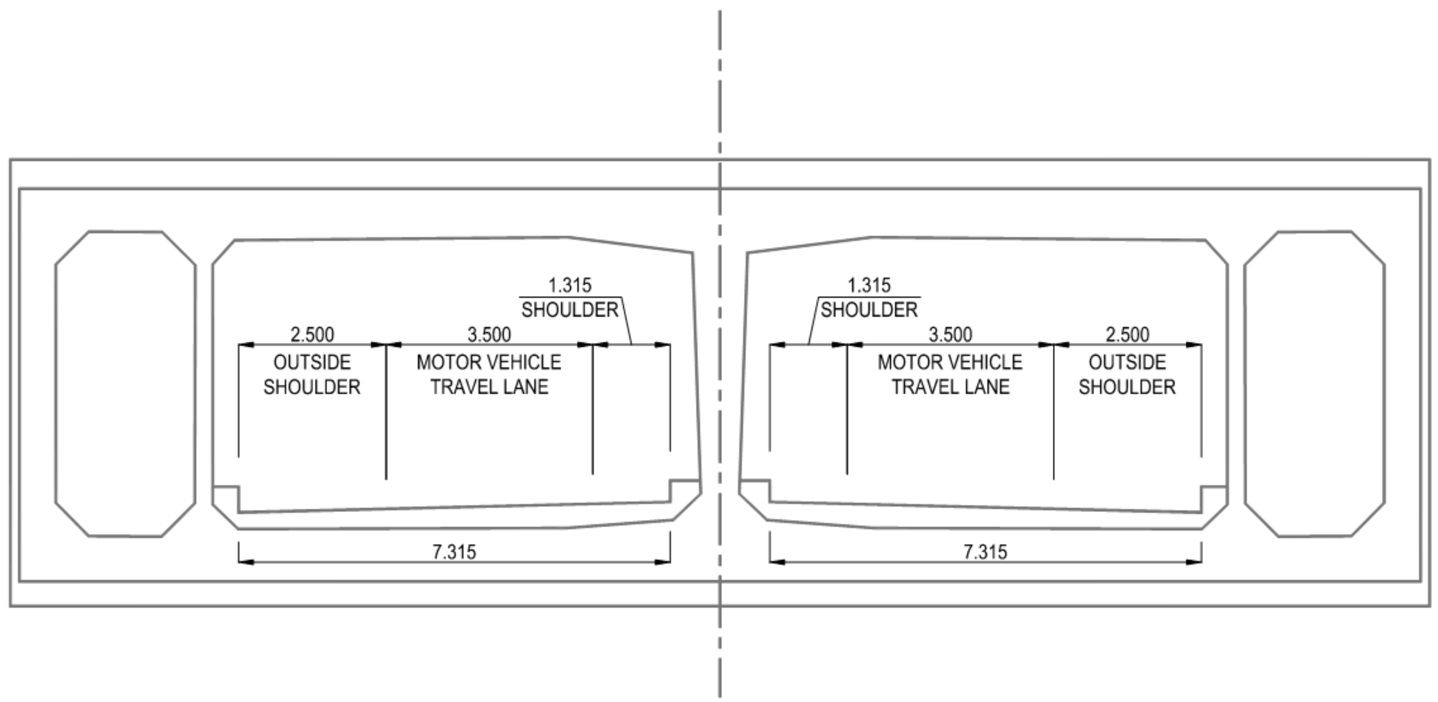
Two options evaluated for Configuration A are summarized in **Table 4**, complete with recommendations for which options are recommended to advance for further consideration by the project team.

Table 4 - Configuration B Cross Section Options

Option		Cross Section	Evaluation of Option	Recommendation for Further Consideration
B1	Cycling and pedestrian in one tube, local traffic in one tube (Multi-Use Pathway)		• Multi-use pathway width exceeds the upper feasible limit. • Accommodation of motor vehicle travel lane widths and shoulders requires confirmation.	**Do not advance for further consideration.**
B2	Cycling and pedestrian in one tube, local traffic in one tube (Delineated Pathways)		• All cross-section widths fit within the recommended design criteria. • Consolidation of users in one two tubes may lead to increased perception of security by pathway users. • Use of only one tube may limit flexibility for pathway connectivity on both ends of the tunnel. • Accommodation of motor vehicle travel lane widths and shoulders requires confirmation.	**Advance for further consideration**, subject to review of anticipated pedestrian/bicycle ridership, connectivity at both ends of the tunnel, and design criteria for local traffic motor vehicle lane widths and shoulders.

Reference: **George Massey Crossing – Pedestrian and Bicycle Accommodation in Existing Tunnel**

CONFIGURATION C – BOTH TUBE USED FOR LOCAL TRAFFIC, NO ACTIVE TRANSPORTATION ACCOMMODATION

	Option	Cross Section	Evaluation of Option	Recommendation for Further Consideration
C1	One travel lane in each tube.		• Anticipate that minimum design criteria for local traffic would be achieved with this configuration. • May accommodate larger shoulder and motor vehicle lane widths than what is required.	**Advance for further consideration**, subject to confirmation of local traffic design criteria.

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