PORT of vancouver | Vancouver Fraser Port Authority

Guidelines

Shoreline protection (Vancouver Harbour), inspection, maintenance, design, and repair v1.1

Engineering and maintenance

June 03, 2022

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Executive summary

As of 2022 there are 29 major marine terminals operating within the jurisdictional area of the Vancouver Fraser Port Authority, as well as many smaller operations. Many of these sites are within the inner Vancouver Harbour (VH) area and are protected by coastal structures of various designs and age.

It is not uncommon for older portions of the shoreline to be protected with an ad-hoc mixture of construction debris. Inspections of the existing shorelines have found a wide variance in the quality of the shoreline protection, with older portions showing evidence of damage or deterioration.

In most cases, the port authority is the direct owner of many of these structures; however, depending upon the terms of the specific lease for individual terminals, the property tenant may be responsible for the maintenance, the repair or the decommissioning of the existing shoreline protection.

This document is intended for use by port authority staff and tenants, and as a default reference for design professionals providing shoreline related services to the port authority or their tenants for the specific purpose of inspecting, maintaining, and designing repairs or replacement of these port authority assets.

The document is not intended to supersede or replace the judgement of the design engineer or professionals or to supersede related standards of practice. The responsibility for shoreline design always remains with the design engineer of record for any project.

The document is intended to provide practical guidance and standards of practice for the following routine activities:

(A) Inspection of existing shoreline assets
(B) Evaluation and development of maintenance, repair, or replacement activities
(C) Definition of design criteria for repair or replacement projects
(D) General or best practice design guidance
(E) Incorporation of general environmental best practices
(F) Guidance for planning of implementation (construction) activities

It is generally recognized that as the result of ongoing climate change, both global and local sea levels will rise over time. There is still considerable uncertainty regarding the rate of both global and local sea levels in the foreseeable future; however, it is generally acknowledged that the uncertainty is most important over durations of several decades or more. Sea level rise has important implications for port authority facilities. Guidance on the selection of appropriate rates of sea level rise and how to consider this process in ongoing operations is provided.

Definitions and glossary

Acronym or symbol	Term	Definition
AEP	Annual Exceedance Probability	The probability of a specific event occurring (or being exceeded) in any given year.
	Armour Stone	Individual rock pieces used in riprap or rock armour slope protection works.

Acronym or symbol	Term	Definition
CD	Chart datum	Approximately equal to the lowest astronomical tide level. In Vancouver Harbour, CD is 3.045 m below CVD28GVRD.
CGVD28	Canadian Geodetic Vertical Datum, 1928	Approximately equal to MSL at the shoreline prior to 2017.
CGVD28GVRD		The specific implementation of CGVD28 in the Metro Vancouver area.
Dn50	Median nominal diameter	The median nominal diameter of rock material. Fifty percent of a sample of material is greater than D50 and 50% is smaller. The percentage is generally referring to the mass of material in the sample.
DS	Designated storm	A storm, which includes concurrent time series of winds, storm surge and waves, with a specific designated AEP.
DWL	Design water level	The design basis water surface elevation, which includes appropriate allowances for SLR, land crustal movement, tide, storm surge and potentially other local effects, including local wind setup.
	Encounter probability	The probability of a specific event with a defined AEP occurring (or being exceeded) in a defined number of years.
	Fetch	The open water area over which the wind can generate waves. The fetch length is typically the longest distance from the upwind shoreline to a defined point.
	Freeboard	The vertical distance between a still water level, usually the DWL and the crest of the shoreline protection system.
	Freeboard allowance	An allowance usually added to the calculated crest elevation of the shoreline protection system to account for uncertainties in the estimate of DWL or wave effects.
HHWLT	Higher high water large tide	Average of the annual highest high tides over the 19-year tidal cycle.
HHWMT	Higher high water mean tide	Average of all the daily higher high tides from 19 years of predictions.

Acronym or symbol	Term	Definition
LLWLT	Lower low water large tide	Average of the annual lowest low tides over the 19-year tide cycle.
LLWMT	Lower low water mean tide	Average of all the daily lower low tides over the 19-year tide cycle.
MRZ	Marine riparian zone	The zonal interface between the land and the ocean. Marine riparian vegetation often grows in the MRZ and has several important ecological roles (e.g., filtering pollutants, providing nutrients and absorbing or damping wave and surface water energy).
MSL	Mean sea level	The average height of the surface of the sea, for all stages of tide, over a 19-year period. Approximately equal to CGVD28.
	Overtopping	The passage of water over the top of a coastal structure as a result of wave runup and related surge and local setup. The water may pass as a flow of water or as spray. The characteristics of overtopping are site, structure, and wave specific.
	Riprap	Slope protection system consisting of a wide gradation of rock material placed in bulk. Riprap tends to have smaller voids due to the wide gradation and can result in higher wave run-up.
	Rock armour	Shoreline protection system consisting of armour stones with a narrower gradation than riprap, individually placed, commonly with two or three layers. Generally placed overtop of under layer materials, which provide both energy dissipation service and filter action for fill or in-situ materials.
$R_{2\%}$		The wave run-up exceeded by 2% of waves in a given sea state.
	Sea state	The condition of the sea surface over a short period of time (approximately 20 minutes to one hour) and characterized by summary wave height, wave period and wave direction parameters.
SLR	Sea level rise	The rise in sea level including: global sea level rise driven by global warming, local effects including tectonic or isostatic (glacial) subsidence or uplift, and local oceanographic effects.

Acronym or symbol	**Term**	**Definition**
H_S	Significant wave height	The mean wave height of the highest 1/3 of waves in a given sea state.
	“Soft” shoreline protection	“Soft” shoreline protection systems include, in general terms: beach nourishment, restoration or construction, dune and wetland construction, shore vegetation preservation or restoration, and construction of nearshore reefs and berms and similar, generally rocky features as part of the system.
	Still water level	The water level that exists in the absence of waves or wind action.
	Storm surge	The non-tidal rise/fall in a body of water mainly due to atmospheric effects.
°T	Degrees, true north	Direction in degrees, with respect to true north.
Tp	Peak wave period	The inverse of the frequency at which a wave energy spectrum reaches its maximum.
VFPA	Vancouver Fraser Port Authority	The Vancouver Fraser Port Authority is responsible for the stewardship of federal port lands at VFPA of Vancouver.
VH	Vancouver Harbour	Defined as that part of the VFPA’s jurisdiction between First Narrows (Lions Gate Bridge) to the west and Second Narrows (Iron Workers Memorial Bridge) to the east.
	Wave effects	A general term including all aspects of wave interaction with a coastal structure including: wave set-up, wave run-up and overtopping.
	Wave run-up	The vertical height reached by waves on a coastal structure. Measured from the concurrent still water level.
	Wave set-up	Super elevation of the water surface in the wave breaking zone due to the onshore mass transport of water by wave action alone. Wave set-up is often implicitly included in wave run-up calculation algorithms.

1. Introduction

1.1. Basis of document

As of 2022 there are 29 marine terminals operating within the jurisdictional area of the Vancouver Fraser Port Authority, as well as many smaller operations. Many of these sites are within the inner Vancouver Harbour area and are protected by coastal structures of various designs and age, and in many cases, the shoreline protection is a rock armour type of structure. Historically, the shoreline in Vancouver Harbour was constructed using fill material of various types, placed seaward of the early natural shoreline. It is not uncommon for older portions of the existing shoreline to be protected with an ad-hoc mixture of construction debris.

Inspections of Vancouver Harbour shorelines have found a wide variance in the quality of the shoreline protection, with older portions showing evidence of damage.

In most cases, the port authority is the direct owner of many of these structures, however, depending upon the terms of the specific lease for individual terminals, the property tenant may be responsible for the maintenance, repair, or decommissioning of the existing shoreline protection. This document is intended to serve as a guideline to inform the inspection, maintenance, or design and repair of shorelines in the Vancouver Harbour Vancouver Harbour portion of the port authority.

There have been many advances in the understanding of the use of rock for shoreline protection in the marine environment over the past 30 years. There is also an increasing awareness of the interaction between the character of the shoreline and the marine environment. The port authority has a strong preference for shoreline protection systems that reflect good shoreline practice and include or consider environmental improvements.

It is also generally recognized that as the result of global climate change, global and local sea levels, and related storm characteristics are going to increase or intensify and the shorelines of the port authority will need to accommodate or adapt to these ongoing processes.

This document is intended for use by port authority staff and tenants, and as a default reference for design professionals providing shoreline related services to the port authority or their tenants. This document is not intended to supersede or replace the judgement of the design engineer or professionals, or to supersede related standards of practice. The responsibility for shoreline design always remains with the design engineer of record for any project.

The port authority encourages alternate and innovative or creative design. Where these designs differ from the guideline principles in this document, designers should clearly explain why the alternates can achieve the same ultimate goals of providing functional, robust and appropriate shoreline protection.

1.2. Purpose and limitations of document

Numerous criteria and issues must be considered in the evaluation and design of shoreline protection; however, variations in exposure, local environment, maintenance practices, and upland usage can materially affect individual sites. The anticipated service life of an existing shoreline protection system will also influence the evaluation and design process. This document presents basic principles for the inspection, maintenance, and design and repair of shoreline protection structures. It is intended for use when considering:

(A) Repair of locally damaged shorelines
(B) Replacement of existing shoreline structures that have reached their end of life or are no longer fit for purpose

(C) Upgrades to shorelines when the adjacent upland area is undergoing change or where new construction is planned
(D) General reinstatement of shorelines to "make good" a shoreline at the end of a lease agreement
(E) New construction of shoreline protection

This document does not apply to shoreline protection for sites outside of the Vancouver Harbour portion of the port authority, for instance, along the Fraser River or at small creek outlets, where river hydraulic conditions may apply. It does not apply to areas of the port authority directly exposed to the environment of the Strait of Georgia.

2. Background

2.1. Overview

For the purpose of this document, Vancouver Harbour is defined as that part of the port authority jurisdiction between First Narrows (Lions Gate Bridge) to the west and Second Narrows (Iron Workers Memorial Bridge) to the east, Figure 1.

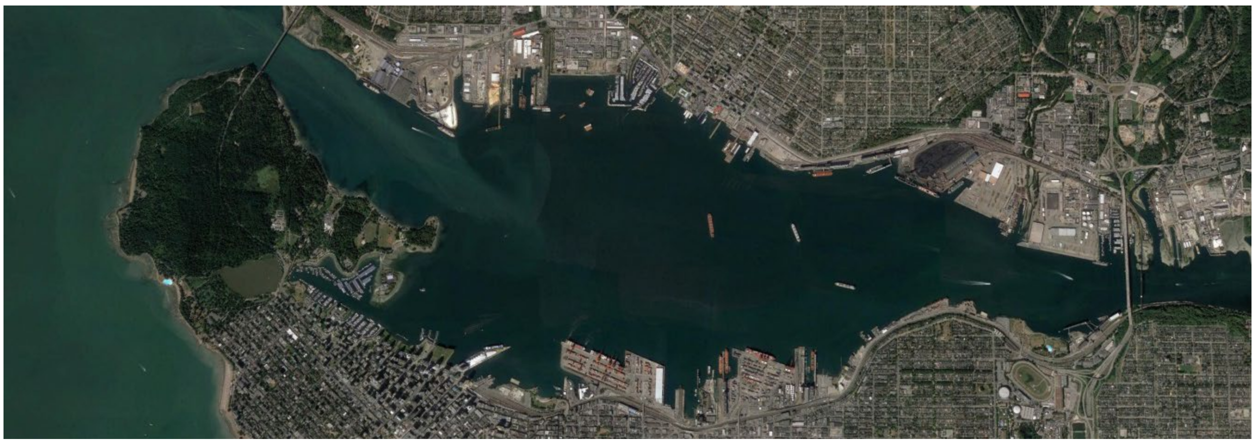

Figure 1: Aerial photo of Vancouver Harbour (Ref: Google Earth, 2017)

Responsibility for the entire shoreline rests with various agencies including the port authority, the City of Vancouver, the District of North Vancouver, the City of North Vancouver, First Nations, and the Department of National Defense.

There is almost no natural shoreline in Vancouver Harbour due to the historical infilling that occurred. For example, the entire south shore from Coal Harbour to New Brighton Park has been infilled from its original waterline (late 1800's) to the present configuration, as shown in Figure 2.

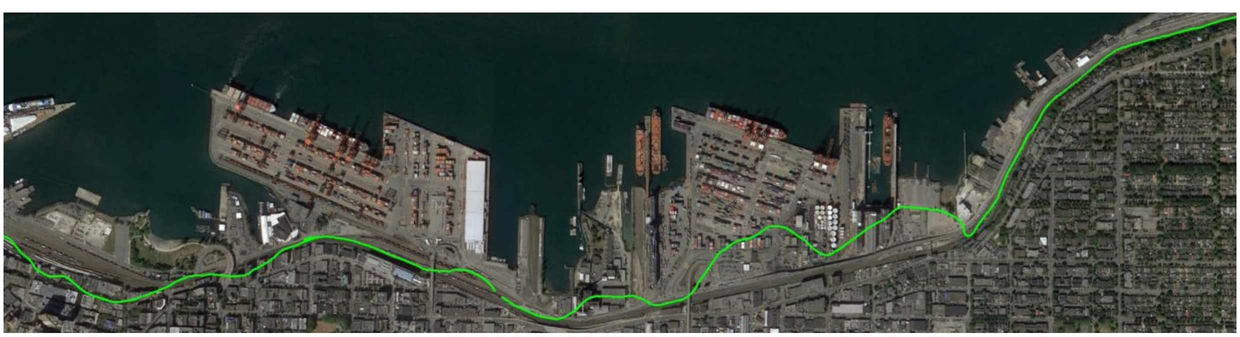

Figure 2: Approximate location (green line) of the shoreline in the 1800s (Ref: Goad's Fire Insurance Maps)

In general, most of the port authority shoreline, especially along the south shore of Vancouver Harbour, is constructed from fill of varying quality and is protected with shoreline systems that vary from newly built systems, in good condition, to old shoreline protection systems, which may include construction refuse (especially concrete or asphalt slabs) as protection. In many cases the shoreline in-filling has resulted in steep shorelines that tend to have a deeper intersection with the natural seabed than occurs where the natural historical shoreline remains more or less in place.

2.2. Shoreline reference systems

Not all the existing port authority shoreline assets have as-built construction or record drawings for the land reclamation and shore protection systems. Where drawings exist, the coordinate systems and reference datum are not always consistent. The port authority is updating their geo-referenced information using a GIS based system for their shoreline assets throughout the harbour area. As part of this work the port authority has designated specific shoreline protection systems or features with unique asset numbers.

The port authority uses a local chainage system for each asset to identify locations and points of interest. The chainage system for shoreline assets in Vancouver Harbour at the time of publication of this document is provided in Appendix A.

Distances are measured along the shoreline using the asset chainage. Offset is measured perpendicular from the chainage baseline. Design and repair documents should use the asset numbers and chainage system.

Horizontal coordinates should be in UTM zone 10, NAD83. Vertical coordinates may reference either chart datum or the geodetic datum (see Section 4.3.2.).

The horizontal and vertical datum must be clearly indicated on all documents and drawings.

Designers should consult the latest Vancouver Fraser Port Authority Record Drawing Standards, Vancouver Fraser Port Authority Linear Referencing Standards, and Vancouver Fraser Port Authority Vertical Datum Guidelines for the latest standards.

3. General inspection and maintenance

Nearly all shoreline protection systems require ongoing inspection and maintenance to ensure they continue to provide the service that was intended at the time of design and initial construction. During the service life of any system, it is always possible to experience a combination of events that equal or exceed the original design criteria and therefore some damage is likely to be experienced. Older existing systems may reflect an accumulation of damage resulting from occasional exceedance of the original criteria.

In any port, the shoreline protection structures are also going to become exposed to changes in related activities, including the deployment of larger or more powerful vessels, or changes in the onshore components of the port activity. These expected changes can result in consequences to the shoreline protection system that also could not be anticipated at the time of design.

The ongoing effects of climate change, including changes in temperature, precipitation, storm characteristics, and sea levels will also create situations, which may have consequences that also could not be anticipated at the time of design. Periodic inspections and necessary maintenance are the only way to ensure that the service requirements and expectations of the system are sustained over the life of the system.

Maintenance of rock armour shoreline protection systems generally requires either ongoing repairs to avoid cumulative damage related deterioration, or replacement, depending upon circumstances. Moderate damage may be acceptable in some locations while in other locations, where the slope protection function may be critical, damage should not be left for a less severe but probable event. The assessment of acceptable and allowable damage is often related to upland usage. For instance, a parking area may be able to tolerate a high level of accumulated damage but an occupied building, adjacent to the slope, or to the storage of high value cargo adjacent to the slope, may create a need and a justification for immediate repair or restoration of the area.

It should be noted that most design methods assume a small but allowable amount of damage to a properly designed and built system in the design event. Successive but less severe storms can then lead to cumulative damage effects that make subsequent storm damage more likely to be more severe.

It is recommended that periodic systematic inspections are undertaken, and that observed damage is put into the context of the rate at which it is occurring and the required life of the shoreline protection system. Any damage that is new, from one inspection to another, is worthy of additional follow-up to determine causes leading to the damage.

3.1. General inspection recommendations

Inspections of shoreline assets should be undertaken:

(A) At a minimum, every five years
(B) After notable storms, especially storms that have resulted in flooding of terminal land areas
(C) After storms resulting in port closure
(D) After storms associated with posted storm warnings by Environment Canada
(E) After storms concurrent with high winter spring tides

3.2. General repair recommendations

Several points to consider for emergency repairs:

(A) Angular rocks can tolerate relatively steep slopes, and temporary stability at a steepness of 1.3:1 (H:V) can be achieved for a short period of time. While not desirable for a long-term repair, steep slopes can be acceptable for an emergency repair to halt erosion or prevent loss of fill material.
(B) A filter layer is critical to preventing washout of fines and in-filling of the void spaces in the armour layers. Fines in the armour layer can de-stabilize the surface armour rocks or riprap cover layers. Emergency repairs should include a filter layer if no or only limited rock material remains on the slope of the damaged area.
(C) Damage at the top of a slope may be caused by localized surface water drainage issues. If there is evidence of localized drainage concentration at the location of damage, drainage improvements or controls should be considered at the time of the emergency repair to prevent further high velocity run-off over the slope protection.
(D) Shoreline protection that abuts vertical and non-porous structures, including bulkhead walls, caissons and sheet-pile walls, should be inspected with specific attention to erosion, or displacement of armour stones at the interface between the vertical or non-porous structure and the shoreline protection system. Attention should be given to undermining or scour at the toe of the shoreline protection. Scour damage should be repaired appropriately.

3.3. Repair situations

In the event of observed localized damage to shorelines, emergency or temporary repairs are recommended to minimize future damage before any proper repairs are undertaken. The following are common examples of situations where damage or cumulative damage has been observed within Vancouver Harbour.

3.3.1. Localized crest erosion

Figure 3 shows an area with localized damage at the crest of the slope protection. Poor construction may have been a contributing factor as there is no visible filter layer material on the upper slope. Such an area is susceptible to further erosion if exposed to waves or currents at high water conditions, or during intense surface drainage events. High water level conditions will become more frequent as sea levels rise.

In the event of minor and localized erosion of the crest, emergency placement of rock material as a temporary measure to halt erosion is recommended.

Longer term solutions may include increasing the surface setback of the concrete barrier wall, improvement to surface drainage and the planting of a riparian strip to help reduce erosion during either high water level and wave events or during heavy rainfall events. Alternatively, the replacement of the upper slope materials to provide protection against wave run-up and provide a free drainage path within the rock matrix may be appropriate.

Figure 3: Minor damage of upper crest of a rock armour slope.

3.3.2. Mid-slope damage

Minor gaps or slumps in the mid-slope sections of a rock system can be repaired by placement of a small amount of armour material and the re-working of the immediate surrounding area using a small excavator with a thumb attachment.

For moderate localized damage to the armour layer, for instance where the inter-locking of the armour rocks has been compromised, an excavator with a thumb attachment can also be used to improve contact between individual armour stones to improve their stability, together with the addition of a limited amount of extra properly sized material. Individual stones should be reworked to ensure each armour rock on the surface layer has at least three points of contact to adjacent rocks.

3.3.3. Toe damage

Damage to the shoreline protection system toe can indicate various flaws, including inadequate rock sizing, poor rock placement, or undermining by scour of the seabed. If damage to the toe is noted, repairs should be conducted as soon as possible, as toe damage can have serious implications to the overall slope stability if up-slope materials rest and rely on a stable toe for support.

The type of repair will depend greatly on the extent and cause of damage. In the case of inadequate rock sizing or improper placement of toe rock, it may be sufficient to repair with large armour stones, which are well-keyed into the surrounding rock. In the case of scour, the repair plan may include backfilling of the scour hole with suitable material to prevent reoccurrence. A self-launching apron on top of the existing toe berm may also be an alternative.

3.4. Geotechnical stability

The geotechnical and seismic stability of shoreline structures is not covered in the scope of this document; however, over-steep slopes, or heavily loaded crests (including high wheel loads close to the crest or stacked containers) may require special geotechnical consideration. As such, assets with these features should have a qualified geotechnical engineer assess the static and seismic slope stability.

3.5. Vegetation control

To facilitate inspections, it is recommended that vegetation at the crest be cut-back regularly to ensure that rock armour slopes and the crest details of the rock armour are visible. This is particularly important for creeping vine plants such as invasive blackberry that can cover these structures and prevent thorough inspections.

Environmental enhancements that include crest vegetation should be designed and maintained such that the vegetation remains on the top of the crest and does not cover the rock slope. Replacement or new designs should encourage the removal of invasive species, promote the planting of native species of vegetation suitable for marine riparian environments, and preserve established native species as much as possible, as described in Section 6.

In some cases, deliberate planting of vegetation at the top of slope may also reduce the extent or effects of upland flooding.

4. Definition of design criteria

4.1. Design service life

The design service or working life of a shoreline asset is generally defined based on the duration for which the shoreline structure must provide the intended purpose, including expected maintenance. The design service life is often closely related to the business model for the terminal on the landside of the shoreline structure.

The design life for new shoreline construction in Vancouver Harbour is generally taken to be 50 years.

The design life for repairs to existing shorelines should be at least 20 years; however, in certain circumstances, the repair design life may be linked to the remaining tenant lease duration.

4.2. Design event

The concept of a design event or storm that should be considered for design is too simplistic in many situations. The definition of appropriate design criteria, for instance: design wind speeds (and directions); design water levels; design sea state parameters (including height, period, and direction parameters); and design current speeds and directions, should be undertaken using a balanced evaluation between the inter-relationship of the various constituents, the risks of the design event occurring, the change in criteria component details that should be expected over the design service life of the shoreline feature and the functional requirements of the structure. This evaluation of factors leads to definition of Annual Exceedance Probabilities (AEP) for definition of appropriate design criteria constituents, as discussed further below.

It is generally recognized that as the result of ongoing climate change, both global and local sea levels will rise over time. There is still considerable uncertainty regarding the rate of both global and local sea level in the foreseeable future; however, it is generally acknowledged that the uncertainty is most important over durations of several decades or more. Sea level rise has important implications for port authority facilities. Guidance on the selection of appropriate rates of sea level rise is provided below.

Rising sea levels also introduce a complicating element in the choice of appropriate design criteria components because of the inherent interaction between the shoreline protection function and the consequences of overtopping on the adjacent land use related infrastructure.

At most sites, the elevation of the top of the shoreline protection system is fixed by the nature of the terminal operations and by the need to interface with supply chain elements including road grades, existing rail lines and berthing structures and related infrastructure.

As sea levels slowly rise over the life of a particular terminal operation, the shoreline protection component of the terminal will experience two important changes:

(A) Storm related processes (winds, storm surge, waves and currents, and rainfall) may change in intensity, duration, or in frequency of occurrence, as the result of climate change. In British Columbia coastal waters, the present understanding is that intensity changes are not expected to be significant and can be ignored. However, it is likely that the occurrence of “design events” (especially in the fetch limited waters of Vancouver Harbour) will become more frequent and the duration of the related storm conditions may become longer.

(B) As sea levels rise, the shoreline protection system will become exposed to storm related processes at higher and higher elevations. This has several implications:

- Depending on the depth of water at the toe of a shoreline system, wave heights may increase because the present water level depth may limit the breaking wave effects.
- If the surface grade of the upland area is not raised, which is the usual situation at an operating terminal, the top of the shoreline protection system will become more exposed to wave run-up and related effects, which may expose the crest of the shoreline structure to damage, more frequently, and for longer, than currently expected.
- An often neglected or not well understood effect is the influence of surface water runoff and interaction effects at the top of the shoreline protection. If the surface stormwater drainage design is not adequate for increasing rainwater related drainage, then surface water runoff at the top of the shoreline system may result in accumulated damage that has consequences when wave related effects occur in the same area at high water (tide and surge) levels.

Increasing frequency and magnitude of wave run-up, means that shoreline systems have several paths to potential failure that should be considered in defining the design criteria constituents:

(A) The shoreline slope armour system needs to be designed to be stable over the full range of water levels expected during the project service life

(B) The shoreline crest design needs to be stable both to the direct effects of waves at the higher water levels but also to the consequences of overtopping, flooding, and subsequent surface water run-off during more frequent though potentially less severe events

This evolving design scenario can best be managed at the design stage for repairs or maintenance by adopting a balanced risk design approach. In this approach, the objective is to ensure that the encounter probability of the design basis criteria remains constant over the expected remaining service life of the project.

An example of this balanced risk approach is illustrated for several scenarios in Table 1. The scenarios correspond to the following:

(A) The acceptable encounter probability over a finite service life is taken to be 39%, based on the common practice of choosing a 1/100 AEP for a 50 year service life in the Port of Vancouver.
(B) The acceptable risk of encountering the “design event” over the remaining life remains constant. The effect on appropriate AEP’s is shown in Table 1.

Table 1: Relationship between encounter probability and annual exceedance probability

	Remaining service life of project				
	50	25	15	5	2
Acceptable encounter probability over life of project	39%				
AEP for project	1/100	1/50	1/30	1/10	1/4

Specific guidance on design event constituent components for selected AEPs is provided below.

4.3. Water levels

4.3.1. Depth of water

The general bathymetry of the harbour and the depth of water at a specific terminal site can be obtained from the latest edition of the Canadian Hydrographic Service (CHS) charts 3493 and 3494. At some sites, the port authority has more recent, high-resolution multi-beam survey data. The port authority’s engineering department should be contacted to determine the latest available data for any given site.

4.3.2. Vertical datum

The port authority uses Chart datum (CD) as the reference vertical datum for all structures on the water. Structures not associated with the water may use geodetic datum.

Water levels (tides) are generally measured within Vancouver Harbour at CHS station 7735 and reported relative to chart datum. Conversions between chart datum and geodetic datum are provided in Table 2.

Table 2: Datum conversions to chart datum in Vancouver Harbour

Geodetic	Conversion to chart datum (CD)	Notes
CGVD2013	2.897m above CD	Canadian Geodetic Vertical Datum of 2013, conversion for Vancouver Harbour at CHS Station 7735. CGVD2013 has not yet been fully integrated within Canada. Metro Vancouver is generally still using CVD28GVRD.
CVD28GVRD	3.045 m above CD	Canadian Vertical Datum of 1928 for the Greater Vancouver Regional District. Conversion for Vancouver Harbour at CHS Station 7735.
Geodetic (MSL)	2.975 m above CD	Geodetic datum conversion adopted by the port authority in 1983 to replace the NHBD. This was likely equal to CGVD28 at the time.
National Harbours Board Datum (NHBD)	25.228 m above CD	Used by the port authority prior to 1983 and still found on some older record drawings.

The geodetic (MSL) datum conversion of 2.975m above CD is still in use by the port authority in 2017; however, the appropriate datum should be confirmed using the most recent version of the Vancouver Fraser Port Authority Vertical Datum Guidelines.

It should be noted that the 1928 and the 2013 vertical datum do not have the same theoretical basis and are not coincident. Care should be taken to ensure accurate references to the datum are recorded on all design documents and drawings.

For sites with no recent (older than 20 years) site survey information, new site surveys with modern survey equipment, tied into current survey monuments, should be used to establish vertical control on site.

4.3.3. Mean sea level and sea level rise

The geodetic and CVD28GVRD vertical datum are essentially referenced to a historical long-term mean sea level. The relative elevation of local mean sea level has been slowly changing in the past and the rate is expected to slowly further increase over the short-term (20 to 25 years). The longer term rise in local sea level will likely increase at faster rates; however, there is still considerable uncertainty regarding the rate of both global and local sea level in the foreseeable future. SLR and the elevation of future mean sea level and elevations of tidal levels are very important considerations with respect to potential overtopping and upland flooding at any terminal site.

Current BC Provincial Guidelines, Ref [1], recommends that shoreline planning should consider 1 m of global average SLR by the year 2100 (above year 2000 water levels). Ref [1] also advises that predictions of future sea level rise should be updated at 10-year intervals or when significant scientific information becomes available.

Local sea level rise will also depend on local crustal movement, which may be different depending on location within Vancouver Harbour. Current guidance on measured crustal movements is provided in Ref [4].

It is also important to note that chart datum is a datum plane that is related to the lowest expected water level. Future SLR will change the relative elevation of chart datum to geodetic datum over time, and this will require careful documentation to ensure no errors are made when working with record drawing sets.

For the design of new or the repair of existing structures, the expected SLR over the remaining design life of the structure should be considered.

4.3.4. Tidal levels

Astronomical tide levels in Vancouver Harbour are defined based on long term measurements at CHS station 7735, located at the northern end of Canada Place and reported relative to chart datum. Tide ranges are officially reported in Volume 5 of the Canadian Tide and Current Tables and updated annually. The latest version of Volume 5 should always be consulted.

The current (2017) tide ranges for Vancouver Harbour are defined in Table 3.

Table 3: Astronomical tide elevations in Vancouver Harbour

Tide level	Chart datum	Geodetic datum	Comment
		Based on port authority conversion factor, Table 2	
HHWLT	5.0	2.0	
HHWMT	4.5	1.5	
MWL	3.1	0.1	CHS constituents for Vancouver Harbour show that MWL (Zo) in the latest tidal epoch analyzed equals 3.06 m with regard to CD.
LLWMT	1.2	-0.3	
LLWLT	0.1	-2.9	
Tide level definitions are available in Volume 5 of the Canadian Tide and Current Tables and in the definitions and glossary of this document.			

4.3.5. Storm surge

Definition of expected storm surges in VH are summarized in Ref [4], based on detailed analysis of residual water level measurements throughout southern British Columbia waters and from CHS Station 7735 within the harbour.

Table 4: Summary of storm surge expected in Vancouver Harbour

AEP (per cent chance of being equaled or exceeded in any year)	AEP (1/average recurrence interval in years)	Vancouver Harbour
50%	Annual expected	0.73
20%	1/5	0.83
10%	1/10	0.9
4%	1/25	1.10
2%	1/50	1.1
1%	1/100	1.2
0.2%	1/500	1.3
0.1%	1/1000	1.4

4.3.6. Total water level for designing purposes

The total water level to consider for the design of shoreline protection is a detailed consideration that should consider all aspects of the shoreline protection system and the implications to the terminal at a given site.

As an example, the stability of the shoreline protection system should consider design criteria constituents (tide level, storm surge, sea level rise, and concurrent winds or waves) that are consistent with the recommendations in Section 4.2, and in Table 1. In this case (shoreline protection stability) the most important parameter to consider is the state of tide to be considered as coincident with the time of arrival of either the expected storm surge or the maximum waves. Waves at low tide may govern the design of toe stability of the shoreline protection system. Waves at high tide, concurrent with some storm surge, will likely govern the stability of the crest of the shoreline protection system.

The stability of the crest of the shoreline protection system, and the expectation of flooding on the upland areas will be very sensitive to the AEP combinations for the individual constituents of the design criteria. A range of both high and low probability event combinations should be checked. Reasonable combinations that might be considered include:

(A) HHWLT + Annual Expected Storm Surge + Annual Expected peak wind generated waves
(B) Modal winter tide level + AEP Storm Surge + AEP Expected peak wind generated waves
(C) HHWMT + Annual Expected Storm Surge + AEP peak wind generated waves.

These suggested combinations should be taken as default combinations that should be checked for the implications to top of slope and related (flooding) issues. In high value or critical (potential loss of life) situations, the guidelines in Ref [1] should be consulted.

4.4. Wind climate

The wind climate in Vancouver Harbour reflects the combination of synoptic scale wind forcing over southern British Columbia and the orographic features of the harbour area. There are no long-term measurements of the winds over the open waters of Vancouver Harbour and the state of practise in the harbour area is to estimate the wind climate based on extrapolations and modifications of wind data from adjacent areas.

Recorded and archived wind records can be obtained from the following stations:

(A) Vancouver International Airport

- Environment Canada Station No.: 1108447
- Latitude/Longitude: 49°11'42"N / 123°10'55"W
- Data Period: 1953-01-01 to 2013-06-13

(B) Vancouver International Airport

- Environment Canada Station No.: 1108395
- Latitude/Longitude: 49°11'41"N / 123°11'02"W
- Data Period: 2013-06-11 to Present

(C) Vancouver Harbour

- Environment Canada Station No.: 1108446
- Latitude/Longitude: 49°17'43.27"N / 123°07'18.73"
- Data Period: 1976-01-20 to 1988-03-31

(D) Point Atkinson

- Environment Canada Station No.: 1106200
- Latitude/Longitude: 49°19'49.30"N / 123°15'53.00"
- Data Period: 1996-05-01 to Present

The Vancouver International Airport (YVR) Stations 1108447 and 1108395 are 150 m apart and are assumed to measure the same wind (speed and direction). This assumption results in a total record of approximately 62 years of wind data at the Vancouver Airport location. This station, subject to the modifications outlined below, can be used as the basis for definition of winds in Vancouver Harbour until such time that overwater winds become available in the harbour area itself.

The Vancouver Harbour station 1108446 anemometer was decommissioned in 1988 and the archived record is too short to reliably define the wind climate throughout the harbour area.

There are several other meteorological stations operated in the Vancouver Harbour area by provincial or municipal agencies. The West Vancouver AUT station is located on the side of Cypress Mountain. The wind speeds and directions do not appear to be representative of over-water winds in Vancouver Harbour. Metro Vancouver also operates meteorological and air quality monitoring stations in the region. One of these stations is located east of Second Narrows Bridge in North Vancouver. Care is needed to interpret wind directions and velocities from this station due to the structural turbulence that has been observed to distort wind direction and velocity at this location.

The winds in the Vancouver Harbour area are very strongly influenced by the interaction of winds flowing into and out of the Fraser Valley and the related convergence effects with winds present in the Strait of Georgia. It is generally recognized that during E through SE and SW directions, the winds in the harbour are both more easterly than measured at Vancouver Airport and typically less than the winds measured at YVR. Unmodified Vancouver Airport based wind data will result in estimates of overwater winds in the harbour that are too high.

The Point Atkinson station typically predicts higher wind speeds than both the YVR and the Vancouver Harbour stations, regardless of wind direction. The Point Atkinson winds also tend to be funnelled east/west due to localized topographic effects at the lighthouse location.

4.5. Wind speeds

A direct comparison of winds measured simultaneously at the Vancouver Harbour (Station 1108446) and the two YVR stations, over the duration of the available matching records, shows that on average, wind speeds at the Vancouver Harbour station are approximately 0.93 * YVR wind speeds. This wind scaling factor is valid for both westerly and easterly winds above 10 knots.

A peak over threshold extreme value analysis, using factored (0.93) YVR winds on a directional basis found that 1/100 (1%) AEP overwater wind speeds were 23.0m/s for westerly winds, and 19.6m/s for easterly winds.

Average annual AEP overwater wind speeds were 16.2m/s for westerly winds, and 13.0m/s for easterly winds.

It is important to note that the “hourly” wind data provided by Environment Canada (EC) is not a true hourly averaged wind speed. Hourly wind data from EC stations are typically a two-minute averaged velocity taken on each hour. Coastal engineering practice has found that the EC “hourly” winds do provide reasonable estimates of wind forcing over open water; however, they likely do not capture shorter duration wind speeds (for instance 20- or 30-min wind speed averages), which can be both higher and over short fetch lengths, may govern.

It should also be noted that the 0.93 scaling factor described above, may not fully reflect overwater acceleration of the harbour winds, especially during westerly wind events, when the Vancouver Harbour station was partially sheltered by the effects of Stanley Park.

While a true hourly averaged wind velocity will typically be a lower value than a two-minute average wind velocity, the EC hourly wind record is presently recommended for estimating design wave conditions in Vancouver Harbour.

4.6. Wave climate

The sea state in Vancouver Harbour is typically a combination of wind-generated waves and various vessel wakes. For the purpose of sizing shoreline protection around the perimeter of Vancouver Hrabour, both sources should be considered.

4.6.1. Wind waves

Design level wind waves within Vancouver Harbour are typically generated from either moderate to strong easterly or westerly winds blowing along the harbour axis. The maximum height of wind waves is limited by the extent of open water fetch across the harbour. The longest fetch in Vancouver Harbour is approximately 7 km, from First Narrows west to Columbia Containers, for westerly winds.

There are several industry standard methodologies, i.e., the Rock Manual (Ref 9, Chapter 4, Section 4.2) for estimating wind wave heights for fetch limited conditions. Wave heights should be calculated at specific terminal locations for the relevant fetch lengths, wind speeds, and exposure directions. Table 5 provides significant wave height values for the longest fetch within the harbour for westerly and easterly winds.

Table 5: Seastate for longest fetches in Vancouver Harbour

Wind direction	Wind speed (WS)	Fetch	Significant wave height (H_s)	Peak wave period (T_p)	Usage
Westerly	16.2 m/s (annual AEP)	~8 km	0.8 m	2.8 s	See Section 4.2
	23.0 m/s (AEP 1/100)		1.2 m	3.2 s	
Easterly	13.0 m/s (annual AEP)	~6 km	0.5 m	2.4 s	
			0.8 m	2.8 s	

At terminal sites exposed primarily to winds from the south or north, the maximum fetch in Vancouver Harbour is less than 3 km and the design wave heights will likely be smaller than those in Table 5.

Wave heights are typically denoted as HP% where subscript provides information on the number of waves which both form the basis for the estimate and provides insight on the number of waves that exceed that height. For example:

- Hm = mean wave height (also known as H1/2)
- H1/3 = average of the highest 1/3 of wave heights (also known as Hs or significant wave height)
- H1/10 = average of the highest 1/10 of wave heights in the sea state
- H2% = wave height exceeded by 2% of wave heights in the sea state

Some formulae for determining rock armour sizing use $H_{2\%}$. The ratio between $H_{2\%}$ and Hs can be taken as ~1.4 for deepwater conditions, Ref [9]. Deepwater conditions are defined as those when the depth of water is greater than one half of the deepwater wavelength and is a depth where the seabed does not interact with the wave.

Waves from English Bay may propagate into Vancouver Harbour through First Narrows on a flood tide, but there is no evidence of long period swell from the Strait of Georgia propagating into the harbour and affecting shorelines. Ebb tides are observed to restrict the propagation of wave energy into the harbour. Assessment of wave heights on the west side of Vancouver Wharves facility (near to the Lions Gate Bridge) should by undertaken by a qualified coastal engineer as this area is subject to complex wave and current interactions, in addition to passing vessel wakes.

Many shorelines within Vancouver Harbour are sheltered either partially or fully, from direct exposure to wind generated waves by adjacent marine structures. While sheltering can reduce the incident wave heights and thus the required size for shoreline rock armour, it is noted that vessel operations such as passing tugboat wakes and propeller induced scour must also be considered in some sheltered areas. These effects may govern.

4.6.2. Vessel induced waves

Vancouver Harbour shorelines are exposed to the wake of harbour vessel traffic. Vessel induced waves of concern for shoreline designs in the harbour are commonly based on three types of typical vessels operating in harbour:

(A) Aframax size tankers

(B) Cape size bulk carrier
(C) Large tugs

Vessel particulars and the estimated design waves are listed in Table 6.

At some locations in the harbour vessel induced waves from the Seabus might be a governing factor due to the relative persistence of this wake effect.

The estimated maximum wave height from a harbour vessel wake is generally less than expected during a design storm, but they are expected on a more regular occurrence. The sailing offset line (the distance between the vessel's track and the shoreline) and its relative orientation, also has an important effect and the values in Table 6 should be checked by a qualified professional engineer if vessel wake is a particular concern at a given site.

Table 6: Vessel particulars and related waves

	Large tanker or bulk carrier	Large tug
Length overall (m)	250 m to 303 m	30 m
Beam (m)	44 m	13 m
Draft (m)	15 m	5.4 m
Cruising speed (kts)	8 kts	12 kts
Sailing line offset from shoreline (m)	450 m	200 m
Maximum wave height	0.2 m	0.8 m
Wave period (s)	3.2 s	3.2 s

4.6.3. Vessel induced currents (propeller wash)

Any shoreline adjacent to vessel operations may experience higher seabed velocities than occur naturally, due to tidal effects. High velocity flows from propeller wash can damage shoreline protection systems. This is particularly the case where tugboats operate in close proximity or where the system may be exposed to bow thruster or main propulsion wash from larger vessels during berthing or departure manoeuvres.

Design of shoreline protection for propeller wash should be undertaken by a qualified professional engineer with coastal engineering experience.

4.7. Tidal currents

In most situations tidal currents are generally weak (less than 2 knots) within Vancouver Harbour with exceptions being the areas close to First and Second Narrows where the constriction accelerates the tidal flows. Current velocities in First Narrows channel can reach 6 knots during spring tides. East of Brockton Point the tidal stream fans out and decelerates. Large back eddies and gyres are present within the harbour, as can be observed between Brockton Point and Canada Place Pier on a flood tide (Ref [12]).

Figure 4 indicates approximately which areas within the harbour are potentially exposed to fast tidal currents (ignoring any propeller wash induced currents). In areas with slow currents (green), it is expected that tidal currents will not be a governing factor in design; however, depending upon the shoreline shape and orientation, local areas of higher tidal currents may exist.

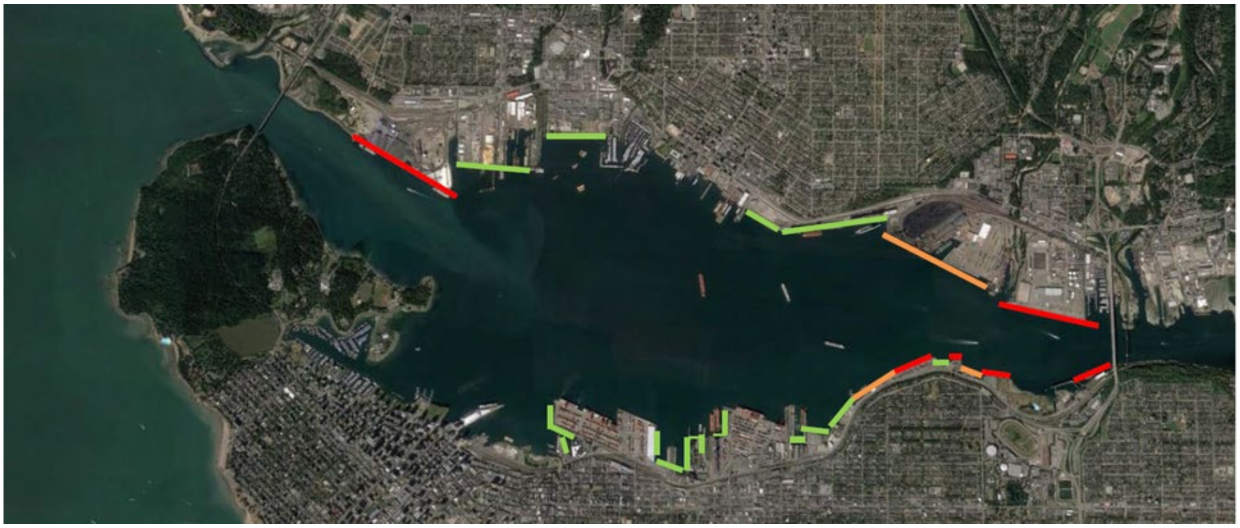

Figure 4: Tidal current zones for planning
(red = fast, orange = moderate, green = slow)

5. Design

The design of rock armour shoreline protection needs to properly account for site-specific conditions, as discussed in Section 4, and should follow established design principles as described in this section.

All shoreline protection works must be designed by a professional engineer with coastal engineering experience. This document is not intended to replace the judgment of the design engineer, and the responsibility for proper shoreline design always remains with the design engineer for the project.

5.1. General design recommendations

For shoreline protection within Vancouver Harbour for the port authority, the following considerations are recommended:

(A) Rock armour should be sized to be statically stable. There should be little to no damage to the armour layer under design conditions
(B) Crest elevations should be set such that no overtopping, or only marginal overtopping, at the shoreline, occurs under the total water level scenarios described in Section 4.3.6. An appropriate allowance for SLR during the remaining service life of the shoreline should be included.
(C) Shoreline rock armour slopes should never be steeper than 1.5:1 (H:V). Generally, slopes with a 2:1 slope or greater are preferred for increased long-term stability and reduced wave run-up.
(D) A suitable layer of filter rock should always be used with both riprap and rock armour protection to prevent loss of fines from the slope material under combined wave and current loads
(E) Due to the nature of some of the fill materials historically used in Vancouver Harbour, a geotextile is recommended below the filter layer to protect against loss of fines. If placement below water is necessary, the engineer could consider adding a second, smaller grain-sized filter layer instead of a geotextile.

(F) When the toe of the slope terminates in material that is susceptible to scour or erosion, the design should include a surplus of material at the toe to accommodate any scour holes that may develop and to maintain the integrity of the slope protection
(G) A freeboard allowance should be included in situations where the upland use of the site has high value. Alternatively, an actively managed setback policy could be considered.

5.2. Rock sizing

Detailed guidance on the design of rock shoreline protection systems is provided in the following references, standards or guideline documents: Ref [9], [16], [7], or [8].

As general guidance and in most deep water, or high water, situations in Vancouver Harbour, the deep water Van der Meer formulae, which are referenced in the above guidance, are generally applicable.

It is important to note that the Van der Meer equation assumes a relatively narrow gradation of rock armour. It is recommended that if a wide gradation riprap is going to be used instead of a narrow gradation material, the median armour stone mass from the Van der Meer formulae should be increased by 30% and the layer thickness should be increased by 50%.

Table 7 provides recommended parameter values for the Van der Meer formulae to provide a reasonably conservative rock size for a statically stable slope experiencing no damage in Vancouver Harbour.

Table 7: Recommended parameters for rock armour design in Vancouver Harbour

Parameter	Symbol	Value
Number of waves	N	3000
Notional permeability parameter	P	0.1
Damage parameter	D	2
Example: For a site with exposure to a long fetch, with sea state of H_s = 1.2 m and T_p = 3.2 s, a water depth of 7 m, and a slope of 1.5:1 (H:V), the Van der Meer deep water equation estimates a median rock weight of 331 kg.		

Structures that are built with wide gradations (riprap) tend to experience large local variations in the size of the individual armour stones over the surface, which both increases the probability of localized damage and tends to result in a greater spatial distribution of damage over the surface (so-called “hot spots”).

When riprap is considered for use, riprap that meets the BC Ministry of Transportation and Infrastructure Guidelines classes, as summarized in Table 8, is recommended. Local quarries are typically readily able to provide material conforming to this specification.

Table 8: BC MOTI Highway Guidelines Riprap Classes Source: Ref [6]

CLASS OF RIPRAP (kg)	*NOMINAL THICKNESS OF RIPRAP (mm)	ROCK GRADATION PERCENTAGE SMALLER THAN GIVEN ROCK MASS (kg)		
		15%	50%	85%
10	350	1	10	30
25	450	2.5	25	75
50	550	5	50	150
100	700	10	100	300
250	1000	25	250	750
500	1200	50	500	1500
1000	1500	100	1000	3000
2000	2000	200	2000	6000
4000	2500	400	4000	12000

5.3. Recommended rock sizes for Vancouver Harbour

Based on the considerations outlined above, five (5) categories of shoreline exposure –considering exposure to wind waves, vessel wake, and tidal currents and creek flow – were developed for the shoreline of the Vancouver Harbour port authority assets. These categories are summarized in Table 9, and are assigned to specific port authority assets listed in Appendix 1.

Table 9: Shoreline exposure to waves and currents

Type	Description
E1	Exposed to both wind waves (long fetch) and vessel wakes
E2	Exposed to vessel wake – area of higher speed boat traffic
E3	Exposed to wind waves only of medium fetch – no vessel traffic nearby
E4	Exposed to river/creek currents – generally sheltered from waves
E5	Sheltered shoreline – low speed boat traffic

Based on the design criteria and approach methodologies summarized above, recommended minimum median rock weight for armour rock and filter rock are provided in Table 10 for the shoreline types in Table 9. These sizes are intended as default guidelines and do not replace the judgment of the design engineer in any specific application.

If riprap gradations are used, they should be increased as recommended in Section 5.2.

If the shoreline is in an area of strong tidal currents (Figure 4), it is also recommended that the median armour mass should be increased by 30% to aid stability of the material.

A well sheltered shoreline can be damaged from exposure to high velocity propeller wash, and these situations should be specifically assessed. Focused propeller wash from powerful tugboats, main propulsion units of cargo vessels, or bow thrusters can produce high velocity currents on the seabed and slopes leading to scour and slope damage of undersized or weak slope protections. In some situations, large tugs or bow-thruster equipped ocean-going vessels propulsion related wash may govern rock stability.

Shorelines exposed to propeller wash from nearby vessel operations should have a qualified professional engineer with coastal engineering experience confirm the suitability of the rock sizes to resistance from scour and damage.

Table 10: Recommended rock armour sizes for different shoreline exposures
Narrow gradation only

Type	Recommended rock armour design (1.5:1 slope)			
	Median mass (kg)	Layer thickness (m)	Filter rock median mass (kg)	Filter rock layer thickness (m)
E1	330	0.9	30 – 40	0.4
E2	150	0.7	15 - 25	0.3
E3	150	0.7	15 – 25	0.3
E4	River conditions not covered in this document			
E5	100	0.6	5 – 15	0.3
The median weights must be adjusted if riprap will be used.				

Rock materials should be angular quarried stone of a dense, hard, and durable character. This requirement allows for better interlocking and friction between rocks, and ultimately a more stable slope. Median sizes for sub-angular or rounded rock will need to be increased.

The aspect ratio, l/d (ratio between the maximum dimension, l, and the minimum dimension, d, of each individual rock piece should be less than 3.0. This prevents rocks from being flat and slab-like, which in turn limits breakage and sliding of individual rocks).

5.4. Toe protection

It is a recommended design practice that a shoreline protection system should include specific toe protection at the toe of the slope. Some examples of toe protection systems are provided in Figure 5. A typical standard toe is three to five stones wide with a thickness of two or three stones. If the seabed material is erodible, an underlying scour protection mat should also be included in the toe detail unless the toe of the protection system is buried.

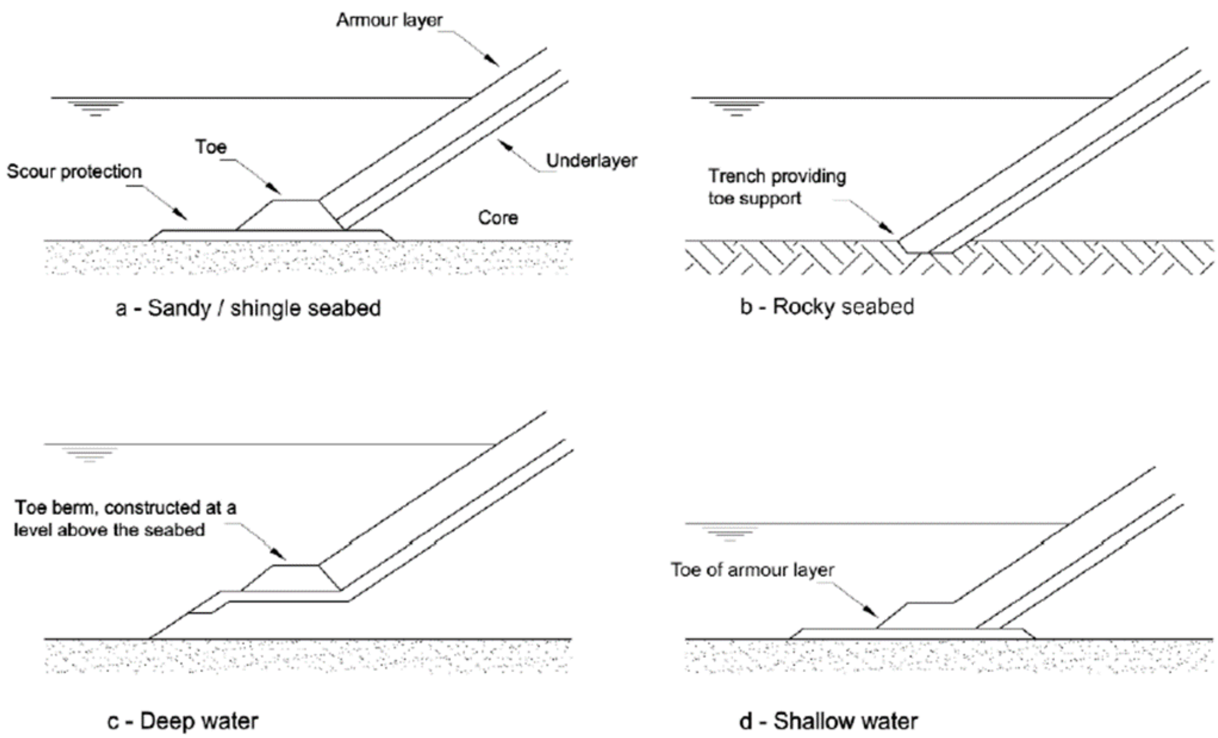

Figure 5: Toe protection examples.
Source: Ref [9]

5.5. Unusual shorelines

Shorelines that have unusual geometries, or interfaces with other structures, may require special attention during design. Examples are:

(A) Shorelines with sharp or tight radius curves. Where the rock armour must turn an abrupt corner in a convex fashion and is exposed to wave action, larger rock armour stones will be required to achieve stability.
(B) Shoreline protection that abuts vertical and non-porous structures. The additional wave reflection from these types of structures will require larger rock armour material adjacent to the structure to achieve stability.
(C) Shorelines that provide valuable riparian or marine habitat may beneficially incorporate some elements of habitat compensation. These shorelines will require special consideration by a design engineer.

6. Environmental considerations

Social, environmental, and financial sustainability are core values of the Vancouver Fraser Port Authority. The port authority prefers shoreline protection systems that include or consider environmental improvements to the foreshore and the operational requirements for slope repair or improved slope stability.

Ideally shoreline protection projects should contribute towards the environmental and financial sustainability of the port authority's shoreline assets. This section summarizes some aspects of environmental considerations that pertain to the typical shoreline protection systems found around the perimeter of the Vancouver Harbour portion of the port authority.

6.1. Envision™

The port authority is interested in integrating the Envision™ Green Infrastructure rating system into its projects. Envision™ is a framework tool that allows users to rate a project's overall sustainability in order to assess areas for improvement. The tool also provides guidance on sustainable best practices. More information can be found here: http://sustainableinfrastructure.org/envision/.

While the framework tool and rating system is not necessarily applicable to most stand-alone shoreline protection projects, many of the Envision™ criteria and overarching principles apply and should be considered. It is recommended that a living document is developed for each shoreline protection project, which outlines each of the 60 Envision™ credits and possible methods for implementation on the project. For ease of implementation, these may be organized relative to the various implementation phases, including site selection, design, tender, and construction.

An example of application of an Envision™ consideration is provided below.

> *Envision™ Credit RA 1.5: Divert Waste From Landfills:*
>
> *During the design phase, the shoreline protection could be designed to reuse existing rock materials and soil where possible. Designers could also consider replanting vegetation where possible, and how any additional excavated material might be used for other VFPA or local projects.*

6.2. Habitat improvements

There are numerous different types of habitat improvements that can be considered in the development of preliminary designs or design options for shoreline protection. The specific goal or objective for habitat improvements should be stated for each design option. The options should be accompanied with descriptions of feasibility and cost for the port authority's consideration as possible ways to work towards their sustainable port goals.

6.2.1. Shoreline slop habitat improvements

Although the addition of habitat benches on the slope of a revetment have demonstrated an increase in habitat diversity (Ref [14]), there are many options to improve the marine habitat or ecological functions that, depending on the circumstances, can also be considered. In many situations the additional of habitat improvements often results in improvements for the slope protection functions of the overall system.

An example of a habitat bench is shown in Figure 6, which includes a bench that also provides toe protection for a rock armour or riprap revetment. The objective of the habitat component should be stated in advance of design and adequate consideration should be given in the design to ensure that self-launching scour or propeller induced scour does not remove the habitat objectives.

Habitat benches can be either continuous along the entire length of shoreline, or can be discontinuous, with variations in width, to create a more natural undulating shoreline. An undulating bench reduces the overall volume of materials and provides a cost benefit.

A roughened revetment slope, which includes distributed, larger than necessary, from purely a stability perspective, armour provides hard points for attachment of marine organisms, provides sheltered void spaces for cover or refuge for marine organism and can result in reduced wave run-up. Reduced wave run-up may lead to beneficial contributions to the interaction between waves and the crest elements of a slope protection system, including habitat considerations added at the crest of the shoreline protection system.

Material size, shape, texture and slopes could be adjusted to increase habitat diversity and promote usage from specific fish species and marine organisms. As an example, the creation of an undulating shoreline, by augmenting existing headland geometry, may allow creation of a small embayment or pocket beach, which can provide both substrate diversity and ecological diversity.

In some cases, existing shoreline protection material can be recycled and re-purposed as the habitat bench.

When space is available, the use of geotextile liners should be discouraged as they may limit the ability of marine organisms to benefit from the substrate and they can result in increased wave run-up resulting in unplanned effects at the crest of the shoreline system.

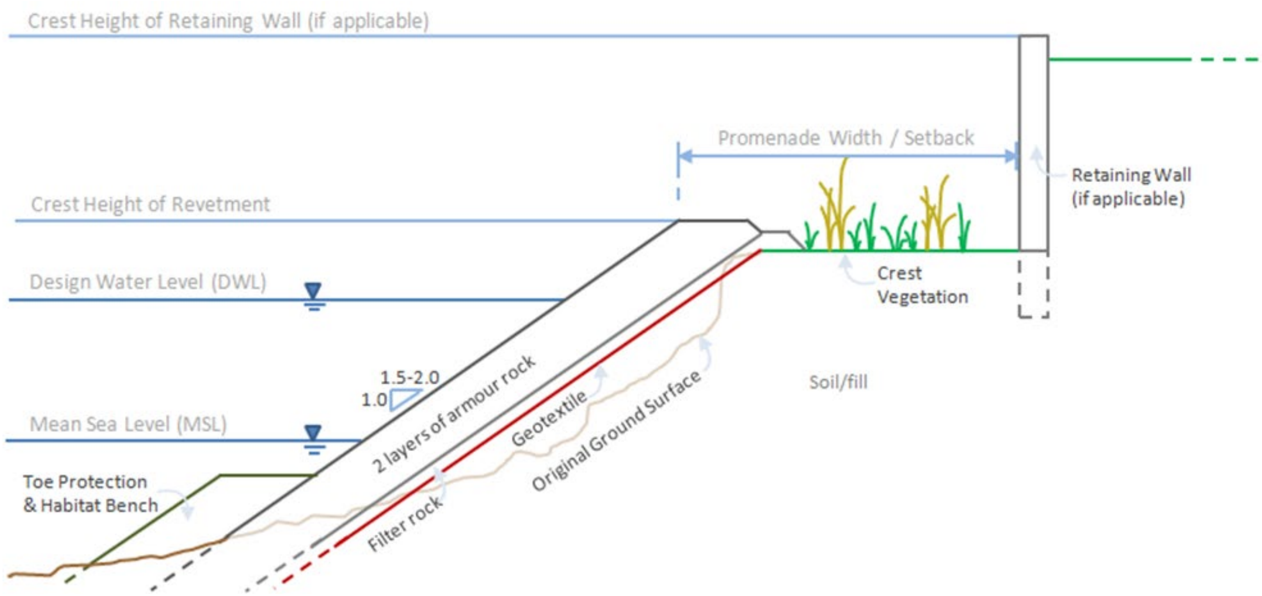

Figure 6: Potential habitat improvements (habitat bench and crest vegetation)

6.2.2. **Crest vegetation**

Marine tolerant vegetation at the crest of the structure (as shown in Figure 6) can provide several mutually beneficial ecological and engineering considerations, including:

(A) Enhances the marine riparian vegetation zone
(B) Limits colonization by invasive species
(C) Improves upland habitat supply and diversity
(D) Provides enhanced resilience of the revetment to future sea level rise
(E) Provides erosion protection against pluvial surface run-off
(F) Results in increased wave energy erosion at the crest and less erosion potential over the adjacent land area
(G) Can improve safety for upland personnel, equipment, and infrastructure by visibly delineating the shoreline edge

As an example, a combination of native dunegrass, beach pea, and goldenrod, along with agrostis as a cover plant to discourage weed growth, was used in Boundary Bay to achieve these benefits along a shoreline dike and public walkway.

Trees should be preserved during construction in order to help provide a vegetated buffer, manage storm water and surface water functions, provide habitat, and manage heat island effects. However, preservation of trees often requires a larger working area setback to accommodate their growth. The roots of large trees may penetrate filter layers and geotextile liners or filter cloth and may affect the stability of the top of slope by the sheer weight of the tree alone. The presence of large trees or of associated root systems should be specifically assessed.

Maintenance of the crest vegetation, particularly weeding, is required to control growth of invasive species while plants are established. Once established, the plants would likely require less maintenance. Specific design and maintenance guidelines are being developed as part of a separate document.

6.3. Improvements to shoreline protection components

Research, Ref [15], indicates that improvements can be made to modify shoreline armouring to enhance habitat diversity, including making subtle changes to material shape, size, and texture.

As an example, concrete blocks with a coarse surface were found to be more rapidly colonized by small green algae than those with a smoother surface. Geometric structures within the slabs (e.g., cups and holes) retained water longer during low tide and favoured the initial colonization by larger green algae. Small adaptations of both the texture and structure of materials within the intertidal zone led to better settlement, colonization, and increased diversity of algae and macro benthos.

Ultimately the creation of macro or micro habitats at a site can act to enhance foreshore habitat diversity and ultimately maintain ecological services.

6.4. Alternate and developing methods

The review and design of alternate shoreline protection systems to improve both the engineering performance and the environmental benefits is an ongoing field of research and application. Some of this work is related to aiding and improving environmental performance and some is driven by the need to develop more efficient and resilient systems in response to the challenges being created for ports by expected sea level rise and its implications.

Designers are encouraged to monitor and review the technical literature and emerging product development to identify suitable approaches. Emerging and novel approaches to increase habitat diversity, quality, and abundance in port environments include the following:

(A) Shellfish gardens – Manmade beach flats or terraces near the low water mark to increase habitat for and promote growth of clams or other shellfish
(B) Biogenic reef creation – Reefs made of tubes or shells from reef building organisms, to provide hard surfaces for habitation of immobile species, such as barnacles
(C) Seawall enhancements – hybrid shoreline systems that incorporate seawall portions on the slope can lead to space for habitat benches, flatter slopes allowing different materials and opportunities to create refugia and habitat enhancement features. Recent examples are summarized here:

  - https://waterfrontseattle.org/seawall
  - https://sites.google.com/a/uw.edu/seattle-seawall-project/home
  - https://www.environment.nsw.gov.au/research-and-publications/publications-search/environmentally-friendly-seawalls
  - https://www.portvancouver.com/wp-content/uploads/2018/10/2018-04-Shore-Protection-Guidelines-Inspection-Maintenance-Design-and-Repair-v1.0.pdf

7. Implementation of repairs

The success of an implementation of a repair or replacement solution is often defined at the implementation (construction) stage of a project. While there are many factors that contribute to the success of a project at the construction stage, this section of this document summarizes some key considerations related to the construction stage that should be considered.

7.1. Timing of work

There are several constraints on the timing of construction that can influence the cost or feasibility of the repairs. Four specific constraints related to work in Vancouver Harbour are:

(A) Fisheries permit regulations restrict the time when work can be undertaken in the intertidal and subtidal areas. For Vancouver (Area 28), the DFO timing window of least risk is from August 16 to February 28 (ref: http://www.dfo-mpo.gc.ca/pnw-ppe/timing-periodes/bc-s-eng.html#area-28). It is possible to get approval for work outside of this timing window; however, extra effort for permitting and often extra costs for construction are usually involved, so, in general, it is best practice that shoreline work is planned to occur within the timing window of least risk.
(B) It is sometimes necessary to restrict against any work (excavation, rock placements, etc.) occurring in-water. For winter months when the lowest tides occur during the night, this can result in extra construction effort and cost. Generally, it is best practice to plan construction for when the largest low tides are during the day. Typically, July and August provide the best day-time tides for this work.
(C) In addition to unfavorable tides, summer or early fall work is often preferred due to increased storm activity in the winter, which can lead to significant delays, damage the work area, and/or impact site safety.
(D) Construction during the fall, winter and early spring can often be exposed to rainfall or snowfall events that lead to additional costs and delays. Run-off from upland facilities can lead to turbidity in the local area.

7.2. Construction methodology

Construction methodology should be considered carefully, giving due regard to site access, environmental conditions, and the shoreline protection design. Construction may be largely or entirely completed from water or from land.

Water-based construction will typically include a spud barge with a large derrick crane and a clam-shell bucket, or possibly a long-reach excavator to prepare the slopes and place material. A crew boat may also then be needed. Materials may also then need to be transported to site using tugboats and barges (see Section 7.3).

The feasibility of working from the water will be largely based on environmental restrictions, upland access considerations, equipment availability, and cost. However, barges and tugs may not be able to operate at the site without sufficient draft (water depth below the hull), which may constrain the work window to high tides only. The reach of excavators/equipment located on the barge will depend on the tide and shoreline slope, which may only allow for short periods when work at the slope crest can be completed. Operations will also be restricted in areas with strong tidal currents or during periods of large winds/waves. In addition, the site may not have any area to tie-up or access the upland from water, which can cause workflow or access complications.

Water-based construction is also typically more expensive due to a limited number of contractors who can complete the work in the area and increased equipment costs.

Depending on the shoreline protection design, some work may still be required from land. For example, placing geotextile, placing rock materials at the slope crest, placing topsoil, or planting vegetation may all require personnel and/or equipment on land.

The feasibility of working from land will be largely based on upland usage and space constraints. For example, in areas where the site is actively being used, other construction works are ongoing, or important infrastructure (i.e., buildings) is located close to the shoreline, it may be necessary to use water-based construction.

If an excavator is used to place riprap, whether from land or water, it will require a bucket with a thumb. If below-water works are planned, excavators will need to be equipped with elevation and location monitoring equipment at the bucket so elevations and slopes of place material can could be monitored during construction. Underwater placement of material can lead to an increase in placed volumes with implications to cost and to habitat offset requirements.

7.3. **Transportation and traffic**

Transportation methods typically include barges (water-based) and trucks (land-based). Selection of transportation methodology should consider a wide variety of factors, including:

(A) Total quantity of material: Typically, trucks will be more economical for low-quantity projects, such as localized shoreline repairs.
(B) Distance from and locations of sources: Nearby quarries to Vancouver Harbour are generally located in areas that will require at least a portion of the journey to be completed by truck. Depending on the source location, it may not be practical to use water-based transportation for material.
(C) Availability of transport methodology: There are a limited number of local contractors with barges available for material transport. Depending on other ongoing projects in the region, certain transportation methods may not be feasible due to a lack of available equipment.
(D) Construction methodology: If water-based construction is chosen, it may improve workflow to have materials available on a barge nearby.
(E) Approvals: When material is provided by barge, approval of materials should occur prior to loading of the barge.
(F) Environmental constraints: Barges may not be able to operate without sufficient draft (water depth below the hull), in strong tidal currents, or in large winds/waves.
(G) Space constraints on land: Some sites may not have sufficient upland space to permit construction on land or stockpiling of material on land. If other work is ongoing upland (construction or active site use), the traffic management on the site may necessitate water-based operations.

In addition to these considerations, materials should be transported such that segregation and breakage is limited. In general, double or repetitive handling of materials can lead to breakage and quality issues.

A traffic management plan should also be developed in collaboration with all stakeholders utilizing the site at the time of construction. This may include the port authority, upland operators, contractors, and operators of nearby sites. The traffic management plan should consider water-based traffic control measures if water-based construction or transportation is chosen.

7.4. **Site preparation**

When preparing the site, care should be taken to ensure that the contractor’s health and safety plan and environmental management plan are properly followed at project onset.

A pre-construction survey should be conducted prior to commencement of other work on site; this will inform QA/QC measures and payment. Take clear photos of all areas on site prior to work. Particular attention should be paid to areas that will need to be restored to their pre-construction condition.

During site preparation, remove any invasive vegetation and clearly mark-off any native vegetation that is to remain, so that it is not damaged during the construction process. Set-aside any reusable materials.

7.5. Placement of materials

Placement of materials should generally follow the order and best practices outlined below:

(A) Placement of fill (if any)

- Should be placed in lifts, typically less than 0.4m, and compacted.

(B) Placement of geotextile (if any)

- Geotextile should be placed directly on a “fill” material to provide a relatively flat and smooth bedding surface. Armour rock should not be placed directly on top of the geotextile.
- When placing geotextile, lay the geotextile on top of the prepared slope, secure at the top, and roll the geotextile down the slope.
- Ideally, geotextile should be placed in the dry. If this is not possible, the geotextile roll will need to weight down/ballasted to avoid floatation during placement. For shallow water placement, contractors can place a steel/heavy pole through the centre of the geotextile roll. The geotextile can then be rolled down the slope, while the steel/heavy pole will weigh down the underwater end and prevent floatation. Filter rock can then be placed on the slope to secure/ballast the geotextile and the pole can be retrieved.
- Each strip of geotextile should have at least 0.3 m of overlap with adjacent sections.

(C) Placement of filter rock

- Filter rock may be placed in bulk and trimmed.
- Filter rock shall be placed beginning from the toe of the slope, working up the slope. The finished surface shall be densely placed and uniform.
- Prevent segregation of the fine and large portions of the gradation when placing.
- Prevent damage to the geotextile. Avoid scraping movements during placement and avoid dumping rock from high elevations.

(D) Placement of rock armour or riprap

- Rock armour or riprap placement should be planned such that no sections of fill, geotextile, or filter rock are left exposed overnight
- Care must be taken when placing armour rock to avoid disturbing the filter layer
  - The toe should be constructed first and to the highest precision – as it is the most important piece
  - Generally the largest armour stone should be reserved for the toe of the slope and the crest of the slope
  - The finest one-third of the armour stone should be evenly distributed throughout the slope. Remove and replace any portion in which material becomes segregated during placement to avoid large areas of under-sized armour rock
  - The finished surface should be densely placed, well-keyed, and uniform. Individual rocks shall have at least three (3) points of contact to adjacent rocks

7.6. Environmental management

The following best management practices (BMP’s) are applicable when working near the foreshore or riparian areas:

(A) Disturbance to intertidal, riparian, or existing adjacent vegetation is to be kept to the absolute minimum required to conduct the works.
(B) Ideally, there should be no in-water works during the construction period. This often requires scheduling work to align with low tides. If in-water works cannot be avoided, additional permitting or environmental restrictions may be required. Environmental measures may include placing silt-curtains around the work area, or monitoring turbidity levels in the water.

(C) Vehicles used for hauling material on- and off-site shall be restricted to pre-defined roads and turn-around areas, to have the least environmental impact. The work should be planned to minimize the number of vehicles/equipment operating on/near the intertidal zone to reduce impacts on the foreshore.
(D) Hauling vehicles and equipment should be cleaned of mud at an off-site location.
(E) All equipment and machinery should be in good operating condition and free of leaks or excess oil and grease.
(F) All hydraulic machinery should use environmentally sensitive hydraulic fluids which are non-toxic to aquatic life and are readily or inherently biodegradable.
(G) Equipment should be fueled prior to arrival on site and no onsite fueling should be permitted.
(H) The contractor should have an appropriate spill prevention, containment, and clean up contingency plan for hydrocarbon products (e.g., fuel, oil, hydraulic fluid), and other deleterious substances.
(I) All fill or rock materials that will contact the waters of Vancouver Harbour, should be clean material, free of organic materials and substances harmful to fish.
(J) All debris and deleterious material generated by the subject works should be collected and disposed of at appropriate upland locations in accordance with all applicable legislation and permits for the works.
(K) Works should be halted if it is observed that ongoing work is causing environmental degradation in the immediate vicinity of the works, or if turbidity levels in the local area are observed to be noticeably higher than before the commencement of work.
(L) During construction, the contractor should alert the client representative if any reptiles are found during excavation or earthworks, and halt work until authorized to continue.
(M) To ensure that the environmental BMP's are followed, it may be necessary to have an environmental representative on-site during construction.

7.7. Quality control/quality assurance

Quality control/quality assurance (QA/QC) is essential to ensuring that the shoreline protection design is executed properly. Best practices include the following:

(A) Inspect rock materials at the quarry prior to them being brought to site. This is especially important for sites with a small work area where it is not possible to sort material on site.
(B) Have personnel experienced in rock placement on site to provide guidance to provide guidance to equipment operators during the initial days of the project. SNC-Lavalin's past experience with rock placement in the foreshore has found that the quality of the work will vary greatly depending upon the skills of the equipment operators, so guidance will often improve the quality of the finished works.
(C) Have an engineering representative on site to perform inspections of rock placement. Inspections should ideally occur daily and be well documented in reports and photographs.
(D) Surveys should be conducted following excavation, placement of fill, and placement of armour rock or riprap. It is standard practice for the contractor to furnish an independent surveyor to undertake these 'check' surveys. The Engineer of Record or a qualified representative should review the surveys to ensure that material excavation and placement is within tolerances.
(E) In water works will pose particular difficulty for inspections by the engineering representative during construction. To allow for inspection of rock placement quality underwater, the contractor should conduct regular multi-beam bathymetric scans of the placed rock that is of good enough resolution to resolve individual placed rocks and void space.

7.8. Additional considerations

7.8.1. Noise mitigation

Generally, the port authority's shorelines are not located in areas with particular noise sensitivity; however noise restrictions may limit work to weekdays or daytime hours (8:00 a.m. to 5:00 p.m.). Where necessary measures to reduce noise, which could include erecting noise barriers or using quieter equipment should be considered and specified in advance if possible.

7.8.2. Excavated marine materials

Materials excavated or removed from the marine environment often exceed acceptable limits of sodium for disposal at a landfill. Special disposal may be needed.

As many of the port authority's shorelines are located in highly industrial areas and some of the existing shoreline protection or fill materials are non-standard, it may be necessary to test materials for additional contaminants.

Contaminated material may require special handling and disposal considerations and must be addressed when the contaminants are identified. The presence of contaminants may influence design options and therefore could trigger an iterative design and permitting process.

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Revision index

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Notice to readers

Appendix 1: Exposure type for select assets in Vancouver harbour

Asset ID	Asset Length (m)	Chainage		Exposure	Crest Setback
		Chainage (from)	Chainage (to)	Type	m
64-N-105	230	0+000	0+105	E2	4.0
		0+105	0+230	E5	4.0
64-N-106	148	0+000	0+148	E5	1.5
32-N-107	214	0+000	0+180	E5	1.5
		0+180	0+214	E2	1.0
68-N-111	338	0+000	0+220	E5	4.0
		0+220	0+275	E2	3.0
		0+275	0+338	E2	7.0
68-N-112	95	0+000	0+040	E5	2.0
		0+040	0+095	E5	3.0
72-N-120	129	0+000	0+060	E1	2.0
		0+060	0+066	E1	4.0
		0+066	0+129	E1	3.0
46-N-121	291	0+000	0+291	E1	2.5
46-N-122	240	0+000	0+100	E1	4.0
		0+100	0+240	E1	3.0
46-N-123	77	0+000	0+045	E2	2.0
		0+045	0+077	E2	1.0
46-N-124	179	0+000	0+040	E1	3.0
		0+040	0+179	E1	2.0
47-N-126	218	0+000	0+218	E1	3.0
47-N-127	34	0+000	0+034	E1	2.0
47-N-128	65	0+000	0+065	E1	0.1
47-N-129	75	0+000	0+049	E1	0.1
		0+049	0+075	E1	3.0
47-N-130	185	0+000	0+055	E1	4.0
		0+055	0+075	E1	9.0
		0+075	0+185	E1	7.0
133-N-172	221	0+000	0+013	E4	14.0
		0+013	0+060	E4	13.0
		0+060	0+150	E4	14.0
		0+150	0+188	E4	16.0
		0+188	0+221	E4	18.0
39-N-134	316	0+000	0+316	E1	7.5
133-N-135	790	0+000	0+115 Left	E4	3.0
		0+115 Left	0+175 Left	E4	0.1
		0+175 Left	0+385 Right	E4	0.1
		0+385 Right	0+115 Right	E2	0.1
		0+420	0+485	E2	2.0
133-N-136	94	0+000	0+025	E2	0.1
		0+025	0+094	E1	4.0
133-N-137	70	0+000	0+024	E1	1.5
		0+024	0+070	E5	3.0
44-N-140	350	0+000	0+060	E1	2.0
		0+060	0+100	E1	1.5
		0+100	0+145	E1	1.0
		0+145	0+165	E1	1.5
		0+165	0+350	E1	0.5

Figure A1: Example of chainage system for several assets in Vancouver Harbour (Ref 1)

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