

## 9.0 ACCIDENTS AND MALFUNCTIONS

### 9.1 OVERVIEW

This section identifies potential accidents and malfunctions that could occur during Project construction or operation, and discusses the potential effects of such incidents on VCs and ICs considered in this Application. An overview of mitigation measures, including design and contract specifications to avoid or minimize environmental effects, is also provided.

During construction, adherence to the practices and procedures contained in the Project management plans (**Section 14.0**) will minimize the potential for accidents and malfunctions. Moreover, the Construction Environmental Management Plan (**Section 14.1**), specifically the Emergency Response and Spill Contingency Plan, the Health and Safety Plan, and the Stormwater Management Plan, outlines the measures to be taken in the event of an environmental emergency. These plans will be developed by the Contractor and presented to the regulatory agencies for review prior to construction.

The new bridge will be designed in accordance with the *Canadian Highway Bridge Design Code* (CSA-S6-14), the BC Ministry of Transportation and Infrastructure (MoTI) supplement to CSA-S6-14, and other Project-specific requirements. Roadway design will focus on providing vehicle operational safety and efficiency by complying with the Transportation Association of Canada *Geometric Design Guide for Canadian Roads* (TAC 2017) and the BC *Manual of Standard Traffic Signs and Pavement Markings* (MoTI 2000). In general, replacement of the bridge and roadway improvements are expected to lower the risk of accidents and malfunctions during Project operations and maintenance relative to current conditions.

### 9.2 POTENTIAL ACCIDENTS AND MALFUNCTIONS SCENARIOS

For this assessment, accidents and malfunctions are defined as follows:

- **Accident:** an unexpected occurrence, unplanned event, or unintended action that can result in an adverse effect.
- **Malfunction:** the failure of a piece of equipment, device, or system that can result in an adverse effect.

Potential accidents or malfunctions that could occur during Project construction or operations and could affect the environment are listed below.

- Spills related to release of contaminants/hazardous materials (e.g., hydrocarbon fuels, lubricants, concrete) from marine or land-based vehicles, machinery, or equipment to the environment during construction.
- Structural failure of water management infrastructure such as existing dikes, ditches, detention ponds, or sediment containment structures, resulting in localized flooding, erosion, sedimentation, or discharge of deleterious material into the aquatic environment during construction.
- Damage to utilities resulting in the release of deleterious material into the environment during construction.

- Impediments to marine navigation or vehicle access caused by construction malfunctions.
- Malfunctions of final infrastructure components during the Operations Phase.
- Marine vessel collision with new bridge piers.

A key goal of the Project is to improve safety for all users, including vehicle operators and passengers, cyclists, and pedestrians. Replacing the bridge and improving cyclist and pedestrian access and facilities will help in achieving this goal. Traffic accidents and other types of traffic-related emergencies will be managed in accordance with MoTI's Maintenance Specifications (MoTI 2003) and related standards and consequently are not included in this assessment.

## 9.3 ASSESSMENT METHODS AND INTERACTIONS

### 9.3.1 Methodology

The potential interactions between accidents and malfunctions and VCs were initially identified through a review of relevant literature and other environmental assessments, and professional judgement. Interactions resulting in a potential effect were then carried forward for this assessment.

For each type of accident or malfunction considered, the following steps were taken to assess the potential risk:

1. Accident or malfunction scenario is described.
2. Measures to reduce the likelihood and consequence of the accident or malfunction on a VC are identified.
3. Likelihood of the accident or malfunction to occur post-mitigation is determined.
4. Consequence of the accident or malfunction (post-mitigation) is assessed by characterizing the magnitude, frequency, geographic extent, and reversibility of the consequence on the VC.
5. Potential level of risk is determined based on the risk evaluation matrix (i.e., likelihood multiplied by consequence).

### 9.3.2 Risk Evaluation Methods and Definitions

The approach to risk assessment for accidents and malfunctions was based on rankings of likelihood (probability) and consequence (severity). In this assessment, likelihood is defined as the probability of the event occurring, and consequence is defined as the measure of the severity and magnitude of the potential effect of the event on the VC. Qualitative rankings and descriptions for likelihood and consequence are provided in **Table 9.3-1**. A risk evaluation matrix was then used to determine the level of risk associated with an event as represented by the probability of occurrence of events and the magnitude of the consequence if these events occur (**Table 9.3-2**). As such, high risk can result not only from high probability outcomes but also from low probability outcomes with very severe consequences.

**Table 9.3-1 Definitions for Categories of Likelihood and Consequence**

Phase	Category	Description
Likelihood	Remote	Event could occur only in exceptional circumstances: <0.1%; 1-in-1,000 years
	Low	Event unlikely to occur in normal circumstances: 0.1-1%; 1-in-1,000 years to 1-in-100 years
	Moderate	Event could occur at some point: 1-10%; 1-in-100 to 1-in-10 years
	High	Event probably will occur in most circumstances: 10-50%; 1-in-10 to 1-in-2 years
	Very High	Event is expected to occur in most circumstances and has a history of occurrence: >50% occurrence; 1-in-2 years or more frequency
Consequence	Negligible	No measureable effect: negligible- to low-level repairable damage to minor structures; no stoppage in Project activity or operations
	Low	Minor effect on Project component or activity: effects are localized and short-term in duration; low-level repairable damage to infrastructure; no stoppage in Project activity or operations
	Moderate	Substantial reversible effect on Project activity or operations: moderate-level repairable damage to infrastructure; potential short-term stoppage in Project activity or operations
	High	Substantial irreversible effect on Project activity or operations: major damage to infrastructure; widespread effects; potential long-term stoppage and delay in Project activity or operations
	Severe	Catastrophic irreversible effect on Project activity or operations: major damage to significant infrastructure; Project forced into closure

**Table 9.3-2 Risk Evaluation Matrix**

Likelihood	Consequence				
	Negligible	Low	Moderate	High	Severe
Very High	Low	Medium	High	Very High	Very High
High	Low	Medium	High	High	Very High
Moderate	Low	Low	Medium	High	High
Low	Low	Low	Medium	Medium	High
Remote	Low	Low	Low	Low	Medium

### 9.3.3 Potential Interactions with Valued Components

The potential interactions of Project-specific accidents or malfunctions with each VC are summarized in **Table 9.3-3**. A check mark indicates that an interaction could occur, in which case it is assessed in subsequent sections.

**Table 9.3-3 Potential Interactions of Project Accidents and Malfunctions with Valued Components**

Project Accidents and Malfunctions ✓ = Interaction - = No Interaction	Valued Components										
	Fish and Fish Habitat	Vegetation	Wildlife	Economic Activity	Marine Use	Land Use	Community Cohesion	Visual Quality	Heritage Resources	Physical Determinants of Human Health	Social Determinants of Human Health
Spill incidents related to release of contaminants/hazardous materials during construction	✓	✓	✓	✓	✓	✓	✓	-	✓	✓	-
Structural failure of water management infrastructure during construction	✓	✓	✓	✓	✓	✓	✓	-	✓	✓	-
Damage to municipal utilities	✓	-	✓	✓	✓	✓	✓	-	-	-	-
Impediments to marine navigation and vehicle access caused by construction malfunctions	-	-	-	✓	✓	✓	✓	-	-	-	-
Malfunction of final infrastructure during operations	✓	✓	✓	✓	✓	✓	✓	-	-	-	-
Marine vessel collision with new bridge piers	✓	-	-	✓	✓	-	-	-	-	-	-

## 9.4 LIKELIHOOD, CONSEQUENCE, AND RISK OF POTENTIAL ACCIDENTS AND MALFUNCTIONS

The likelihood and consequence of the potential Project-related accident or malfunction scenarios identified above are discussed in this section. Mitigation measures to minimize the likelihood of accidents or malfunctions and their consequence are presented, and a conclusion on the potential risk of the particular accident or malfunction is provided.

### 9.4.1 Spill Incidents

#### 9.4.1.1 Description of Potential Accidents and Malfunction

For the purposes of this assessment, a spill is considered to be any release or discharge into the environment, not authorized under the provincial *Environmental Management Act*, of a substance in an amount equal to or greater than the amount specified in the *Spill Reporting Regulation* (BC Reg. 187/2017). The Project assessment considers both spills reportable under the *Spill Reporting Regulation* and spills that would not meet reporting criteria under this regulation.

Sources of spills during construction are generally associated with the storage and use of fuel and machinery; spills associated with vehicle or vessel collision are less likely. During construction and bridge decommissioning, there is potential for accidental spills involving the release of hydrocarbon fuels, lubricants, uncured concrete, concrete-affected waters, or other materials into the aquatic environment. Spills of hazardous substances into the environment could result in temporary degradation of watercourses or terrestrial areas. The accidental release of cement-based or lime-containing construction materials to the aquatic environment could elevate pH levels, with potentially lethal effects on fish and other aquatic organisms.

The most likely spill scenario is the spill of relatively small amounts of fuels, lubricants, or other equipment fluids during refuelling or from machinery leaks. Given the urban nature of the Project, on-site fuel storage will likely be limited to small quantities of fuel in 230 L (or less) storage containers, with most equipment being filled directly from purpose-designed fuel trucks periodically servicing the construction site. The volume of such potential refuelling spills or machinery leaks would be minor (less than a few litres), localized, limited to on-site containment areas, and readily cleaned up. On-site storage and use of hazardous materials will comply with all relevant regulations, including the provision of secondary containment measures. Together, these procedures and facilities will generally preclude the possibility of an uncontained spill.

#### 9.4.1.2 Mitigation Measures

Mitigation measures to reduce the likelihood and consequence of an accidental spill include:

- Training construction and maintenance personnel on spill prevention and management
- Training construction and maintenance personnel on environmentally sensitive areas within the Project Boundary
- Maintaining equipment and machinery and conducting regular inspections for leaks

- Storing spill abatement equipment on site
- Providing secondary containment for all hazardous materials
- Locating refuelling and maintenance areas a minimum of 30 m from any waterbodies or sensitive areas
- Using biodegradable hydraulic fluids on hydraulic machinery located within or adjacent to a watercourse
- Developing and implementing requirements for reporting and monitoring of any spill of hazardous material to the authorities as per the *Spill Reporting Regulation* (BC Reg. 187/2017)

Measures to prevent the direct or indirect release of wet concrete or concrete wash water to the aquatic environment may include isolation of works with a waterproof barrier (e.g., polyethylene sheets and wood forms or sealed sandbag coffer dams) to prevent leachate generation and to contain leachate and raw materials for the duration of the product curing period (a minimum of 48 hours) (MoTI 2013). Containment facilities must be provided for wastewater generated when washing concrete trucks and other tools and equipment.

Project contractors will be required to have materials and equipment on hand as a contingency measure to minimize the impacts associated with an accidental release of concrete or concrete washwater in or adjacent to a watercourse. For example, a carbon dioxide tank with a regulator, hose, and gaseous diffuser kept immediately available on site and ready for use during concrete pours within 15 m of, or in work areas above, the wetted perimeter of any watercourse to neutralize pH levels in the event of a spill (MoTI 2013). Construction crews will be trained in the use of this equipment. All spills involving concrete products of a reportable quantity under the *Spill Reporting Regulation* will be reported.

The Emergency Response and Spill Contingency Plan (**Section 14.0 Management Plans**) will include detailed information on pre-emergency planning, emergency organization and responsibilities, spill reporting, incident site security, emergency response, procedures to be followed to contain, clean up, and restore an affected area, and a description of emergency reporting protocols and procedures.

#### 9.4.1.3 Likelihood

The potential of a spill of contaminants or hazardous materials entering the environment and resulting in an adverse effect to terrestrial or aquatic wildlife, agricultural use, land use, or human health is unlikely post-mitigation. The mitigation measures described above will be implemented to avoid or minimize the potential for a spill to occur, and to mitigate and manage the potential effect in the event of a spill. With mitigation in place, the likelihood of a relatively minor spill incident is considered moderate, with a more significant spill unlikely to occur in normal circumstances (low likelihood).

#### 9.4.1.4 Consequence

The geographic extent of a spill would depend on the quantity and location of the material spilled. With the implementation of appropriate spill response procedures and the mitigation measures described above, it is anticipated that a spill would be localized in geographic extent. Spills into the environment would be infrequent and the effects are anticipated to be reversible; baseline conditions would be restored naturally

after the disturbance has ceased and appropriate remediation measures have been applied. The magnitude and duration of any potential effects of a hazardous material spill would depend on the type, quantity spilled, location of the spill, and (potentially) the time of year in which the incident occurs.

Emergency spill response procedures will be developed to contain and manage a spilled product within a localized area, thus limiting potential interaction with the receiving environment. Based on the above, the consequence of spill of contaminants or hazardous materials resulting in adverse effects to VCs is assessed to be low.

#### **9.4.1.5 Risk**

The mitigation measures outlined above are standard practice in the industry and have proven effective in reducing the likelihood of a spill to occur. The spill contingency and cleanup measures to be implemented are well-tested and effective means of reducing the consequences of spills. Being based on well-documented cause–effect relationships, the level of confidence in this assessment is high.

With the implementation of the mitigation measures described, a spill has a low likelihood of occurring and resulting in an adverse effect to VCs. Although spills during construction are possible—even with the preventative mitigation measures applied—the planned emergency response, spill contingency, and cleanup measures are expected to reduce the consequence (low) of an adverse effect to receptor VCs in the event of a spill. Given the low likelihood and low consequence of a spill of contaminants or hazardous material resulting in an adverse effect on VCs, the risk is determined to be low in accordance with the risk evaluation matrix classification.

### **9.4.2 Structural Failure of Water Management Infrastructure**

#### **9.4.2.1 Description of Potential Accidents and Malfunction**

The Project design will provide for existing and anticipated drainage requirements, including stormwater management along the affected roadways and runoff from the new bridge deck. Stormwater runoff will be collected and treated using biofiltration methods before release. Sediment and erosion control structures will also be installed during Project construction for work in and around riparian zones and waterbodies.

The types of water management infrastructure considered for this assessment include existing dikes, stormwater drainage features, biofiltration ponds, and sediment and erosion control structures, the failure of which during Project construction would result in localized flooding, erosion, sedimentation, or discharge of sediment-laden water into the aquatic environment. Failure under unexpectedly severe weather conditions or events could potentially release sediment-laden water into road-side ditches or watercourses.

An accidental influx of sediment into an aquatic environment could result in elevated turbidity levels and degradation of aquatic habitat, with adverse effects on fish and fish habitat, riparian habitat, and wildlife. The presence of suspended sediments in the water column may limit the ability of fish to detect and secure prey or avoid predation by clogging gills and interfering with other aspects of respiratory function.

#### 9.4.2.2 Mitigation Measures

Water management features will be designed in accordance with the *Design Build Standard Specifications for Highway Construction* (BC MOTI 2013). Mitigation and best practices to prevent the potential release of deleterious substances into the environment will be incorporated into the Project design and implemented during construction; these are outlined in the Erosion and Sediment Control Plan and the Stormwater Management Plan (**Section 14.0**). The Project will have no effect on existing dikes because roadways will be elevated over the dikes along the Fraser River shoreline.

Adverse effects associated with accidental sediment discharge resulting from structural failure of water management infrastructure will be minimized by providing for on-site storage and deployment of materials such as clean rock, granular materials, and filter fabric in order to rapidly respond to, divert, and contain a potential release. In the event, appropriate temporary sediment control devices would be installed immediately to prevent sediment from entering watercourses. Further contingency and mitigation measures are outlined in the Erosion and Sediment Control Plan and the Stormwater Management Plan (**Section 14.0**).

#### 9.4.2.3 Likelihood

With consideration of MoTI's design standards and mitigation measures applied to the Project, the likelihood of a structural failure of water management infrastructure such as an existing dike, stormwater collection ditch, or sediment and erosion control structure is assessed as low.

#### 9.4.2.4 Consequence

In the unlikely scenario that water management infrastructure fails and sediment-laden water reaches the aquatic environment (Fraser River), the extent of the effect would depend on the amount of sediment-laden water released relative to the size of the receiving body and the potential for dispersion. With the implementation of mitigation measures and contingency planning, the volume of untreated water or sediment released into the environment would likely be low and of local extent.

The magnitude of the effect of a low-volume release of untreated water or sediment is anticipated to be low and unlikely to result in a noticeable effect over baseline conditions, given the natural variability of suspended sediment in the river seasonally and annually (see **Section 4.2 Sediment and Surface Water Quality**) and the quality of upland watercourses.

The duration of the effect is anticipated to be short term because any sediment released during water management infrastructure failure would likely dissipate quickly. Considering the existing variability of sediment levels in the Fraser River, the effect on fish and fish habitat is anticipated to be reversible, with baseline conditions restored naturally after the disturbance has ceased.

Given the contingency and immediate response measures outlined in the management plans, the consequence of a structural failure of water management infrastructure is low, with potential effects on the aquatic environment expected to be localized, low in magnitude, and reversible over the short term.

#### **9.4.2.5 Risk**

The likelihood and consequence of structural failures of water management features, and the associated effects on VCs, are anticipated to be low, given BC MoTI design specification requirements, mitigation measures, and contingency procedures, which are well-established industry standards that have proven capable of ensuring water management features, are built and perform as intended. In the unlikely event of a failure, these standard mitigation and contingency measures are expected to be effective at managing localized flooding, erosion, sedimentation, or discharge of deleterious materials into the aquatic environment. With implementation of mitigation, the potential event is assessed as low risk.

### **9.4.3 Damage to Utilities**

#### **9.4.3.1 Description of Potential Accidents and Malfunction**

Review of the existing utilities within the Project Boundary has been conducted to identify potential utility conflicts; data were compiled from different sources, including BC One Call, City of Surrey, City of New Westminster, and various utility owners. The utilities that could be affected by Project activities include storm and sanitary sewers, watermains, electrical distribution lines, natural gas lines, and telecommunications systems such as fibre optic, cable, and telecom.

The potential for accidental damage is mostly associated with ground disturbance during construction (e.g., excavating, trenching, pile driving, ground improvements). Damage to utilities could result in the disruption of municipal services for residential, commercial, or industrial users; a spill of wastewater or chlorinated water that could affect fish, fish habitat, and wildlife if the spill entered the aquatic environment; and potential health and safety implications from an accidental breach in the integrity of a natural gas pipeline.

#### **9.4.3.2 Mitigation Measures**

To minimize the likelihood of unexpected utility disruption, underground utilities within the Project boundary will be located and mapped on detailed design drawings before the start of construction or maintenance activities involving ground disturbance. Contractors will be required to contact BC One Call, a central agency that helps identify buried underground utilities and facilities, in advance of any ground works.

Where new roads and ramps will be constructed over existing pavement and utilities, the latter will be protected in designs and monitored for signs of damage during construction. Specific monitoring requirements will be agreed upon with utility owners. For utility components that will be abandoned in place, the Contractor will be required to either remove them or use appropriate methods to, for example, clean, treat, and leave them in the ground, in accordance with road authority and utility agency requirements. Where utility relocations are required, the relevant utility agency will need to approve the relocation designs before the work is done.

Any interruption of services related to utility outages is anticipated to be limited to a few hours. In the event of a schedule or accidental disruption to underground utilities, the municipality and the relevant utility will be contacted immediately.

The Emergency Response and Spill Contingency Plan (**Section 14.0**) will include detailed information on emergency response in case of accidental damage to utilities.

#### **9.4.3.3 Likelihood**

Due to the standard nature of construction methods envisaged and the use of appropriate mitigation measures, including the proper identification and protection of utilities before construction, the likelihood of accidental damage to utilities resulting in adverse effects to VCs is considered low.

#### **9.4.3.4 Consequence**

Any disruption of utilities is expected to be addressed in an effective, timely manner through the implementation of the overall Construction Environmental Management Plan and specifically the Emergency Response and Spill Contingency Plan. This will ensure that potential effects of such incidents are localized in extent, temporary in duration, and minimal in consequence. The consequence of accidental damage to a utility is anticipated to be low to moderate, depending on the type of utility damaged and the extent of the damage.

#### **9.4.3.5 Risk**

The proposed mitigation measures are expected to reduce the likelihood of utility damage during construction and maintenance and the consequence of any unlikely incident. With mitigation, the likelihood and consequence of residual adverse effects are considered low. The potential risk associated with accidental damage of utilities during Project activities is, therefore, assessed as low. Given the low risk and the remote likelihood of such an effect occurring, further assessment of potential effects of an accident or malfunction involving utility disruption is not considered necessary.

### **9.4.4 Impediments to Marine Navigation or Vehicle Access**

#### **9.4.4.1 Description of Potential Accidents and Malfunction**

Malfunctions during the construction of major infrastructure such as a bridge have been known to take place, albeit infrequently. Cases of construction machinery malfunction, such as girder or crane collapse, or the fall of debris during concrete casting, have been documented.

Bridge building involves the use of heavy-lift equipment to move large pieces of prefabricated bridge materials and components. A machinery malfunction during bridge construction is not only a serious health and safety risk for on-site workers and marine traffic but could result in large debris or machinery impeding marine navigation and use. Since the existing bridge would be used for vehicle traffic during construction of the new bridge, and no overlap of use would occur until the new bridge was completed, there is no potential for a construction-related malfunction to impede bridge traffic during Project construction. However, vehicle access to the bridge could be affected by a construction malfunction along the roadways or ramps.

#### 9.4.4.2 Mitigation Measures

A Traffic Management Plan (**Section 14.7**), a Marine Access Management Plan (**Section 14.24**) and the Marine Communication Plan (**Section 14.16**) will be developed before the start of construction. The Traffic Management Plan will be prepared in accordance with applicable regulations and standards including the *BC Workers Compensation Act* and *Occupational Health and Safety Regulation*, and the *Traffic Control Manual for Work on Roadways* (MoTI 2015). The Marine Access Management Plan and Marine Communication Plan will meet the requirements of the Transport Canada Navigation Protection Program pursuant to the federal *Navigation Protection Act*.

These management plans will outline the mitigation measures to be implemented to prevent or manage potential land- and marine-related traffic hazards during construction, such as:

- How current information regarding construction activities, construction periods, and route options will be communicated to stakeholders, emergency responders, municipalities, and adjacent land users (e.g., businesses, residents), such as through radio notices, signage, a website, a telephone line, and changeable message boards.
- Communication requirements to share traffic management information during Project construction, traffic control measures, traffic interruptions and delays, restrictions, and re-routing scenarios.
- Measures to promote safety and security of on-site personnel and all users of the corridor, including the public, minimizing the potential for vehicle-related accidents.
- How access will be provided for emergency vehicles in the event of an incident or emergency, both within and externally to the Project, where emergency vehicle and response personnel require passage through the site.
- Mitigation measures to minimize the potential for vessel-related accidents, including communications protocols with marine users, navigational procedures, and emergency preparedness procedures.
- Specifications for navigational clearances for the new bridge into the Project design in accordance with the requirements of Transport Canada Navigation Protection Program, pursuant to the *Navigation Protection Act* (R.S.C., 1985, c. N-22).

Per the Health and Safety Plan (**Section 14.0**), training will be mandatory for all contractors and operators to understand and adhere to machine operation procedures and to be familiar with the hazards and mitigation measures identified in the Traffic Management Plan, the Marine Access Management Plan and the Marine Communication Plan.

#### 9.4.4.3 Likelihood

With mitigation measures in place, including operator training, the likelihood of impediments to marine navigation or vehicle access resulting from construction malfunction is assessed as low in normal circumstances.

#### 9.4.4.4 Consequence

In the unlikely scenario of a construction malfunction where large machinery or debris impedes marine or vehicle access, marine or land use could be affected. With the mitigation measures in place, the extent of the effect is anticipated to be local, the magnitude to be low, and the duration short term. The consequence of a construction malfunction resulting in impediments to marine navigation or vehicle use is assessed to be low, as any disruption in access would likely be addressed in an effective, timely manner through the implementation of the Traffic Management Plan, the Marine Access Management, and the Marine Communication Plan.

#### 9.4.4.5 Risk

The likelihood and consequence of construction malfunction impeding marine navigation and vehicle access is anticipated to be low, given MoTI's design specification requirements, Contractor requirements for health and safety, and implementation of the Traffic Management Plan, the Marine Access Management Plan and the Marine Communication Plan. In the unlikely event of a construction failure, these plans and procedures will provide effective and timely response to any disruption of access. With implementation of mitigation, the potential event is assessed as low risk.

### 9.4.5 Malfunction of Final Infrastructure

#### 9.4.5.1 Description of Potential Accidents and Malfunction

Vehicle or marine vessel collisions, or unstable ground conditions, could result in malfunction or failure of piers and the overall structure during operations. The new bridge, interchanges, and associated infrastructure will be designed and built to withstand collisions from vehicles and marine vessels without structural failure. Parapets and railings will be designed to prevent vehicles from leaving the roadway, as set out in CSA S6-14 *Canadian Highway Bridge Design Code* and the MoTI's *Bridge Standards and Procedures Manual* Volume 1, Supplement to CHBDC S6-14.

Embankments and retaining walls will be required for the project and based on geotechnical site investigation (Golder Associates 2017), areas where these components could be located are expected to be underlain with weak and highly compressible organic and fine-grained sediments. These deposits will be subject to deformations and instability under embankment and retaining wall loads as well as seismic shaking. Malfunction or failure of the embankments and retaining wall structures can constitute a health and safety hazard and lead to debris or other materials being deposited in drainage systems, riparian areas, and watercourses.

#### 9.4.5.2 Mitigation Measures

The Project will be designed and constructed in accordance with federal and provincial standards to minimize the potential for damage resulting from structure failure, including the CSA S6-14 *Canadian Highway Bridge Design Code* and MoTI's *Bridge Standards and Procedures Manual* Volume 1, Supplement to CHBDC S6-14. Extensive geotechnical investigations have been and are continuing to be undertaken, including soil liquefaction assessments, to improve the understanding of subsurface conditions and to direct detailed design for stable foundations for bridge structure, roadways, and secondary structures (retaining walls and embankments).

MoTI's maintenance contractors will be required to respond to structural damage as set out in Chapter 7-800 (Structure Damage Response) of the *Maintenance Specifications* (MoTI 2003). In general, the objective of the response is to ensure the safety of users, to restore all affected structures to their original condition, and to maximize their functional life (MoTI 2003). Where the safety of bridge users is affected, MoTI's maintenance contractors must immediately notify the MoTI so that a Bridge Structural Engineer may make an inspection. If there is determined to be a risk of structural failure under loading, then the bridge may be load restricted or closed to all traffic or uses while the bridge is repaired to a safe and stable condition.

In the event of a structural failure, priority will be given to ensuring the safety of users and stability of the structure. Once public safety is assured, MoTI's contractors will be required to take the necessary steps to reduce the risk posed by debris or other materials to drainage systems, riparian areas, and watercourses. The removal of such debris will commence as soon as possible, in consultation with the Ministry of Environment and Climate Change Strategy, Ministry of Forests, Lands and Natural Resource Operations, and Department of Fisheries and Oceans, as applicable. Measures will be implemented to prevent sediment and other deleterious materials from entering road drains and watercourses during debris removal.

#### **9.4.5.3 Likelihood**

The likelihood of malfunction of final infrastructure components is considered remote, given the strict regulations and standards that apply to the design, construction, and operation of major infrastructure.

#### **9.4.5.4 Consequence**

Design standards and the mitigation measures discussed above are expected to ensure that the potential consequences of any malfunction of final infrastructure are minimized. The potential consequence to human health and safety and the Project VCs in an unlikely event involving malfunction of a final infrastructure component is assessed as low, given the design, construction, and maintenance specifications and requirements of the proposed structures.

#### **9.4.5.5 Risk**

Based on the remote likelihood of an accident or malfunction resulting in the structural failure of a Project component during Project operations, and the low consequence of such an incident on VCs, the risk associated with structural failure during operations is determined to be low. Given the low risk involved and the remote likelihood of such an effect occurring, further assessment of potential effects of an accident or malfunction involving failure of a Project component during operations is not considered necessary.

## 9.4.6 Marine Vessel Collision with Bridge Piers

### 9.4.6.1 Description of Potential Accidents and Malfunction

A Collision Risk and Pier Impact Assessment, provided in **Attachment 9-A**, describes the principles, approach, and site-related parameters that will be used for this risk assessment. More information on key components such as the final pier locations and bridge configuration details is required, and the final assessment of ship impact risks will therefore be undertaken during detailed design.

Vessel impact scenarios to be considered, as detailed in **Attachment 9-A**, include the following cases:

- Drifting Vessel: Vessel impact loads associated with an empty barge that has broken loose from its moorings during a storm event. This load will be combined with one-half of the predicted long-term plus one-half of the predicted short-term scour.
- Aberrant Vessel: Vessel impact loads associated with an aberrant vessel being driven into the bridge under normal environmental and operating conditions. This is combined with one-half the predicted long-term scour. This case will be used to evaluate the overall stability of the bridge pier subject to the maximum impact force, and to design the local capacity of the structural elements, such as columns, pylons, or piles, that could be contacted by an impacting vessel.
- Vessel Collision with Bridge Superstructure: Based on the assumed future passage of a Handymax vessel at the site, a minimum clearance of 32 m over the river is recommended.

### 9.4.6.2 Mitigation Measures

The Project will be evaluated for vessel collision risk, and corresponding design loads will be established to ensure that the annual frequency of collision-induced structural collapse is less than or equal to a probability of 1% in 100 years. Design loads will be calculated in accordance with CSA-S6-14 and the AASHTO Guide Specification. Vessel impact forces are dependent on the number of instream piers, the pier locations, and the final configuration of the bridge. To begin managing risks associated with vessel impact, pier-free zones have already been established.

All structural components that connect the superstructure to the substructure (bearings, shear keys, diaphragms) will be designed to resist the demands imposed by the pier impact and superstructure impact loads.

### 9.4.6.3 Likelihood, Consequence Risk

Final assessment of ship impact risks will be undertaken during detailed design based on information on pier location and bridge configuration details; thus, the likelihood, consequence, and risk are not further detailed here. Based on the Project criteria whereby the annual frequency of collision-induced structural collapse is less than or equal to a probability of 1% in 100 years, along with the design mitigation measures discussed above, the risk of marine vessel collision with the Project is anticipated to be manageable and within acceptable limits.

## 9.5 REFERENCES

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**ATTACHMENTS**

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## Attachment 9-A

# Collision Risk and Pier Impact Assessment

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## 9-A.0 PATTULLO BRIDGE REPLACEMENT PROJECT COLLISION RISK AND PIER IMPACT ASSESSMENT

### 9-A.1 OVERVIEW

The proposed new Pattullo Bridge will be designed to meet current standards such that the risk of vessel collision-induced structural collapse is less than or equal to a probability of 1% in 100 years. This is equivalent to a catastrophic vessel collision event with a return period of 10,000 years. Design loads will be calculated in accordance with CSA-S6-14 and the AASHTO Guide Specification. Two types of vessel impact scenarios will be considered:

- Impact to bridge piers
- Impact to the bridge superstructure

The assessment of vessel collision risk is related to a number of factors, including:

- Acceptable risk profile with regard to ship impact
- Establishment of pier-free zones and appropriate bridge deck height above water to minimize constraints to navigation and therefore manage the probability of vessel impact on the new bridge
- Vessel characteristics, including weight, dimensions, and existing and future frequency of transits
- Vessel velocity and direction during tides, floods, and seasonal variations such as freshet
- Water depth and river bathymetry, including local and general scour depths
- Vessel operation considerations, including loss of steerage, breakaway from moorage, and errors in navigation
- Pier locations, orientation, and dimensions

Key components of this risk assessment require information on the final pier location and bridge configuration details; therefore, final assessment of ship impact risks will be undertaken during detailed design and after award of a Design-Build contract. The following establishes the principles, approach, and site-related parameters that will be used for this risk assessment.

Collision risk impact assessment will be carried out in accordance with the *Canadian Highway Bridge Design Code CSA-S6-14 (S6-14)* as amended by British Columbia *Bridge Standards and Procedures Manual* (MoTI 2016). S6-14 allows the *AASHTO Guide Specification and Commentary for Vessel Collision Design of Highway Bridges* (AASHTO 2009) to also be used. Several jurisdictions in the USA and Europe have undertaken extensive research with regard to ship impact risk assessment, and the resulting design guidelines are also valuable resources in this regard.

## 9-A.2 ACCEPTABLE RISK PROFILE

Given the importance and cost of the proposed new bridge, as well as the importance of the Fraser River, the new bridge will be designed as a “critical/essential” structure. This means that the design will be based on a probability of structural collapse caused by vessel collision equal to or less than 1% in 100 years. This corresponds to a return period of 10,000 years, which is considerably more stringent than return periods used for seismic design and for what is generally used for “normal” bridges, which are designed for an impact event with a return period of 1,000 years.

## 9-A.3 ESTABLISHMENT OF PIER-FREE ZONES AND APPROPRIATE BRIDGE DECK HEIGHT

An important element in managing risk associated with vessel impact is understanding navigation challenges and requirements at the site and then, based on this understanding, establishing a pier-free zone to help minimize the risk of vessels colliding with the bridge.

The new bridge will be located within Queens Reach on the Fraser River, approximately 36 km upriver from where the river enters the Salish Sea. The presence of existing bridges—SkyBridge, the existing bridge during construction, and the New Westminster Rail Bridge (NWRB)—directly downstream of the proposed new bridge and the river configuration at the Project site complicate the navigability of the Fraser River in this part of Queens Reach. Complicating factors include the close spacing of these structures, numerous existing instream piers, the constriction of the Fraser River at the Project site, the bend in the river at the site and the complex currents arising from convergence of the flow split created by the Sapperton Dyke upstream of City Bank.

Currents directly upstream from the proposed new bridge tend to push vessels towards the north riverbank, making it challenging under certain conditions to navigate through the available navigation openings of the NWRB. The NWRB bridge has been struck by vessels on numerous occasions in the past, with consequent closure of the bridge for varying durations. For example, on December 26, 1975, a runaway logging barge, driven by a westerly gale, carried away a 116m span of the bridge. Although, as would be expected, most collisions occur in the vicinity of the swing span, one of the largest damaging events happened when a 130m span was hit by a runaway barge that left its moorings during a windstorm. The bridge was out of service for approximately three months.

There are currently two navigation channels at the site:

- Main navigation channel, as defined by the openings provided by the swing span of the NWRB
- Secondary channel, as defined by the NWRB span directly north of the swing span

The domestic channel services vessels that have sufficiently low air draft and do not need the NWRB to be opened.

To minimize constraints and impediments to navigation, a design vessel based on current and future commercial use of the river has been used to establish pier locations and deck elevation for the new bridge. The design also follows Permanent International Association of Navigation Congresses (PIANC)

guidelines for the design of navigation channels. The development of the design vessels used to establish the pier-free zone is based on the current and future inventory of the Fraser River and summarized in **Table 9-A-1**.

**Table 9-A-1 Design Vessels for Pier-Free Zone**

Channel Type	Lanes	Vessel Name	Displacement Tonnage (t)	Length (m)	Beam (m)	Draft (m)
Main Navigational Channel	One	Marersk Radiant	38,500	270	32.3	11.5
Main Navigational Channel	Two	Average Chip Barge	8,225	175	20.5	9.6
Secondary Channel	One	Average Chip Barge	8,225	175	20.5	5.6

PIANC guidelines consider a range of factors that affect navigation and help identify areas where piers should not be placed. The following factors were considered in establishing “no-pier” zones for the new bridge:

- Vessel details:
  - Envelope of vessel dimensions based on inventory of existing and future vessels
  - Vessel maneuverability
  - Vessel speed
  - Cargo hazard
  - Traffic density/congestion
- River characteristics and geometry (channel alignment):
  - Depth/Draft effects
  - Bottom surface bank suction effect or proximity to and nature of channel edges.
  - Availability of aids to navigation
- Environmental factors:
  - Cross winds
  - Cross currents
  - Longitudinal current
  - Waves

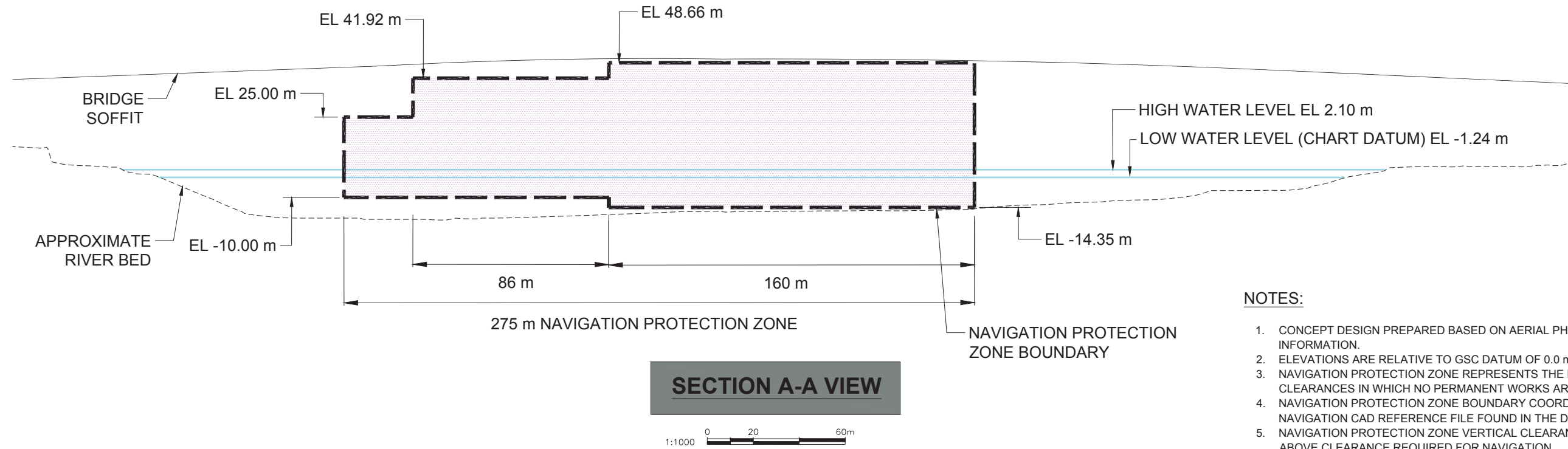
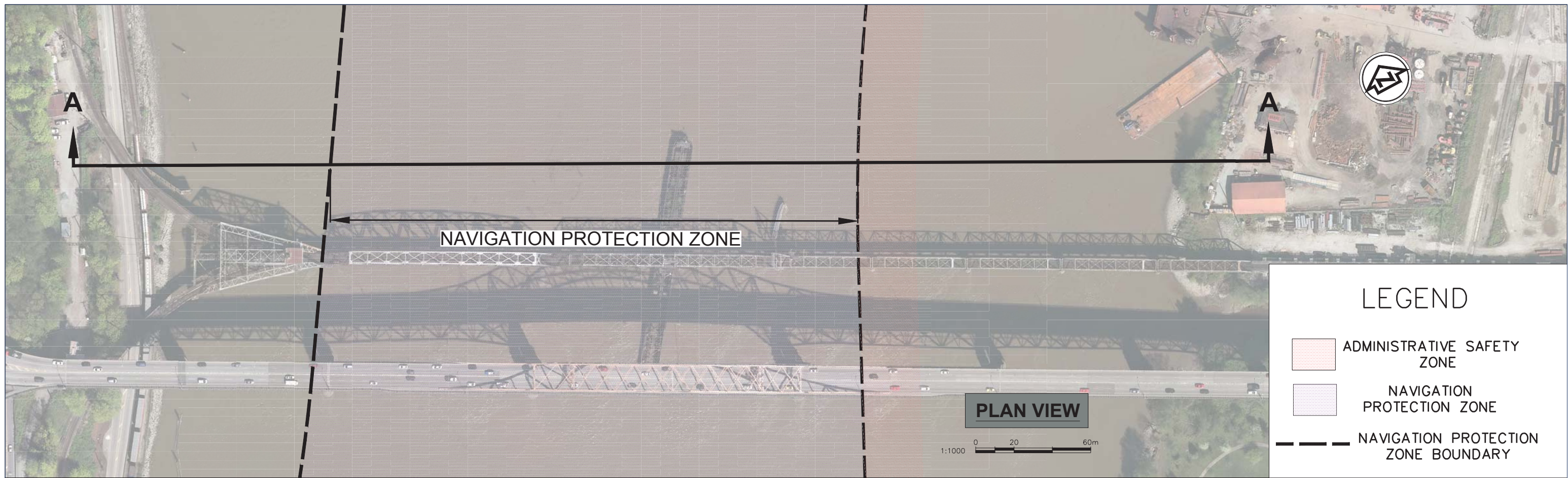
The elevation of the bridge deck was based on the height of existing upstream and downstream structures (**Table 9-A-2**).

**Table 9-A-2 Elevation of Bridge Deck**

Structure	Vertical Clearance above High Water [m]
New Port Mann Bridge	42
Existing Pattullo Bridge	45
SkyBridge	44
Alex Fraser Bridge	57

Based on the above considerations two no-pier zone and bridge deck elevation were established with the location and dimensions shown in **Figure 9-A-1**. These details will be stipulated within the procurement documents.

File: C:\pwworking\bc\p001488a\cims07069\sk-c-346 (Fig 9-A-1) Navigational Protection Zone-MDT.dwg Save Date: Jun 26, 2018 10:06 AM Saved By: P001488A



**NOTES:**

1. CONCEPT DESIGN PREPARED BASED ON AERIAL PHOTO AND PLANIMETRIC SURVEY INFORMATION.
2. ELEVATIONS ARE RELATIVE TO GSC DATUM OF 0.0 m.
3. NAVIGATION PROTECTION ZONE REPRESENTS THE HORIZONTAL AND VERTICAL CLEARANCES IN WHICH NO PERMANENT WORKS ARE PERMITTED.
4. NAVIGATION PROTECTION ZONE BOUNDARY COORDINATES PROVIDED IN NAVIGATION CAD REFERENCE FILE FOUND IN THE DATA ROOM.
5. NAVIGATION PROTECTION ZONE VERTICAL CLEARANCE INCLUDES A 2 m BUFFER ABOVE CLEARANCE REQUIRED FOR NAVIGATION.

REV	DATE	REVISIONS	SIGNATURE
A	2017-11-27	ISSUED FOR RFQ	SC
B	2018-01-10	ISSUED FOR RFQ	SC
C	2018-01-24	ISSUED FOR RFQ	SC

**BRITISH COLUMBIA** MINISTRY OF TRANSPORTATION AND INFRASTRUCTURE

SCALE 0 10 1:1000 50m

DESIGNED \_\_\_\_\_ DATE \_\_\_\_\_  
 QUALITY CONTROL \_\_\_\_\_ DATE \_\_\_\_\_  
 QUALITY ASSURANCE \_\_\_\_\_ DATE \_\_\_\_\_  
 DRAWN \_\_\_\_\_ DATE \_\_\_\_\_

**PATTULLO BRIDGE REPLACEMENT PROJECT**  
**RFQ REFERENCE CONCEPT**  
 NAVIGATION PROTECTION ZONE

ELEVATION OF NAVIGATION CHANNEL AND PROFILE OF BRIDGE SOFFIT

FILE NUMBER	PROJECT NUMBER	REG	DRAWING NUMBER	REV
			FIGURE 9-A-1	C

## 9-A.4 DESIGN VESSEL CHARACTERISTICS

### 9-A.4.1 Vessel Fleet Inventory

Vessel fleet data for the Pattullo were developed by updating studies conducted for the Port Mann Bridge replacement with information obtained from interviews with Fraser River marine operators. The vessel fleet inventory is based on conditions forecast for 2036 and is summarized in **Table 9-A-3**.

The number of vessel transits shown in **Table 9-A-3** includes all vessel traffic expected to transit under the Pattullo Bridge through both the main and secondary navigation channels and in each direction. Self-dumping log barges and Handymax ships must use the main channel at the NWRB because of their air draft, whereas most other vessel types are able to use the domestic channel. The domestic navigation channel has sufficient vertical clearance and water depth to allow the transit of a significant portion of the chip and gravel barges, especially when fully loaded. Captain Phill Nelson, President of the Council of Marine Carriers, suggests that approximately 25% of total barge traffic currently uses the domestic channel. It can be reasonably assumed that this will not change, even if the NWRB is replaced, since many operators prefer to use the domestic channel to avoid the need to coordinate with a bridge opening.

**Table 9-A-3 Preliminary Vessel Fleet Data for Vessel Collision Risk Assessment (to be updated during Project Execution)**

Vessel Group	Vessel Description	Load Condition	Transit Direction	Vessel Type	Average LOA (m)	Average Beam (m)	Average Draft (m)	Average Weight <sup>1</sup> (tonne)	Main Channel Transits <sup>2</sup>	Domestic Channel Transits <sup>2</sup>	Transit Speed (knots)
1	SD Log Barge	Loaded	Upstream	SDLB	128.9	26.8	6.6	16818	3	0	6.0
2	SD Log Barge	Loaded	Downstream	SDLB	128.9	26.8	6.6	16818	0	0	6.0
3	SD Log Barge	Light	Upstream	SDLB	128.9	26.8	1.5	7200	0	0	6.0
4	SD Log Barge	Light	Downstream	SDLB	128.9	26.8	1.5	7200	3	0	6.0
5	Barge > 10,000 t	Loaded	Upstream	Barge	108.0	24.5	5.6	12130	8	2	6.0
6	Barge > 10,000 t	Loaded	Downstream	Barge	108.0	24.5	5.6	12130	212	70	6.0
7	Barge > 10,000 t	Light	Upstream	Barge	108.0	24.5	1.3	2674	212	70	6.0
8	Barge > 10,000 t	Light	Downstream	Barge	108.0	24.5	1.3	2674	8	2	6.0
9	Barge 5,000 - 10,000 t	Loaded	Upstream	Barge	83.0	21.7	4.3	7150	577	192	6.0
10	Barge 5,000 - 10,000 t	Loaded	Downstream	Barge	83.0	21.7	4.3	7150	1295	431	6.0
11	Barge 5,000 - 10,000 t	Light	Upstream	Barge	83.0	21.7	1.2	1875	755	251	6.0
12	Barge 5,000 - 10,000 t	Light	Downstream	Barge	83.0	21.7	1.2	1875	37	12	6.0
13	Barge 2,000 - 5,000 t	Loaded	Upstream	Barge	59.7	15.6	3.8	3437	2907	968	6.0
14	Barge 2,000 - 5,000 t	Loaded	Downstream	Barge	59.7	15.6	3.8	3437	3629	1209	6.0
15	Barge 2,000 - 5,000 t	Light	Upstream	Barge	59.7	15.6	0.9	1005	724	241	6.0
16	Barge 2,000 - 5,000 t	Light	Downstream	Barge	59.7	15.6	0.9	1005	2	0	6.0

Vessel Group	Vessel Description	Load Condition	Transit Direction	Vessel Type	Average LOA (m)	Average Beam (m)	Average Draft (m)	Average Weight <sup>1</sup> (tonne)	Main Channel Transits <sup>2</sup>	Domestic Channel Transits <sup>2</sup>	Transit Speed (knots)
17	Barge < 2,000 t	Loaded	Upstream	Barge	36.8	14.3	1.9	768	257	85	6.0
18	Barge < 2,000 t	Loaded	Downstream	Barge	36.8	14.3	1.9	768	257	85	6.0
19	Barge < 2,000 t	Light	Upstream	Barge	36.8	14.3	1.9	768	0	0	6.0
20	Barge < 2,000 t	Light	Downstream	Barge	36.8	14.3	1.9	768	0	0	6.0
21	Handymax	Loaded	Upstream	Ship	171.2	24.7	11.6	35000	12	0	6.0
22	Handymax	Loaded	Downstream	Ship	171.2	24.7	11.6	35000	12	0	6.0
23	Handymax	Light	Upstream	Ship	171.2	24.7	2.8	12800	0	0	6.0
24	Handymax	Light	Downstream	Ship	171.2	24.7	2.8	12800	0	0	6.0

<sup>1</sup> Weight is reported as total displacement for barge-type vessels, and DWT for ship-type vessels.

<sup>2</sup> Annual future transits.

## 9-A.4.2 Vessel Velocity

Typical vessel transit speeds are variable and are influenced by many factors, including vessel type and power, waterway type, waterway depth, navigational obstructions, traffic density, weather conditions, tidal and seasonal variations in currents, and imposed speed limits. To determine a reasonable value for vessel velocity to be used in assessing ship impact, the Project conducted interviews with local vessel operators and officials at the Port of Vancouver. Estimates of transit speed provided in these interviews suggest that 6 knots is an appropriately conservative velocity for all vessel types. This value represents “speed over ground” and therefore includes the effects of current.

In general, vessel operators cease operation during extreme weather or flood events, and therefore such events are not representative of vessel impact risk caused by mechanical malfunction or navigation errors. Rather, as required by AASHTO, collision risk and loads associated with these events are considered using the annual average of all cyclic conditions and not extreme values corresponding to floods and storms.

## 9-A.5 RIVER BATHYMETRY AND WATER DEPTH

Although extreme events such as floods and storms are not considered in assessing risks associated with vessels impacts caused by mechanical malfunction or navigation errors, such events do need to be considered for vessels that break free from their moorage and subsequently collide with the new bridge. Under such conditions water depths in the river are sufficient for a loose vessels to reach any instream pier and piers within the floodplain also need to be considered in this regard.

## 9-A.6 VESSEL IMPACT SCENARIOS

In designing for ship impact it is assumed that the maximum vessel impact is highly unlikely to occur simultaneously with another extreme event such as the flood of record or an earthquake. As such, AASHTO recommends that the following vessel impact events be considered:

- Vessel impact associated with an empty barge that has broken loose from its moorings (drifting vessel) during a storm event
- Vessel impact associated with an aberrant vessel being driven into the bridge under normal environmental and operating conditions

Given the tidal effects at the site, vessels can be moving either upstream or downstream for either of these events. In general, however, the risks associated with upstream moving vessels are not likely to govern the design of the new bridge given its close proximity to the downstream NWRB and the relatively low velocity of upstream tidal flows.

### *Drifting Vessels*

S6-14 and AASHTO require piers to be designed to resist the impact of a drifting vessel while being subjected to an extreme scour and hydraulic loading. A reasonable vessel in this regard is an unloaded displacement of approximately 1,000 tonnes.

This load case is intended to represent a flood or other extreme environmental condition in which empty barges may break loose from their moorings and be propelled into a pier by currents, wind, or waves. For the Pattullo Bridge site, the most appropriate extreme condition for this load case is the 100-year flood event. Consequently, the 100-year flood current velocities are used to establish the impact velocity.

Typical draft for an empty barge is approximately 0.6 m. Therefore, any pier outside the typical riverbanks but where the 100-year flood water level is more than 0.6 m over the surrounding grade will be designed for an impact load associated with a drifting barge, but based on reduced river current because currents will be significantly reduced in areas of shallow water in the floodplain.

The design drifting barge impact velocity is the maximum 100-year flood current velocity at any location in the river. Based on this metric, drifting impact velocity is 5.4 knots for any pier located within the riverbanks. During the 100-year flood event, piers outside the typical riverbanks but inside the floodplain may also be exposed to impact by drifting vessels. Therefore, for locations outside the riverbanks but within the floodplain, drifting impact velocity is set equal to the minimum 100-year flood current velocity at any location in the river, or 1.0 knot.

### *Aberrant Vessel under Normal Environmental Conditions*

This load case corresponds to the scenario in which a vessel is being piloted under normal operating conditions and experiences mechanical failure or an error in navigation, resulting in an impact with the new bridge at full speed. Under such conditions, vessel motion is driven under its own power, or in the case of a barge tow, the power of a tug. For this assessment, vessel displacements and impact velocities will be in accordance with the data provided in **Table 9-A-3**. A probabilistic risk assessment will be used to assess this risk.

Loads from this load case will be assumed to occur at a time when one-half of the predicted long-term scour has taken place.

### *Collision with Bridge Superstructure*

The height of the bridge deck soffit must be set to mitigate the risk of vessel collisions with the bridge superstructure. Specifically, the mast or deckhouse of a tall ship could strike the superstructure if the ship were to stray from the vertical clearance envelope provided over the main navigation channel.

With reference to the fleet inventory provided in **Table 9-A-3**, the most significant risk for superstructure collision is posed by the Handymax ship. Exact mast and deckhouse heights for such vessels are not available from the manufacturer. Recognizing that such data are often difficult to obtain, AASHTO provides design charts in which mast and deckhouse clearances are provided for various vessel types as a function of vessel deadweight tonnage (DWT). Based on this analysis the profile will provide 32 m of vertical clearance above mean high water (MHW) over the river, so as to preclude deckhouse impact from Handymax ship vessels

## **9-A.7 PIER LOCATIONS AND CONFIGURATION**

Impact load is strongly sensitive to the number and location of piers in the waterway. Impact loads near the channel increase significantly with each additional pier. Also, impact loads near the channel are much more sensitive to pier width. Regardless of bridge layout, maximum impact loads are higher for piers located near the navigation channel. Given the presence of the secondary domestic channel, maximum impact loads will be asymmetric about the main channel centreline, with higher loads on the New Westminster side.

Impact loads associated with drifting barges are independent of the width of the pier or number of piers in the river. Based on the assumptions regarding drifting impact velocity, all piers within the river will be designed for a minimum impact load. During a major flood event, the riverbanks may expand to expose additional piers to potential vessel collision.

Given that the number and location of piers will not be known until after award of the construction contract, these important parameters cannot yet be evaluated. Bounds have however been placed on pier locations as noted above under the description of the navigation channel.

## **9-A.8 SUMMARY AND RISK MITIGATION MEASURES**

The proposed new bridge will be evaluated for vessel collision risk, and corresponding design loads will be established to ensure that the annual frequency collision-induced structural collapse is less than or equal to a probability of 1% in 100 years. Design loads will be calculated in accordance with CSA-S6-14 and the AASHTO Guide Specification. Vessel impact forces are dependent on the number of in-stream piers as well as pier location and will depend on the final configuration of the bridge. To begin managing risks associated with vessel impact, pier-free zones have been established, and the number of piers in the river have been limited to not more than four.

Pier impact strength will be evaluated for the following cases:

- **Drifting Vessel:** Vessel impact loads associated with an empty barge that has broken loose from its moorings during a storm event. This load will be combined with one-half of the predicted long-term plus one-half of the predicted short-term scour.
- **Aberrant Vessel:** Vessel impact loads associated with an aberrant vessel being driven into the bridge under normal environmental and operating conditions. This is combined with one-half of the predicted long-term scour. This case will be used to evaluate the overall stability of the bridge pier subject to the maximum impact force, as well as to design the local capacity of structural elements that an impacting vessel could come into contact with, such as columns, pylons, or piles.
- **Vessel Collision with Bridge Superstructure:** Based on a future Handymax vessel being used at the site, a minimum clearance of 32 m over the river is recommended to avoid this load case.

### *Superstructure and Pier Protection*

All structural components that connect the superstructure to the substructure (bearings, shear keys, diaphragms, etc.) will be proportioned to resist the demands imposed by the pier impact and superstructure impact loads.

Maximum impact loads can be significantly reduced if piers are protected from impact directly by dolphins or similar sacrificial systems. While such systems are effective in reducing pier collision risk, construction and life-cycle costs, including potential repair or replacement, can be significant. Also, such systems pose a significant navigation hazard in addition to the bridge. Further investigation would be required to determine whether such pier protection is cost-effective or acceptable from the perspective of a vessel operation or river impact.