Klohn Crippen Berger

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Neil Snowball, P.Eng
Design Manager

Dear Mr. Snowball:

Centerm Expansion Project
Geotechnical-Marine Summary in Support of Project Environmental Review (PER) Application

We are pleased to present our technical summary covering geotechnical-marine aspects of the Centerm Expansion Project (CEP). This summary (rev.2) is issued in support of AECOM's submission to Port of Vancouver for the Project Environmental Review (PER) application for the CEP project.

Please contact us if you have any questions.

Yours truly,

KLOHN CRIPPEN BERGER LTD.

Geoff Cooper, P.Eng.
Project Manager

2016-11-01-CEP-MEM-KCB-FINAL Rev.2 Geotech-Marine PER Summary
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Drawings (attached in a separate supporting document)

1 INTRODUCTION

The Port of Vancouver and DP World Vancouver have proposed expanding port facilities at the Centerm Container Terminal (Centerm), which is located at the west end of the South Shore Trade Area (SSTA), close to the Canada Place cruise terminal and downtown Vancouver. AECOM Canada has been retained as Owner's Engineer for preliminary design of the proposed Centerm Expansion Project (CEP), and Klohn Crippen Berger (KCB) has been retained by AECOM Canada to provide marine, structural and geotechnical consulting services for the CEP project.

This summary report provides technical information on geologic setting, seismic hazard, demolition of existing marine facilities, proposed construction of new marine facilities and terminal expansion areas, in support of the submission to Port of Vancouver for the Project Environmental Review (PER) application for the on-terminal CEP scope.

1.1 Scope of Summary Report

The on-terminal CEP scope is as follows:

- **Western Expansion:** Extension of Berth 6 through the introduction of a 78 m long caisson wharf extension at the west end of the existing wharf, and filling of approximately 2.9 ha of Burrard Inlet, together with the western extension of the associated container yard and intermodal yard.
- **Eastern Expansion (includes removal and rehabilitation of the Ballantyne Pier):** Removal of the existing pulp shed (Shed 3), Ballantyne Pier pile and deck structure, marginal wharf, and the west portion of the Southern Railway wharf. Construction of a new perimeter rock dyke, filling approximately 1.7 ha of the inlet to create additional land for terminal operations.
- **Reconfiguration of Intermodal Yard, Container Yard and Terminal Entrance Area:** Addition of a fifth track to provide a total of five parallel tracks, each of 914 m long. Extension of RTG container stacks (east and west to match intermodal yard), relocation of reefer towers to western stacks, and reconfiguration of the northern container yard. New terminal entrance gate and operations infrastructure including: pre-in gate, main in gate, pre-out gate, main out gate, initial on-terminal staging, and trouble vehicle parking.
- **Removal of the Heatley Ave Overpass:** Demolition of the overpass and adjacent Main Office building to facilitate eastern expansion of the intermodal yard and associated container yard stacks and terminal gates.
- **Container Operations Facility:** Remediation of the existing Ballantyne heritage building to create a combined operations and administration centre. This remediation includes seismic retrofit and foundation improvements.
- **Terminal Operations Parking and New Employee Parking Capacity:** Provision of stalls adjacent to the Container Operations Facility to accommodate internal transfer vehicles and terminal support vehicles. Employee parking lot located adjacent to the Container Operations Facility.

This summary technical report covers only the **Western Expansion** and the **Eastern Expansion**, as those are the marine facilities and terminal expansion areas within the overall CEP scope.

1.2 Key Assumptions

This summary technical report is predicated on the following key assumptions:

a) The CEP is currently envisaged to be contracted as a Design-Build project, which may allow the contractor some flexibility in construction approach, methods and materials. Notwithstanding that flexibility, this technical summary is based on the current preliminary design and the CEP basis of design.

b) The Western Expansion will include a wharf extension using concrete caissons without a piled deck frontage.

c) The Western Expansion and Eastern Expansion will be constructed as marine reclamations using sand backfill with perimeter rockfill dykes. Marine dredge materials will be disposed off-site and not incorporated into the terminal reclamation fill.

d) Supplementary field investigations will be undertaken to support the design and construction of the marine facilities.

2 GEOTECHNICAL CONDITIONS

2.1 Geological Setting

Vancouver Harbour is generally underlain by Tertiary Bedrock. Locally, bedrock may be covered by Vashon Drift and Capilano Sediments, consisting of a relatively thin (<10m thick) veneer of glacial drift consisting of till, glaciofluvial sand to gravel, and glaciolacustrine stony silt. Marine derived lag gravel deposits are typically less than one metre thick mantle till. Salish Sediments consisting of mountain stream marine deltaic deposits of medium to coarse gravel and minor sand derived from the rivers draining the North Shore Mountains may also mantle bedrock. Much of the shoreline along the southern shore of the harbor has been infilled with Salish Sediments including sand, gravel, till, crushed stone and refuse to establish shipping terminals. Historical documentation reports dredging of moderately thick silt deposits during construction of the Ballantyne Pier.

The existing Centerm terminal is generally built on variable depths of heterogeneous fill, up to 40m thick, including engineered sand and gravel fills, as well as lower quality fills such as wood chips and construction waste materials. Native soil under the fill consists of unconsolidated marine sediments up to 20m thick, underlain by relatively dense till-like soil and bedrock. The depth from the ground surface to till-like soil is in the range of 2 to 40m, and the thickness of till-like soils over bedrock is generally at least 2m. Bedrock was not always encountered in past investigations.

2.2 Geotechnical Exploration Program

A geotechnical exploration program and laboratory testing of soil samples was undertaken in marine and upland areas of the CEP project by KCB in December 2015 through to January 2016. The exploration program included seismic cone penetrometer tests, cone penetrometer tests, and drill holes. The exploration and laboratory testing program are summarized in KCB's Geotechnical Data Report, dated March 23, 2016. A supplementary geotechnical exploration program is planned for the fall of 2016.

2.3 Site Characterization

The Centennial Terminal site is situated in Burrard Inlet, which is part of the Indian Arm fiord. The site is underlain by post-glacial fluvial and marine sediments overlying dense to very dense glacial till comprised of silt, sand and gravel with occasional cobbles and boulders. The glacial till is underlain by sedimentary bedrock varying from sandstone to poorly cemented conglomerate and occasional mudstone seams. The post-glacial sediments primarily control the geotechnical engineering behaviour of the Centerm Expansion Project (CEP). The post-glacial sediments generally consist of the following strata in order of increasing depth:

1. Upper Sand – The materials vary from silty sand to fine sand with trace silt of variable thickness with some silt interbeds. These materials may occur as seams, lenses and layers and continuity of individual layers is difficult to establish between widely spaced drill holes. The materials are loose to compact. Note that the uppermost 1.5 to 2.5 m of each cone

penetrometer test and the sampled drill hole were cased to stabilize the drill rods and no sampling was carried out. The shallow soil conditions are therefore not defined.

2. Marine Sediments – This stratum is generally massive fine-grained materials with trace sand to sand and fine-grained material. Atterberg limits indicate that the marine sediments vary from low plasticity silt to intermediate plasticity clay. The marine sediments contain trace shells and are very soft to soft with the natural moisture content generally above the liquid limit.

2.4 Site Characterization – Western Expansion

Material types for the Western Expansion area are inferred primarily on soil classification from cone penetrometer tests, supplemented by sampled drill holes.

2.4.1 Sand to Silty Sand

The field investigations indicate that the surficial sand to silty sand deposit extends from the seabed down to a maximum of about 3.75 m depth. The sandy stratum is absent or thin in some areas and the thickness increases to nominally 6.5 m near the western edge of the existing marine terminal. The data also indicates that the surficial sand to silty sand stratum is nominally 9.0 m thick at the southern end of the terminal expansion area, where it is underlain by glacial till.

2.4.2 Marine Sediments

The field investigations indicate that the marine sediments are thin or absent near the western side of the existing terminal. The marine sediments thicken to the west to nominally 8.85 m. Sampling indicates that the upper 4.25 m is generally comprised of fine silty sand to sand and silt and the lower 4.6 m silty clay with trace fine sand. The data also indicates that the marine sediments are thin or absent near the southern edge of the proposed reclamation fill. Marine sand was encountered near the proposed south dyke. The transition from profiles governed by marine sand to profiles governed by marine sediment may occur near the south-west extent of the proposed expansion (i.e., where the west dyke meets the south dyke). The actual transition is unknown. The marine sediments thicken to the north (to about 17.5 m thick) as the sea bottom elevation decreases and the depth to till below seabed level increases.

2.4.3 Glacial Till and Bedrock

The marine deposits are underlain by a dense till-like stratum. This material was found to be very dense, and comprised predominantly of fine to medium or fine to coarse sand, with varying amounts of silt. The drilling action was suggestive of the presence of gravel and cobbles. Boulders may be present in the till stratum, but none were encountered in the drill holes. The field investigations indicate that the top of the glacial till stratum slopes downward from nominally El. -23.5 m near the western side of the existing terminal to El. -30 m further west. The data also indicates that the glacial till slopes downward from nominally El. -20 m near the southern edge of the proposed reclamation fill to nominally El. -42 m north of the berth area. The drill holes indicate that the upper portion of the glacial till stratum may be dense due to weathering or softening by sea water. The underlying glacial till is very dense. Bedrock was not encountered in any drill holes in the Western Expansion area.

2.4.4 Fill Materials

Upland investigations, located over existing fill materials placed during the previous expansion generally encountered various grades of granular fill materials to a depth of 14 m (-6.7 m elevation). These fill materials ranged from sand to gravel, with occasional cobble-sized particles. From a depth of 14.0 m to 23.2 m, a mixture of sand, silt and gravel was encountered. Timber and other evidence of fill was encountered in the lower 5 m of this zone, and a strong hydrocarbon odour was observed from approximately 20.5 m to 21.0 m depth. Sand was encountered from a depth of 23.2 m to 29.9 m. Trace shells were encountered in this zone, and it is likely that this zone is the original marine sediment that was filled over during the previous expansion of the terminal. Glacial-till like material was encountered from a depth of 29.9 m to the terminal depth of 33.2 m. The glacial-till like material became noticeably denser below a depth of 31.7 m, suggesting that the upper 1.5 m to 2.0 m may be somewhat weathered.

2.5 Site Characterization – Eastern Expansion

Material types for the Eastern Expansion area are inferred primarily on soil classification from cone penetrometer tests, supplemented by sampled drill holes. Limited drill hole information is available in the Eastern Expansion area; this hindered the assessment of dyke stability and fill settlements in this area.

2.5.1 Silty Sand and Marine Sediments

The limited field investigations conducted at the Eastern Expansion area indicate relatively thin marine deposits (3.5 m or less) in the Ballantyne Pier area. Historic drawings indicate that marine dredging was carried out to nominally El. -10 m to El. -12 m in this area and the marine sediments here may be recent (post-dredging) deposits. The thickness of marine deposits between Ballantyne and the Southern Rail Dock are expected to range from approximately 1 m at the south end to nearly 4 m thick near the north end of the Southern Rail Dock. Approximately 1.35 m of soft silt with trace to some fine sand was encountered in the marine investigation near the marginal wharf. The silt was underlain by sedimentary bedrock. A 0.8 m layer of sandy materials was encountered west of the southern third of the Southern Railway Pier, while a 3.5m layer of surficial sand with some silt to silty sand was encountered in the marine area east of the middle of Ballantyne Pier. Dense glacial till / sedimentary bedrock was encountered below the granular soils. One drill hole encountered a zone of fine sand from 6.4 m to 6.9 m. Shells were present in this zone, and it is possible that this is an original marine deposit. Insufficient sample was recovered from the other Eastern Expansion drill holes to conduct representative testing on the marine deposits.

2.5.2 Glacial Till and Bedrock

Nominally 1.8 m of glacial till was encountered in one marine drill hole, and nominally 11.2 m of glacial till was encountered in the upland investigation near the southern end of Ballantyne Pier. The glacial till is comprised of fine to medium or fine to coarse sand, with varying amounts of silt. Gravel and portions of cobbles (consistent with the maximum size of the sonic rig drill bit) were recovered. Boulders may exist in the till deposit, but were not encountered in the drill holes. The materials appear to be dense to very dense. A layer of glacial till-like silty sand was encountered in one drill hole from 6.9 m to a maximum depth of 17.1 m. Sedimentary bedrock was cored in the marine drill holes and penetrated in the upland hole in the eastern section of the Centerm Expansion area. The drill holes indicate that the bedrock consists of sandstone and conglomerate with some mudstone. The upper portion of the rock is moderately to highly weathered, poorly cemented and classified as weak to very weak. The rock appears to be less weathered below 2 m depth and is classified as moderately strong.

2.5.3 Existing Terminal Fill Materials

Upland investigations within the terminal boundary encountered variable fill material to a nominal depth of 6.4 m. The fill material typically comprised sand, gravel, and cobbles. Concrete was encountered from a depth of 0.91 m to 1.22 m. Golder Associates drilled a number of holes in Ballantyne Pier area in 1990s and performed Becker penetration tests to assess the soil density (found to be loose to compact). The drill holes indicate that the fill materials consist of gravel with some sand and cobbles and trace silt and boulders. A report from the original (1925) construction of Ballantyne Pier indicates that this material was dredged in the Second Narrows area and transported to site.

3 SEISMIC HAZARD

The seismic hazard at Centerm can be characterized by the following dominant sources of seismicity:

- Shallow crustal events within the continental North American Plate;
- Deep seismicity within the subducting Juan de Fuca Plate, also referred to as 'intraslab' events; and,
- Events associated with the interface of the subducting Juan de Fuca Plate, also referred to as 'subduction' or 'mega-thrust' events.

The design return periods for the marine facilities of the CEP are:

- **A100 (Operating Level Event, OLE)**: The OLE is defined as the seismic event that produces ground motions associated with a 100-year return period (A100), i.e. an annual exceedance probability of 0.01. The performance objective for A100 can be summarized as: minor easily repairable damage with no interruption to operations. After the OLE event, the terminal expansion should have minimal, if any, interruption of operations. The A100 event is used for the design of all perimeter dykes, and is also used as a design performance level for the caisson wharf structure.
- **A475 (Contingency Level Event, CLE)**: The CLE is defined as the seismic event that produces ground motions associated with a 475-year return period (A475), i.e. an annual exceedance probability of 0.0021. The performance objective for A475 can be summarized as: repairable damage with some interruption to operations, but no collapse. After the CLE event, there may be temporary loss of operations, which should be restored within a few months. The level of associated damage is anticipated to preclude any loss of life on the marine infrastructure of the terminal expansion. The A475 event is used as a design performance level for the caisson wharf structure.

Crustal event seismic hazards relating to these two return periods, and based on the 2010 NBCC hazard model, have been used where appropriate in the design. In addition to this, a subduction zone hazard has been considered for the caisson wharf structure that has been designed for the A475 return period. According to Geological Survey of Canada, large subduction earthquakes are expected to have an average return period of 500 to 600 years.

The seismic hazard for the CEP is based on the 2010 NBCC seismic hazard model, which only includes crustal sources. The 2010 NBCC seismic hazard model does not include the subduction zone event or intraslab events in the hazard; however, seismic hazard de-aggregation using the 2015 NBCC seismic hazard model suggests a mean and modal magnitude of between 8.5 and 9.0 may be appropriate for the subduction event. As the basis for the CEP design is the 2010 NBCC hazard model, the higher magnitudes from the 2015 hazard model would not be appropriate. A conservative moment magnitude of Mw = 8.5 has therefore been adopted for the subduction event. For the subduction hazard, the median hazard values reported by the Geological Survey of Canada have been adopted.

For the CEP project site, the peak ground accelerations (PGA) for the three seismic hazards are:

- A100 (Operating Level Event, OLE): PGA (g) = 0.115
- A475 (Contingency Level Event, CLE): PGA (g) = 0.242
- Subduction Event: PGA (g) = 0.160

These seismic hazards are based on a ‘Site Class C’, or ‘Firm Ground’ conditions. The marine deposits are underlain by dense to very dense glacial till at the CEP site, which is assumed to be consistent with ‘Site Class C’ firm ground conditions, and the seismic hazard has not been altered to reflect any site amplification. The response of the overlying marine deposits is determined by site response analyses.

4 GEOTECHNICAL HAZARDS

4.1 Potential for Liquefaction

Marine Sand

The preliminary geotechnical design analyses indicate that the marine sand in the free-field areas and in the reclamation fill areas will liquefy under the A100, A475 and Subduction earthquake events. The marine sand liquefaction hazard for the A100 earthquake can be mitigated by performing vibro-replacement ground improvement in the reclamation fill areas.

Marine Sediment

The preliminary geotechnical design analyses indicate that the fine-grained marine sediment in the free-field areas will liquefy under the A100, A475 and Subduction earthquake events. Liquefaction will result in cyclic softening of the materials rather than true liquefaction. The marine sediments will not liquefy in the reclamation fill areas under the A100 earthquake. The liquefaction hazard in the fine-grained marine sediments cannot be mitigated by performing vibro-replacement ground improvement; however, vibro-replacement could be carried out to increase the shear strength of the soil mass by the installation of granular columns. Other forms of ground improvement, such deep soil mixing, cutter soil mixing, or jet grouting, are not likely feasible in these fine-grained soils in a deep marine environment due to environmental considerations.

Granular Fills

The granular reclamation fill placed in the 1990 western expansion of the terminal is liquefiable under the A100, A475 and Subduction earthquake events. New granular reclamation fill placed below tide level in the proposed western expansion and eastern expansion areas using similar materials and placement methodology will likely have similar density and liquefaction susceptibility. Densification of the general fill in the proposed terminal expansion areas to mitigate the liquefaction hazard is feasible, but does not appear to be required to meet the seismic design requirements for the A100 earthquake in these areas. Densification of the fill materials in the vicinity of the caisson wharf is required to meet the A475 seismic design criteria. This includes densification for the general fill (directly behind the caissons), berm filter and berm rock behind the caissons, and the mattress rock foundation below the caissons. The reclamation fill may require a rockfill closure dyke (not shown on the preliminary drawings) as a containment berm for general fill placement. The dyke rockfill is assumed to be clean crushed rock with high hydraulic conductivity that is incapable of generating significant excess pore pressure during the A100 earthquake. Densification of the dyke core rock is therefore not required.

4.2 Marine Foundations and Fill Materials

The foundation designs for the Western Expansion and Eastern Expansion are depicted on the **Drawings** (attached in a separate supporting document). Relevant conclusions, and design requirements, from the stability analyses are summarized in the following sections.

4.2.1 Western Expansion – Caisson Wharf

Excavation of the marine sediments to glacial till below the caisson wharf extension is required for both seismic and construction stability. The excavation would be backfilled with mattress rock, which would be densified to limit increases in pore pressure, to provide shear strength during a seismic event and to minimize caisson wharf settlements. A zone of ground improvement is required in the fill materials behind the caissons (berm rock, filter rock and general fill), to limit seismic deformations and to minimize wharf apron settlements.

4.2.2 Western Expansion – West Dyke

Excavation and replacement of the marine sediment under the west dyke is required for both the A100 seismic event and for construction stability. The excavation would be backfilled with dyke rockfill. While no ground improvement is required in the general reclamation fill behind the west dyke, a zone of sand and gravel is included in the preliminary design (behind the dyke berms) to act as a filter zone between the general fill and the rockfill dyke.

4.2.3 Western Expansion – South Dyke

The preliminary geotechnical design analyses for the south dyke indicate that the static resistance is acceptable without ground improvement. However, the marine sand will liquefy during the A100 seismic event, leading to slope instability. Ground improvement is therefore required to mitigate the liquefaction hazard in the marine sand below the south dyke. While no ground improvement is required for the general reclamation fill behind the south dyke, a zone of sand and gravel is included in the preliminary design (behind the dyke berms) to act as a filter zone between the general fill and the rockfill dyke.

4.2.4 Western Expansion – Terminal Fill

The terminal reclamation fill at the Western Expansion is contained by the caisson wharf structure, and the west / south perimeter dykes. The terminal fill below tide level will be placed hydraulically and the preliminary design includes surcharging with preload material to minimize long-term settlement. The preload material will be placed in stages, and then removed prior to pavement construction.

4.2.5 Eastern Expansion – East Dyke

The east dyke design concept was initially based on the preliminary design analyses performed for the Western Expansion (west dyke). However, the required ratio of the width of the excavated marine sediment to height of the dyke here was found to be greater, due to the anticipated slope of the glacial till surface with respect to the alignment of the dyke. While no ground improvement is required in the general reclamation fill behind the east dyke, a zone of sand and gravel is included in the design (behind the dyke berms) to act as a filter zone between the general fill and the dyke rock fill.

For preliminary design it is assumed that the tie-in portion of the east dyke along the Southern Railway wharf embankment will not need any sub-excavation, since the wharf embankment core is standing at a steep slope (likely comprised of large crushed rock), from which it can be reasonably inferred that the embankment has sufficient shear strength to buttress the new dyke toe in this area.

4.2.6 Eastern Expansion – Northeast Dyke

Excavation and replacement of the marine sediment under the northeast dyke is required for the A100 seismic event. The excavation would be backfilled with rockfill to form a dyke to constrain the reclamation fill during placement. A zone of sand and gravel is included in the design (behind the dyke berms) to act as a filter zone between the existing fills and the rockfill dyke. The existing fills below the rockfill dyke zone should be densified, along with the new reclamation fill behind the crest of the dyke (sand and gravels). At the north end of Ballantyne Pier, the three wharf caissons and the small rotated caisson that were all installed in 1998 will be left in place with the new perimeter dyke sloping down and around in front of those caissons.

4.2.7 Eastern Expansion – Terminal Fill

The terminal reclamation fill at the Eastern Expansion is contained by the east / northeast perimeter dykes. The terminal fill below tide level will be placed hydraulically and the preliminary design includes surcharging by preload material to minimize long-term settlement. The preload material will be placed in stages, and then removed prior to pavement construction.

4.2.8 Characteristics of Proposed Fill Materials

The terminal reclamation fill is anticipated to comprise imported Fraser River sand, or similar material with low fines content. Alternate sources for general fill include sand and gravel sourced from maintenance dredging of the First Narrows or Second Narrows fluvial areas.

The preliminary design assumes that the caisson mattress rock, caisson ballast, berm rock, filter rock, perimeter dykes, and pavement granular base/sub-base will all comprise crushed rockfill, of varying size and gradation to suit the intended purpose, sourced from local quarries. It is likely that none of these rock materials will exceed 150mm nominal maximum particle size. Rock materials that are required by design to be vibro-densified will likely be no larger than 100mm nominal maximum particle size. All imported sand / rock materials will include a small amount of fines, due to their nature.

Concrete demolition debris (selected for suitability in terms of size and minimal fines) may be used for caisson ballast or as replacement for other imported rockfill materials.

The outer exposed slope of all perimeter dykes will be faced with armour rock (riprap) as protection against marine environmental forces. The riprap, and bedding if required, will be sourced from local quarries, to the size required for the shore protection design.

4.3 Settlement of Terminal Fills

4.3.1 Settlement of Western Expansion

The preliminary design assessed settlements associated with the Western Expansion, and preloading options for that terminal expansion area. The settlement predictions were based on a preliminary loading model using assumed loads, construction schedule and site grades. Surcharge preloading the site, even for a relatively short period, will help in reducing the post construction settlements. In the absence of post-construction settlement criteria, the preliminary design for the Western Expansion assumes a 4 m high preload (from a nominal pavement subgrade elevation of 6 m) for nominal 6 months as this duration is considered the optimal balance between minimizing post construction settlements and minimizing potential impacts to the construction schedule.

4.3.2 Settlement of Eastern Expansion

The limited drill hole data available in the Eastern Expansion area hindered the assessment of the thickness and lateral distribution of compressible marine sediments for settlement analysis. The data suggests that the marine sediments at the Eastern Expansion are much thinner than at the Western Expansion, so construction and post-construction settlements in the Eastern Expansion are expected to be lower than the Western Expansion, and surcharge preloading will have limited benefit. Surcharge preloading may not be required for the southern portion of the east expansion site where the available data indicates the marine sediments are thin. Surcharge preloading may, or may not be required for the northern portion of the Eastern Expansion, depending on whether post-construction (incremental) settlement is within the post-construction settlement tolerance for operations and surface water drainage. Surcharge preloading may be beneficial at the boundaries between existing / new terminal fill to reduce the differential settlement gradients in these areas. In the absence of post-construction settlement criteria, the preliminary design for the Eastern Expansion assumes similar surcharge preload requirements as for the Western Expansion, but possibly of shorter duration.

5 MARINE STRUCTURES

5.1 Caisson Wharf Arrangement

The wharf extension structure adopted for preliminary design uses two new concrete caissons installed along the existing wharf berthing face, i.e. set forward from the existing caissons. The new caissons would be precast concrete structures built off-site and floated to the terminal. Following mattress foundation preparation, the caissons would be sunk into position onto a layer of levelling course material above the densified crushed mattress rock foundation, and would then be filled with ballast rock to provide the required mass to resist sliding and overturning forces. Partial height ballasting in the front cells is optimum for caisson design, and would provide marine habitat within the front cells, the interior habitat being accessed through “fish refugia” openings in the front wall.

Between the two new caissons, a full-height precast concrete keyway would be installed to retain the berm rock backfill. At the interface with the existing caisson, a full-height L-shaped precast keyway could be used to retain the backfill across this gap. A cantilevered concrete slab would bridge the gap to the existing piled deck structure. Filter cloth could be installed behind the keyways and over the connecting slabs and cover slabs to help prevent loss of fines. A seismic / movement joint would be installed between the new caisson wharf and the existing piled deck slab, to cater for differential movements across this interface.

Tremied concrete or precast slabs would be used to provide scour protection directly adjacent and attached to the caisson toe slab along the full length of the wharf extension. This would protect the caisson toe from undermining, which might otherwise occur due to propeller wash or bow-thruster forces above the seabed.

The cope wall would support the fender system and mooring bollards, and would also have a continuous steel bull rail along the leading edge, with two electrical receptacle boxes built into the bull rail. The cope wall would also support the front rail extension for the ship-to-shore gantry cranes, including an extension of the existing Cavotec cable slot system just outboard of the seaward rail. It would be necessary to retrofit a short length of the existing piled deck, at the front crane beam, to connect the existing cable slot to the wharf extension. The rear crane rail would transition from the crane rail support beam on the existing caissons to a new grade beam founded on the densified fill material. Crane rails would probably be installed on a continuous grouted soleplate using an elastomeric pad system.

For preliminary design, the new rear crane beam is not structurally connected to the existing rail support beam, but instead the new crane beam should be allowed to settle during the latter stages of construction, with installation of the crane rail delayed for as long as possible. Long-term settlement and consequential rail re-levelling would be accommodated by initial installation of longer anchor bolts and allowance for re-grouting the rail soleplates. The existing crane stops can be re-used at the extended rail ends.

A retaining wall would be required on the west face of the terminal expansion just behind the caisson wharf. The preliminary design shows this as an anchored sheet-piled bulkhead, designed to A475 seismic criteria in order to provide seismic withstand capability for the crane rail system (since the rear crane beam is supported by the retained soils). A concrete dead-man will secure the tie rods. The rock berm, filter rock and sand backfill material directly behind the sheet-piled bulkhead will be densified to increase shear strength and thus improve seismic performance and minimize long-term settlements.

5.2 Wharf Construction Sequence

The anticipated construction sequence for the caisson wharf extension is as follows:

1) Dredge marine sediments to dense glacial till.
2) Place mattress rock (and mattress overbuild layer for top-feed vibro-densification) and rough screed to required elevation.
3) Vibro-densify the mattress rock (which draws down the overbuild feedstock layer).
4) Remove residual overbuild rock, and re-use elsewhere (as scour protection in front of wharf).
5) Rough screed the densified mattress rock to required grade.
6) Place levelling course and fine screed to required grade ready for caissons.
7) Install caissons onto prepared leveling course, and fill with water ballast.
8) Place ballast rock in front and rear cells of caissons. Ballast rock in upper portion of rear cells may be delayed and placed at same time as upper zone of berm rock, for better control of caisson settlement / rotation.
9) After 30 days lag to allow for initial settlement/rotation of caissons, install precast concrete keyways between two new caissons and at joint with existing caisson.

At this point, two work paths can proceed nearly simultaneously (backfill behind caissons – see Work Path 1, and concrete works on top of caissons – see Work Path 2):

10) **Work Path 1**: Place berm rock, then filter rock, and then general fill behind caissons. The berm rock is also placed between each caisson behind the precast keyway.
11) Densify berm rock, filter rock and general fill (using vibro-densification in lower zone, and dynamic compaction in upper zone).
12) Install sheet pile end retaining wall (with tie-backs and dead-man anchor block), vibro-densify the backfill zone, and then install the cast-in-place concrete cap beam.
13) Compete dyke armour protection in front of retaining wall.
14) **Work Path 2**: Install precast concrete cover slabs over caisson cells, then construct cast-in-place connecting slabs between two new caissons and at joint with existing piled deck.
15) Construct cast-in-place concrete cope wall, including mooring bollards and marine fenders.
16) Construct rear crane beam (compacted granular base and cast-in-place concrete).
17) Complete apron utilities (storm drains, potable water, and electrical duct banks).
18) Install and grout front / rear crane rails.
19) Complete asphalt pavement structure (sub-base, granular base, and paving).

20) Install tremie concrete toe protection slab and tie into scour protection rock at caisson toe.

5.3 Wharf Fenders and Mooring Bollards

Marine fenders for the new caisson wharf extension would be designed to match the general layout, specified energy absorption, specified reaction and performance of the existing Berth 6 fenders, which were designed for a maximum ship size of 8,100 TEU. It is noted that DPWV plans to limit berthing approach speeds for vessels larger than the Maximum Design Ship (up to 13,000TEU containerships) to prevent overload of both the existing and wharf extension fender systems. It would be advantageous for DPWV to consider future berthing operations and undertake additional investigations into the feasibility of upgrading the existing fender system to accommodate 13,000 TEU vessels with no reduction in berthing velocity. At the northwest corner of the wharf extension a corner fender is to be provided, of similar capacity to the wharf face fenders, to protect the northwest corner from accidental ship impact.

Berths 5 & 6 are currently equipped with 125 tonne mooring bollards at 25m spacing. In light of DPWV's intent to dock larger containerships (up to 13,000TEU), the wharf extension should include five new bollards of 200 tonne rated capacity, similar in style to the existing 2-horned bollards. Future investigations should be conducted to assess the feasibility of upgrading four bollards (between berth 5/6) to a 200 ton rating to accommodate the largest ships calling at the terminal. The quick release hook (and electric capstan) currently installed at the mooring dolphin would be relocated to the west end of the berth extension. An access platform with guardrail is to be provided at the west end of the caisson wharf extension, as a safety measure for working on mooring lines at the end bollard.

5.4 Demolition of Mooring Dolphin

Construction of the caisson wharf extension at the Western Expansion will require demolition of the existing steel-piled mooring dolphin located 76m from the west end of Berth 6. This unavoidable operational loss will adversely impact the terminal operator's ability to berth large containerships during construction of the west extension. Although it would appear preferable to install some form of temporary mooring dolphin during this outage, in reality this is not practical due to safety considerations (for terminal operations personnel, and for construction workers and equipment).

5.5 Demolition of Ballantyne Pier and Marginal Wharf

Rehabilitation of the Ballantyne Pier and Marginal Wharf at the Eastern Expansion will require demolition of the upper part of the existing 1923 concrete structure, which is in poor condition and operationally constrained by limits on live / surcharge loading.

At the original Ballantyne Pier, the Shed 3 structure and part of the cruise facility building will be removed down to their foundations, and the existing concrete piles supporting the warehouse and the steel piles at the cruise facility would be cut off below final grade. It is planned to re-use the heritage portion of the cruise ship facility in development of the Container Operations Facility. At the east, west and north aprons of Ballantyne Pier (and at the north deck apron of the Marginal Wharf) the reinforced concrete deck, girders, floor beams and trusses would be completely demolished and removed, and the existing large diameter concrete shafts supporting the deck superstructure will likely be cut off and removed just above low-tide. This demolition limit is chosen so that the remnant cylindrical shafts would not cause significant distress to the final pavement structure due to differential settlement. Demolition of the concrete shafts will have to be done cautiously to safely release the post-tensioned bars installed in 1995. The existing triangular-shaped steel-piled deck north of Ballantyne Pier (built in 1998) will also be demolished. Although this triangular structure is relatively new and in apparent good condition, it relies on the existing Ballantyne Pier for transfer of berthing forces, and would not be able to carry any significant berthing loads if left free-standing. A portion of the cope wall on the adjacent caissons will also be demolished and re-built due to incompatibility with the planned terminal apron grade.

At preliminary design stage, it has been assumed that the Ballantyne Pier concrete rubble will be removed from site and disposed; however, there may be opportunity to crush and re-use the concrete debris elsewhere in the CEP project, if sufficient space is available on-site for the necessary crushing and stockpiling operations.

5.6 Demolition of Southern Railway Wharf

At the east side of the Ballantyne bight, the terminal perimeter east dyke would tie into the pre-existing berm core of the Southern Railway wharf embankment, about which little is known. It will likely be necessary to demolish most of the west portion of the Southern Railway wharf concrete structure (which is in poor condition) to achieve this. However, it may be feasible to leave the Southern Railway barge ramp in place, undisturbed by the east reclamation construction activities.

6 LIMITATIONS

This summary technical report is an instrument of service of Klohn Crippen Berger Ltd. The report has been prepared for the exclusive use of AECOM Canada and Port of Vancouver for the specific application to the Centerm Expansion Project. The report's contents may not be relied upon by any other party without the express written permission of Klohn Crippen Berger. In this report, Klohn Crippen Berger has endeavoured to comply with generally-accepted professional practice common to the local area. Klohn Crippen Berger makes no warranty, express or implied.

The preliminary design as described in this technical summary report is based on data derived from a limited number of test holes obtained from widely spaced subsurface explorations. The methods used indicate subsurface conditions only at the specific locations where samples were obtained or where in-situ tests would infer, only at the time they were obtained, and only to the depths penetrated. The samples and tests cannot be relied on to accurately reflect the nature and extent of strata variations that usually exist between sampling or testing locations.

7 CLOSING

We trust this summary report meets your requirements. Please contact us if you have any questions.

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DRAWINGS

(Drawings are attached in a separate supporting document)

32-481-201	Western Expansion / Existing Wharf Demolition Plan
32-481-202	Western Expansion / Existing Wharf and Terminal Demolition – Sections
32-481-203	Western Expansion / Terminal – Plan
32-481-204	Western Expansion / Wharf Extension – Plan
32-481-205	Western Expansion / Wharf Extension – Sections
32-481-206	Western Expansion / Terminal – Sections
32-481-207	Western Expansion / Caisson C42 and C43 – Plan and Section
32-481-208	Western Expansion / Caisson Toe Protection – Plan & Section
32-481-209	Western Expansion / Keyway, Cover Slab & Connection Slab
32-481-210	Western Expansion / Crane Beam – Plan & Sections
32-481-211	Western Expansion / Sheet Pile Wall – Plan and Sections
32-481-212	Western Expansion / Mooring and Fendering
32-481-231	Eastern Expansion / Existing Ballantyne Pier – Demolition Plan
32-481-232	Eastern Expansion / Existing Ballantyne Pier – Demolition Sections – Sheet 1 of 2
32-481-233	Eastern Expansion / Existing Ballantyne Pier – Demolition Sections – Sheet 2 of 2
32-481-234	Eastern Expansion / Existing Southern Railway Wharf – Demolition Plan and Section
32-481-235	Eastern Expansion / Existing Southern Railway Wharf – Demolition Section
32-481-236	Eastern Expansion / Existing North Apron at Berth 2 – Demolition Plan and Sections
32-481-237	Eastern Expansion / Existing Marginal Wharf – Demolition Plan and Section
32-481-238	Eastern Expansion / Terminal – Plan
32-481-239	Eastern Expansion / Terminal – Sections – Sheet 1 of 2
32-481-240	Eastern Expansion / Terminal – Sections – Sheet 2 of 2D-01Testing Location and Section Plan