# Section 3.13: Berth Procedures and Provisions

# TERMPOL Surveys and Studies

## ENBRIDGE NORTHERN GATEWAY PROJECT

***FINAL - REV. 0***

**Prepared for:**
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# 1 Objectives

The objective of this study is to verify that the berthing and mooring provisions at Kitimat Terminal are adequate for the design vessels. This study examines the various types of loading that must be accounted for in the design of the marine terminal structures in order to ensure that the marine terminal can perform its primary functions. In particular, this study summaries the berthing analyses and mooring simulations which demonstrate the suitability of the berths and moorings to safely accommodate the full range of ships expected to call on the terminal. The study also summarizes the berthing and mooring strategies for the marine terminal and the various factors which affect the berthing and mooring operations.

## 1.1 Primary Functions of the Marine Terminal

It is incumbent upon the terminal operator to provide adequate reception facilities for the visiting vessels. To accomplish this, the terminal must provide marine facilities that serve two main functions:

1. Provide an adequate berthing and mooring system to safely dock and "hold" a tanker in place with as little movement as possible while the cargo transfer operations are being conducted.
2. Support the topside equipment required for the cargo transfer system in a fashion that maintains the integrity of the cargo and reduces the potential for cargo release.

Although the two main functions are somewhat independent of one another, a certain amount of integration is required in the design of the various components of the marine terminal.

## 1.2 Marine Terminal Components

Each tanker berth at the marine terminal is comprised of several independent marine structures. Each structure or "component" performs a different role which allows the marine berth as a whole to accomplish its two primary functions. The main components for each tanker berth include a central loading platform, berthing structures, mooring structures, and access structures.

### 1.2.1 Central Loading / Unloading Platform

The central loading / unloading platform provide the interface for transferring cargo between the ship and the on-shore tank facilities. Located in the middle of each berth, the central platform will be an independent structure with a large deck area that supports the cargo transfer arms and other topside equipment necessary for the safe transfer of cargo. Piping, loading arms and other equipment will take up a portion of the deck space, and the remaining area will be available for maintenance vehicle access such as a mobile crane or truck. The platform is not designed to contact nor provide any support for a moored vessel.

### 1.2.2 Berthing Structures

The berthing structures are independent structures located on either side of the central loading platform and are fitted with rubber fenders designed to absorb the kinetic energy from a berthing vessel. A main function of the berthing structures is to prevent the ship from contacting the loading platform and potentially damaging the cargo transfer system. Four fender locations, two on each side of the central platform, are required to accommodate the range of design vessels. The berthing structures also form part of the mooring system as they are equipped with mooring hooks to secure the vessel's mooring lines, and the fenders act as mooring reaction points.

### 1.2.3 Mooring Structures

The mooring structures form the balance of the mooring system and are equipped with multi-line quick release hooks which are used to secure the vessel's mooring lines. A typical tanker uses 14 to 20 mooring lines to provide enough restraint to keep it secure in the berth. Mooring lines are classified according to their orientation relative to the ship as follows:

- Breasting lines, oriented more or less perpendicular to the ship, which restrain the ship from moving away from the berth (i.e. offshore);
- Spring lines, oriented parallel with the ship, which restraint the ship from moving along the berth (i.e. fore and aft directions ); and,
- Head and stern lines, which are typically oriented at 45 degrees to the ship.

The mooring arrangement for a modern terminal relies mainly on breasting and spring lines, since these are more efficient in providing the necessary restraint. (Refer to Figure 2-3 in TERMPOL Study 3.10 for a diagram showing a typical mooring line arrangement). Nonetheless, some vessel masters prefer to also deploy head and stern lines as an added measure of safety and redundancy and provision for this will be incorporated in the layout.

A minimum of six mooring structures for each berth are required to accommodate the breasting lines for the range of design vessels expected. The mooring structures are located inshore from the fender line by a distance of 40 to 50 metres or greater. The final number, location and size of the mooring structures will be confirmed by the detailed mooring analysis conducted during the design phase of the project. As noted above, mooring hooks will also be placed on the breasting structures to accommodate the vessels spring lines. Additional mooring points will be provided on shore for head and stern lines.

### 1.2.4 Access Structures

Typically the central loading platform is connected to the land by one or more access trestles or causeways. The access ways are typically wide enough to accommodate a vehicle lane and the required pipelines and other utilities for the cargo transfer system. The berthing and mooring structures can also be connected to the central platform and the shore via catwalks or walkways thereby providing pedestrian access to all marine structures.

# 2 Structural Loads

The marine structures are designed for combinations of different types of specified loads resulting from the vessel operations, the cargo transfer operations, and the environment. These specified load types include, but may not be limited to, dead, live, berthing, mooring, wind, wave, current, earthquake, snow, rain, ice, buoyancy, and earth pressure. The design of the various components will be in accordance with recognized industry design codes, standards, and guidelines. For a list of applicable codes and standards, refer to Appendix B in TERMPOL Study 3.10.

Dead and live loads are mostly gravity loads that are a direct result of cargo transfer operations and other related activities occurring on the decks of the marine structures. Berthing loads result directly from vessel operations, and mooring loads are influenced by both vessel operations and environmental conditions. Most of the structural loads are caused by environmental forces. Design loads for wind on vessels, waves, and current, are derived from historical data, data from recent studies, and other published references (see TERMPOL Study 3.10, Appendix B). Design loads for wind on marine structures, snow, rain, temperature, and earthquake are based on the 2005 National Building Code of Canada. Design loads for ice accretion are based on CAN / CSA-S6-06 Canadian Highway Bridge Design Code.

The individual load types as listed below were used for preliminary design purposes and are subject to change pending final design and final vendor selection.

## 2.1 Dead Loads

Dead loads include the weight of the entire structure and any permanent attachments such as loading arms, pipelines, deck crane, fire monitor towers, gangway structure and mooring hardware. Dead loads include but are not limited to the following:

### 2.1.1 Central Loading Platform

- Loading Arms:
  - Dead weight (each): 38,000 kg (373 kN)
- Equipment and Piping:
  - Equipment and piping area (total): TBA
  - 3-tonne davit crane (dead weight): 1,300 kg (13 kN)
- Light Tower;
  - Dead weight: 18,000 kg (177 kN)
- Fire Monitor Tower:
  - Dead weight: 10,195 kg (100 kN)
- Operator's Shed:
  - Dead weight allowance: 2.0 kPa

### 2.1.2 Main Trestle

- Pipe Rack
  - Piping and conduit: 2,230 kg / m (22 kN / m)
  - 36-inch expansion joint with containment: TBA
  - Expansion loops for other piping: 3,630 kg (36 kN)
  - Cable Tray: 45 kg / m (0.44 kN / m)

### 2.1.3 Secondary Trestle

- Piping and Utilities: 3.0 kN / m

### 2.1.4 Berthing Structures

- Gangway tower with 5-ton crane on top: TBA
- 2-Hook quick release mooring hook: 2,500 kg (25 kN)
- Fenders (each): 6,600 kg (64.7 kN)
- Fender Panels: 400 kg / m^2 (3.9 kPa)
- Chains (per / panel): 10,000 kg (98 kN)

### 2.1.5 Mooring Structures

- Docking assistance display board weight: TBA
- 3-Hook quick release mooring hook: 3500 kg (34 kN)

## 2.2 Berthing Loads

Berthing loads result from the impact of a docking vessel as it makes contact with the fender units on the berthing structures. The energy from the vessel impact is known as the berthing energy and it must be absorbed by the fender units, typically through elastic compression of their rubber elements. As the fender units are compressed, a reaction is produced which must be resisted by the berthing structures. This reaction is the design berthing load for the structure and is a function of the size and type of fender units selected.

### 2.2.1 Berthing Analysis

A preliminary berthing analysis was conducted to determine the required energy absorbing capacity for the selection of the fender units and the design berthing load for the berthing structures. For the various design vessels expected to berth at the marine terminal, four separate berthing scenarios were investigated to determine the maximum berthing energy (Ref. 1):

1. VLCC loaded to normal ballasted condition (Normal Event).

2. VLCC fully loaded for re-berthing scenario (Rare Event).
3. Suezmax condensate vessel berthing fully loaded (Normal Event).
4. Aframax condensate vessel berthing fully loaded (Normal Event).

The berthing energies for each scenario were determined using the kinetic energy method in accordance with PIANC 2002 [Ref. 2]. Berthing energies were calculated for both normal and abnormal berthing conditions. The abnormal berthing energies are equal to the normal berthing energies multiplied by a factor to account for uncertainties such as mishandling, malfunction or adverse wind and currents. The design criteria and the calculated berthing energies for each of the above scenarios are summarized in Table 2-1.

## Table 2-1 Design Vessel Data and Berthing Energy Parameters

| PARAMETER | | BERTHING SCENARIOS | | | |
|---|---|---|---|---|---|
| | | 1 VLCC 50% Ballasted (Normal) | 2 VLCC Fully Loaded (Rare) | 3 Suezmax Fully Loaded (Normal) | 4 Aframax Fully Loaded (Normal) |
| Dead Weight Tonnage (t) | DWT = | 160,000 | 320,000 | 160,000 | 90,000 |
| Overall Length | LOA = | 343 | 343 | 274 | 240 |
| Length Between Perpendiculars (m) | LBP = | 320 | 320 | 265 | 230 |
| Beam (m) | B = | 58 | 58 | 48 | 40 |
| Laden Draft (m) | D = | 23.0 | 23.0 | 17.1 | 13.4 |
| Displacement Tonnage / DWT ratio | DT / DWT = | N / A | 1.20 | 1.25 | 1.30 |
| Actual Displacement Tonnage (t) | DT = | 224,000 | 384,000 | 200,000 | 117,000 |
| Impact Velocity (m / s) | $V_n$ = | 0.125 | 0.105 | 0.130 | 0.165 |
| Virtual Mass Factor $C_m$ | $C_m$ = | 1.793 | 1.793 | 1.713 | 1.670 |
| Maximum Berthing Angle (Degrees) | θ = | 7° | 7° | 7° | 7° |
| Eccentricity Coefficient | $C_E$ = | 0.782 | 0.853 | 0.785 | 0.717 |
| Softness Factor | $C_S$ = | 1.00 | 1.00 | 1.00 | 1.00 |
| Berth Configuration Factor | $C_C$ = | 1.00 | 1.00 | 1.00 | 1.00 |
| Abnormal Impact Factor | $C_{AB}$ = | 1.25 | 1.25 | 1.35 | 1.50 |
| Friction Coefficient (Fender Face to Ship) | μ = | 0.20 | 0.20 | 0.20 | 0.20 |
| Maximum Hull Pressure (kN / $m^2$) | P = | 200 | 200 | 200 | 200 |
| Calculated Normal Energy Requirement (kNm) | $E_N$ = | 2453.9 | 3237.7 | 2271.9 | 1907.0 |
| Calculated Abnormal Energy Requirement (kNm) | $E_A$ = | 3067.3 | 4047.1 | 3067.0 | 2860.6 |

### 2.2.2 Berthing Analysis Results and Fender Selection

The fender units shall have an energy absorption capacity greater than the energy demand for abnormal berthing conditions. The results of the berthing analysis indicate a maximum abnormal berthing energy of 4047 kNm occurs for Scenario 2, a fully loaded VLCC. In calculating the design berthing energy requirements of the fender, additional allowances must be applied to the abnormal berthing energy as follows:

- 10 percent allowance for reduction in fender energy capacity due to manufacturing tolerances.
- Angular correction factors.
- Reduction in fender energy capacity due to temperature effects based on the 2.5 percent maximum design temperature for Kitimat in accordance with the temperature influence factors from PIANC 2002 [Reference 2].
- Velocity and deceleration impact factors.

Based on the above allowances, the resulting design berthing energy is equal to approximately 4500 kNm. The selected fender system must have enough energy absorption capacity to meet this energy requirement. Based on the preliminary berthing analysis, each fender unit will likely require one or two cone-type fenders with diameters of at least 1.8 metres in order to obtain an energy absorbing capacity greater than 4500 kNm. Several viable options exist for the actual fender selection based on manufacturer, size, number of fenders, rubber composition, etc. Finalization of the fender unit design will be based on the final berthing analysis conducted during the detailed design phase.

### 2.2.3 Design Berthing Loads

The maximum berthing force applied to the berthing structures is taken as the rated reaction from the selected fender system. To determine the design berthing force, the following allowances are made to modify the rated reaction of the selected fender system:

- 10 percent allowance for increase in fender reaction force due to manufacturing tolerances (if limit states design is used, the manufacturing tolerance may be considered to be accounted for in the application of the load factor).
- Angular correction factors.
- Increase in fender reaction force due to temperature effects based on a minimum design temperature of 0 deg. C (freezing point of water) in accordance with the temperature influence factors from PIANC 2002.
- Velocity and deceleration impact factors.

Assuming that for each fender unit the selected fender system is comprised of two Fentek SCN1800 (E1.2) Supercone Fenders, the manufacturer's total rated reaction for these fenders would be 4952 kN. After adjustments for the above allowances, the specified berthing reaction load is calculated to be 5442 kN. This value represents the compressive thrust that is applied by the fender onto its supporting structure and is considered the design berthing load for the berthing structures. This load shall be factored in accordance with the appropriate design code for design of the berthing structures as per limit states design.

In addition to the normal compressive thrust from the fenders, vertical and horizontal friction shear forces resulting from the vessel rubbing against the fender face panel, need to be considered also. Assuming a friction coefficient of 0.2, the vertical and horizontal design friction forces are equal to 0.2 x 5442 = 1088 kN. The friction coefficient will be confirmed upon the final selection of the fender system during detailed design.

A summary of the design berthing loads is as follows:

- Maximum Fender Compressive Thrust: 5,442 kN
- Maximum Fender Vertical or Horizontal Shear Load: 1,088 kN

## 2.3 Mooring Loads

Mooring loads are the forces caused by wind, waves and currents acting on a ship while it is docked at the berth. Mooring lines are deployed from the vessel and hooked onto the mooring hardware mounted on the mooring structures. The mooring line configuration may vary depending on the type and size of vessel. The mooring lines provide a means of holding the vessel against the berth's fender units and restricting the movements of the ship while cargo transfer operations are conducted.

The mooring loads may occur both as a tensile pull on the mooring lines and as a compressive thrust on the fender units. The mooring hooks and mooring structures are designed to resist these induced tensile loads from the mooring lines. Since multiple mooring lines can be attached to a single hook assembly or mooring structure, the total load induced by all the lines must be considered in the design of the hardware and mooring structure.

The berthing structures are required to resist the compressive thrusts induced on the fender units. The berthing structure design is governed by either the berthing loads or the mooring loads whichever is more critical.

### 2.3.1 Mooring Analysis

As part of the detailed design phase, the mooring system will be analyzed with sophisticated mooring simulation computer models. These models will generate ideal mooring line arrangements for all sizes of design tankers and will determine the safe operating limits with respect to the environmental conditions at the marine terminal. The mooring analysis will also determine the design forces for the mooring hardware and structures.

To estimate the structural design forces on the mooring structures, a preliminary static mooring analysis was conducted for two mooring line configurations based on VLCC and Suezmax class vessels [Ref. 1]. For the given design vessels, the purpose of the mooring analysis was to determine the maximum vessel movements, maximum mooring line tension and the maximum design forces on the mooring and berthing structures.

For the mooring analysis, the wind load was based on a 50-year return period. For any given mooring analysis, the following wind speed corrections may be required depending on the conditions under which the wind data was collected:

- Wind speed adjusted to a reference elevation of 10 m above the water surface;

- Wind speeds measured in over-land conditions converted to over-water conditions; and,
- Wind gust duration adjusted to 30-second duration.

The design wind speeds as given in Table 2-5 have already been adjusted to a reference elevation of 10 m and represent over-water conditions. However, since this basic metocean wind data is in the form of "hourly wind speeds", for the purposes of the mooring analysis, they were converted to "30-second duration" wind speeds using a conversion factor of 1.33 [Ref. 1]. Table 2-2 lists the metocean conditions used in the mooring analysis.

### Table 2-2 Metocean Criteria Used in the Mooring Analysis

| **Wind** | **Speed (30-second duration):** | **32.45 m / s (63.1 knots)** |
|---|---|---|
| | **Direction:** | **All**[1] |
| Current | Velocity: | 1.5 knots |
| | Direction: | Varies + / -10$^{o}$ to berth face on both sides |
| Wave | Significant Wave Height: | 1.81 m |
| | Wave Period: | 4.9 seconds |
| | Direction: | Varies 30$^{o}$ to berth face on sea side |
| Tide (Hydrographic Datum) | Recorded Extreme High Tide: | +6.7 m |
| | Mean Sea Level: | +3.3 m |
| | Low Normal Tide (LNT): | 0.0 m |
| | Recorded Extreme Low Tide: | -0.2 m |

## 2.3.2 Mooring Analysis Results

The mooring loads induced by a VLCC are the most critical and a summary of the governing mooring analysis results is as follows:

- Maximum Vessel Movements:
  - Maximum vessel surge: 1.5 m
  - Maximum vessel sway: 1.0 m
- Maximum Mooring Line Tension: 618 kN (63.0 tonnes)

[1] It is recognized that the predominate wind directions are aligned with the axis of Douglas Channel, i.e. either "inflow" or "outflow" winds that are roughly parallel to the tanker berths. For the purposes of the preliminary mooring analysis, winds were conservatively assumed to come from any direction. This analysis will be refined during the detailed design to account for the wind directionality.

- Maximum Mooring Loads on the Mooring Structures:
  - Maximum horizontal mooring hook load: 1,555 kN (158.6 tonnes)
  - Maximum vertical mooring hook uplift: 453 kN (46.2 tonnes)
- Maximum Mooring Loads on the Berthing Structures:
  - Maximum fender compressive thrust: 2,354 kN (240 tonnes)
  - Maximum fender frictional shear load: 471 kN (48.0 tonnes)
  - Maximum horizontal spring hook load: 1,153 kN (117.6 tonnes)
  - Maximum vertical spring hook uplift: 453 kN (46.2 tonnes)

### 2.3.3 Design Mooring Loads

Under limit states design, the marine structures are designed for both service limit states and ultimate limit states. The service limit states for mooring loads are used to determine vessel movements at the berth and establish limiting environmental criteria for vessel operations, see Section 4.6.8. The ultimate limit states will typically govern the structural design of the mooring system.

For the preliminary structural design of the mooring system, two loading conditions were used to determine the ultimate mooring hook design load. The maximum of the factored loads from the two load conditions will govern the design of the mooring structures. The two load conditions are given as follows:

1. Service level mooring hook loads derived from the results of the mooring analysis and multiplied by load factor of 1.5.
2. Overload mooring hook loads derived from a formula based on the Minimum Breaking Load (MBL) of the mooring lines multiplied by a load factor of 1.0.

For the first load condition, the mooring analysis is conducted with winds based on a 50 year return period. The results from the analysis are service level loads and thus need to be multiplied by a load factor greater than 1.0 to achieve factored or "ultimate" design loads. For preliminary design a load factor of 1.5 was used, see Section 3.0. The following are the factored mooring loads derived from the mooring analysis:

- Maximum Factored Mooring Loads on the Mooring Structures:
  - Maximum horizontal mooring hook load: 2,400 kN (244.7 tonnes)
  - Maximum vertical mooring hook uplift: 809 kN (82.4 tonnes)
- Maximum Factored Mooring Loads on the Berthing Structures:
  - Maximum fender compressive thrust: 3,591 kN (366 tonnes)
  - Maximum fender frictional shear load: 719 kN (73.2 tonnes)
- Maximum horizontal spring hook load: 1,574 kN (160.4 tonnes)
- Maximum vertical spring hook uplift: 653 kN (66.5 tonnes)

The second load condition derives loads which are considered to already be at the "ultimate" load level and thus are multiplied be a load factor equal to 1.0. The second load condition protects the berth structures in an overload situation by ensuring the mooring lines from the vessel will fail first before the actual mooring structures or hardware. This is accomplished by ensuring the mooring structure and its hardware are stronger than the combined strength of all the mooring lines attached to it. These "overload" mooring hook loads are derived from a formula which accounts for the Minimum Breaking Load of the mooring lines and the number of mooring lines attached to a particular structure as follows:

- Factored Mooring Hook Load (Overload Conditions) = 1.0 x $C_h$ x MBL

  Where:

  1.0 = Load Factor

  $C_h$ = 1.2 x [1+ (n-1) ·0.75] (Coefficient for Multiple Hooks)

  n = 2, 3, or 4 (Number of hooks on the structure)

  MBL = Minimum Breaking Load of each mooring line.

For preliminary engineering it is assumed that the Minimum Breaking Load for a typical 42 mm diameter 6x37 IWRC mooring line is MBL = 1187 kN (121 tonnes). Based on the above formula and the given MBL, the factored overload mooring hook loads can be calculated as:

- Maximum Factored Overload Mooring Hook Loads
  - Horizontal mooring hook load (2 hooks) 2,493 kN (254 tonnes)
  - Horizontal mooring hook load (3 hooks) 3,561 kN (363 tonnes)
  - Horizontal mooring hook load (4 hooks) 4,630 kN (472 tonnes)

By comparing the factored loads from the two load conditions, the governing ultimate factored mooring loads for the design of each mooring structure can be summarized as follows:

- Mooring Structures with 4 Hooks:
  - Maximum Factored Horizontal Mooring Hook Load: 4,630 kN (472 tonnes)
  - Maximum Factored Vertical Mooring Hook Uplift: 809 kN (82.4 tonnes)
- Berthing Structures with 2 Hooks:
  - Maximum Factored Horizontal Spring Hook Load: 2,493 kN (254 tonnes)
  - Maximum Factored Vertical Spring Hook Uplift: 635 kN (66.5 tonnes)

In addition to the mooring loads on the spring line hooks, the berthing structures are also designed to resist the mooring load reactions and berthing loads on the fenders. A comparison of the service level mooring load reactions from the mooring analysis and the service level berthing loads from the berthing analysis indicates that the berthing loads are much larger and are the governing design load on the fenders.

## 2.4 Seismic Loads

The seismic accelerations for various probabilities of exceedance were derived by the interpolation of the 2005 National Building Code of Canada (NBCC) seismic hazard values for the project site as located at [53.95º N, 128.70º W]. Table 2-3 summarizes the Uniform Hazard Response Spectrum for the project site.

**Table 2-3 Uniform Hazard Response Spectrum**

| Performance Level | Probability of Exceedance in 50 Years | Probability of Annual Exceedance | Spectral Response Accelerations* (5% Damping) | | | | PGA** | Return Period in Years |
|---|---|---|---|---|---|---|---|---|
| | | | Sa(0.2) | Sa(0.5) | Sa(1.0) | Sa(2.0) | | |
| OBE | 10% | 0.2105% | 0.17g | 0.11g | 0.06g | 0.04g | 0.09g | 475 |
| SSE | 2% | 0.0404% | 0.38g | 0.24g | 0.13g | 0.08g | 0.18g | 2,475 |

**Notes:** * Sa = 5% damped horizontal Spectral Response Accelerations for the periods of 0.2, 0.5, 1.0, and 2.0 seconds.

** PGA =5% damped horizontal Peak Ground Acceleration.

Structural performance criteria are established in accordance with the requirements of the NBCC 2005. The performance criteria for the level of acceptable seismic damage shall be based on the following two seismic events:

- Operating Basis Earthquake (OBE).
- Safe Shutdown Earthquake (SSE).

The OBE is defined as the seismic event that produces ground motions associated with a 475-year return period. After the OBE event, the berth should be operable.

The SSE is a rare and extreme seismic event that produces ground motions associated with a 2,475-year return period. After the SSE event, the level of berth damage shall preclude any loss of containment of crude oil or condensate.

## 2.5 Temperature Loads

The following design temperature data is in accordance with Table C-2, in Appendix C of the National Building Code of Canada, for the "Kitimat Plant" (Alcan site).

- 2.5 percent July Design Temperature[2]: 23°C
- 2.5 percent January Design Temperature: -16°C
- Degree Days Below 18°C: 4,000

[2] 2.5% July temperature represents the 97.5 percentile maximum temperatures on record for that month. Similarly, the 2.5% January temperature is the 97.5 percentile lowest temperatures for that month.

Water temperature changes are not as great as atmospheric temperature changes. The following recorded water temperatures for near surface depths are applicable to the marine structures:

- Maximum Monthly Average (August): 16°C
- Minimum Monthly Average (January): 5°C

The marine structures shall be designed to accommodate the forces and effects of thermal expansion and contraction of pipelines, equipment, and structural elements due to temperature differentials derived from the above design values.

## 2.6 Wind Loads

Hourly design wind speeds for the project site are given in Table 2-4. These values are based on a statistical analysis of the Nanakwa Shoal wind data using the ACES Code of Extremal Analysis program [Ref. 6]. This program used Weibull distributions to determine extreme wind speeds for the return periods of 2, 5, 10, 25, 50 and 100 years. The equivalent design wind pressure for a given hourly design wind speed is also given in Table 2-4.

### Table 2-4 Uniform Hazard Response Spectrum

| Return Period (years) | Maximum Sustained Wind (m / sec) | | | |
|---|---|---|---|---|
| | Wind Speed From NE | Wind Speed From SW | Governing Speeds (All Directions) | |
| | | | Wind Speed, V | Equivalent Wind Pressure* (kPa) |
| 2 | 16.0 | 13.8 | 16.0 | 0.165 |
| 5 | 19.1 | 16.4 | 19.1 | 0.236 |
| 10 | 21.0 | 17.9 | 21.0 | 0.285 |
| 25 | 23.0 | 19.5 | 23.0 | 0.342 |
| 50 | 24.4 | 20.6 | 24.4 | 0.385 |
| 100 | 25.6 | 21.6 | 25.6 | 0.424 |

**Note:** * Equivalent Wind Pressure: $q\ (kPa) = 0.00064645 \times V^2$

For comparison to the design wind speeds based on the Nanakwa Shoal wind data, the following wind reference velocity pressures for return periods of 10 and 50 years are given in accordance with Table C-2, in Appendix C of the National Building Code of Canada, for the Kitimat Plant (Alcan).

- $q_{(1/10)}$: 0.36 kPa
- $q_{(1/50)}$: 0.48 kPa

For the determination of mooring loads, wind loading on the design vessels shall be based on the wind data from the Nanakwa Shoal dataset for a 50 year return period.

The marine structures shall also be designed for a 50 year return period wind reference velocity pressure applied directly to the structures and topside equipment in accordance with the National Building Code of Canada.

## 2.7 Wave Loads

### 2.7.1 Wind Generated Waves

Based on the estimated wave heights, the design wave heights given for the return periods of 2, 5, 10, 25, 50 and 100 years are summarized in Table 2-5. The maximum wave period of 4.9 seconds is conservatively used for all return periods.

**Table 2-5 Design Wave Heights**

| Return Period (Years) | Wave Height, H (m) | | | Wave Period, $T_p$ (sec) |
|---|---|---|---|---|
| | $H_s$ | $H_{1/10}$ | $H_{1/100}$ | |
| 2 | 1.08 | 1.37 | 1.80 | 4.9 |
| 5 | 1.33 | 1.69 | 2.22 | |
| 10 | 1.53 | 1.94 | 2.56 | |
| 25 | 1.68 | 2.13 | 2.81 | |
| 50 | 1.81 | 2.30 | 3.02 | |
| 100 | 1.92 | 2.44 | 3.21 | |
| **Notes:** $H_{1/10} = 1.27H_S$ (Upper 10th percentile wave height); and $H_{1/100} = 1.67H_S$ (Upper 1st percentile wave height) | | | | |

The significant wave height, $H_S$, is the average of the highest one-third of all waves. The peak spectral period, $T_P$, is the dominant frequency of the wave energy spectrum. Return period is defined as the mean interval between events of a given magnitude.

For structural design of the proposed marine terminal, the following wave heights are typically used associated with appropriate service life of the structures:

- Significant wave height, $H_S$, shall be used for design of flexible structures, e.g. riprap slopes and rubble mound breakwaters;
- $H_{1/10}$ shall be used for design of semi-rigid structures, e.g. sheet pile walls; and,
- $H_{1/100}$ shall be used for design of rigid structures, e.g. wharf structures, caissons, keyways and cope wall.

### 2.7.2 Vessel Generated Waves

A vessel wake study was carried out to characterize the ship- and tug-generated waves from the proposed VLCC and tugboat traffic in Douglas Channel (Ref. 7). Based on this analysis, vessel wakes were found to be small (generally less than 0.3 m) which is considerably less than ambient wind wave conditions. Therefore, vessel wakes are considered to be negligible in terms of their effects on the marine facilities or on the potential for erosion to the shoreline along the proposed tanker routes.

### 2.7.3 Tsunami Waves

Tsunamis are low-frequency ocean waves generated by underwater disturbances such as earthquakes, volcanic eruptions, landslides, etc. Tsunamis generated from earthquakes and volcanoes can travel great distances from the source, whereas those generated by landslides tend to be more localized. The risk of a tsunami in Kitimat Arm originating from distant (e.g., Pacific Rim) sources is considered to be low, due to the complex nature of the coastal inlets between Kitimat and the open sea which tends to attenuate distant tsunami energy. On the other hand, there was a well-documented underwater landslide at Moon Bay in Kitimat Arm in 1975 which generated a tsunami. The wave travelled across the channel and caused damage at Kitamaat village.

To investigate the risk of locally-generated tsunami, a numerical modeling study was recently completed to evaluate the effects of the 1975 tsunami on nearby areas within Kitimat Arm [Ref. 9]. The study showed that a similar landslide originating at the same location could generate wave run-up heights on the order of 1.5 to 3m at the Kitimat Marine Terminal site. Additional research and analysis is currently underway to quantify the level of risk of tsunamis originating from other potential areas of landslides within Kitimat Arm. The results of this analysis will be documented and incorporated in the project design criteria at a later date.

### 2.7.4 Design Wave Loads

Wave loading on the design vessels for the determination of mooring loads on the marine structures shall be based on the significant wave height "Hs" for a 50 year return period.

Wave loading applied directly on the marine structures shall be based on the upper 1st percentile mean wave height "$H_{1/100}$" for a 50 year return period. Wave forces on pile or jacketed structures shall be determined by application of the Morison equation to a suitable wave theory. The drag and inertia coefficients shall be as follows:

- $C_D$ = 0.7 to 0.9
- $C_M$ = 1.5

## 2.8 Current Loads

Based on the recent and historical recorded data; the published CHS Marine Chart data; and the estimated wind-generated currents, a maximum design current velocity of 80 cm / s (1.5 knots) was used for the marine terminal design.

Current forces on the design vessels for the determination of mooring loads on the marine structures shall be based on this design current velocity.

Current forces applied directly to the marine structures shall be based on the design current velocity and a drag coefficient as follows:

- $C_D$ = 0.7 to 0.9

## 2.9 Snow and Rain Loads

The closest location to Kitimat Terminal for listed snow and rain loading is the Kitimat Plant located approximately 10 km north along the shoreline from the project site. The following rainfall data is in accordance with Table C-2, in Appendix C of the National Building Code of Canada, for the Kitimat Plant:

- 15 Minutes: 13 mm
- One Day Rainfall (1 / 50): 193 mm
- Annual Total Precipitation: 2,500 mm

The following snow and rain load data is in accordance with Table C-2, in Appendix C of the National Building Code of Canada, for the Kitimat Plant:

- Ground Snow Load, Ss: 5.5 kPa
- Rain Load, Sr: 0.8 kPa

The snow and rain loading shall be applied as per the National Building Code of Canada.

## 2.10 Ice Accretion Loads

The following design ice thickness and density for ice accretion loads is in accordance with Figure A3.1.4, Annex A3.1, CAN / CSA-S6-06 Canadian Highway Bridge Design Code:

- Ice Accretion Zone: Heavy
- Ice Thickness: 31mm
- Ice Density: 9.8 kN / $m^3$

From the ice thickness and density, the additional loading on a surface due to ice build-up is calculated to be:

- Ice accretion loading: 0.30 kPa

The ice accretion loading shall be applied as per CAN / CSA-S6-06.

## 2.11 Live Loads

Live loads are variable loads resulting from the intended use and occupancy of a structure including loads caused by pedestrian traffic, moveable equipment, vehicles and general operations. In addition to the minimum live loads stipulated by the National Building Code of Canada, live loads shall include but not be limited to the following:

### 2.11.1 Central Loading / Unloading Platform

- Cargo Arms:
  - Max Overturning Moment: TBA
- Equipment and Piping:
  - 42-inch thrust loads at 90 degree elbow: TBA
  - 3-tonne davit crane (rated capacity): 3,000 kg (29.4 kN)
    An impact allowance of 25 percent will be added to the davit load.
- Vehicle Loads:
  - See main trestle vehicle loads.
- Uniformly Distributed Loads:
  - Uniform live load within open deck areas: 15.0 kPa
  - Uniform live load within topsides / piping areas: 4.8 kPa

### 2.11.2 Main Trestle

- Pipe Rack:
  - Uniform live load within topsides / piping areas: 4.8 kPa
- Roadway:
  - CL – 625 Truck (Gross load, 625kN)

    1st axle: 50 kN

    2nd axle: 125 kN

    3rd axle: 125 kN

    4th axle (if applicable): 175 kN

    5th axle (if applicable): 150 kN

    An impact allowance of 30 percent will be added to the above loads.

- 30 ton hydraulic mobile crane

  G.V.W. Front axle load: 14,446 kg (142 kN)

  G.V.W. Rear axle load: 13,544 kg (133 kN)

  Crane rated capacity (30ton=60,000 lbs): 27,223 kg (267 kN)

  Maximum outrigger pad load: 22,498 kg (221 kN) over 419 mm square pad

  An impact allowance of 20 percent will be added to the above loads.

- Uniform live load within open deck areas: 15.0 kPa

- Walkway:
  - Uniform live load within walkway areas: 4.8 kPa

### 2.11.3 Secondary Trestle

- Maintenance vehicle load (G.V.W. = 80kN)
  - Front axle: 2,446 kg (24kN)
  - Rear axle: 5,708 kg (56kN)
  - An impact allowance of 20 percent will be added to the above load.
- Uniform live load: 10.0 kPa

### 2.11.4 Berthing Structures

- Gangway tower 5-tonne crane (rated cap.): 5,000 kg (49 kN)
- Tower / Gangway operating weight: TBA
- Uniform live load: 4.8 kPa

### 2.11.5 Mooring Structures

- Uniform live load: 4.8 kPa

### 2.11.6 Catwalks

- Uniform live load: 2.4 kPa

## 2.12 Earth Fill and Hydrostatic Pressure Loads

Hydrostatic loads on the pile-supported marine structures will include buoyancy effects due to the displacement of seawater. Buoyancy will reduce the effective dead weight of the structures and is critical when considering uplift or overturning load combinations.

The pile-supported marine structures will not experience earth pressure loads however, earth pressures may act on the trestle abutments depending on their final structural configuration. Earth pressures due to both fill and surcharge loading may develop behind the head wall and wing walls of an abutment if it is principally designed as a retaining wall structure. These earth pressures along with hydrostatic pressures will act as lateral forces on the walls and will need to be accounted for in the design and stability of the abutment structure.

# 3 Load Combinations

The limit states load factors and combinations recently adopted by the 2005 National Building Code of Canada (NBCC) were used for the preliminary design of the marine structures. These load factors and load combinations are based on the "companion action" principle as described in the User's Guide to the NBCC 2005 [Ref. 8]. In the process of developing these load combinations, the specified structural loads, as given in the previous section, are divided into three categories:

1. Permanent loads, such as dead load and earth pressure;
1. Variable loads, such as live (use and occupancy), snow, and wind loads; and,
2. Rare loads, such as earthquake loads.

In general, the load combinations can be determined by separating these specified loads into two components: a sustained or frequently occurring component, including such loads as dead load, earth pressure, and sustained live load; and a transient component, which includes rare or short duration loads such as impact, wind, earthquake, and short term live loads. Because the transient components of different loads are unlikely to occur simultaneously, the critical load combination for a given structural effect is estimated by combining the factored permanent loads with the factored variable or rare load having the greatest transient component (principal load), plus the sustained or frequent components of all other variable loads (companion loads) [Ref. 8].

For structures that have vehicle loading, the basic load combinations from the NBCC were supplemented with combinations from CAN / CSA S6-00 Canadian Highway Bridge Design Code (CHBDC). Specific combinations were also developed for vessel loading conditions, where vessel loads are given the same load factor as live loads. The following list of load factors was used in the preliminary design of the marine terminal:

- Dead: Load Factor = 1.4 ; 1.25
- Dead (Overturning Condition): Load Factor = 0.9
- Live (Use and Occupancy): Load Factor = 1.5
- Live (Vehicle): Load Factor = 1.7
- Snow and Rain: Load Factor = 1.5
- Ice Accretion: Load Factor = 1.3
- Wind on Structure: Load Factor = 1.4
- Wave on Structure: Load Factor = 1.5
- Current on Structure: Load Factor = 1.5
- Earthquake: Load Factor = 1.0
- Hydrostatic / Buoyancy: Load Factor = 1.5
- Lateral Earth Pressure: Load Factor = 1.5

- Temperature: Load Factor = 1.25
- Ship Berthing: Load Factor = 1.5
- Ship Mooring (ultimate level): Load Factor = 1.0
- Ship Mooring (service level): Load Factor = 1.5

For each independent marine structure, the applicable load combinations used for the preliminary design are given in the load combination tables in Appendix A.

It should be noted that the National Building Code of Canada was developed primarily for buildings and despite TERMPOL recommendations, may not be entirely sufficient for the design of non-building marine structures. Other codes may be more relevant such as the newly developed California State Lands Commission - Marine Oil Terminal Engineering and Maintenance Standards (MOTEMS) which is specific to marine oil terminal design and was just recently adopted into California law. The final load factors and load combinations will comply with the design code that is selected for the detailed design of the marine structures.

# 4 Berthing Strategy

As described in the following sections, the berthing strategy in terms of the tanker's approach and departure from the terminal berths determines the requirements for tug assistance, mooring assistance, and the maximum allowable berthing velocity.

## 4.1 Pilot Requirements

In accordance with the *Canada Shipping Act*, the *Pilotage* Act, and the Pacific Pilotage Requirements, it is compulsory that foreign-flag ships over 350 gross registered tons utilize the services of a marine pilot when they enter coastal waters in British Columbia. The marine pilot's responsibilities are to ensure that the vessel is safely navigated in coastal waters so that there is no damage to the ship, its crew, or to the marine environment.

The pilots will be taken onboard an inbound tanker in the coastal areas of Dixon Entrance or Hecate Strait. The services of two pilots will likely be required for the estimated 12 to 18 hour voyage between the coastal waters and Kitimat Terminal. The pilots' role is critical for assisting with the navigation of the vessel through the inner waterways and the berthing / mooring operation once the vessel arrives at the terminal.

## 4.2 Pre-Berthing Activities

Before arriving at Kitimat Terminal, the Master, officers and the pilot will devise a plan for the berthing and mooring operations. The berthing / mooring operations plan will include such subjects as the placement of the assisting tugs, the terminal mooring plan, the sequence of mooring line connections, safety of the mooring operation, and other pertinent issues.

## 4.3 Berthing Operations

### 4.3.1 Tug Assistance Requirements

Tug assistance will be required for berthing and un-berthing the tankers at Kitimat terminal. For a loaded tanker of the design size range, it is typical practice to use three or four tugs for berthing or unberthing a laden ship and two or three tugs for berthing or un-berthing a ballasted ship. Harbour tugs will meet an incoming vessel at a safe location, such as towards the outer harbour limits (approximately 5 km south of the marine terminal), and then escort the tanker to the berth. The incoming vessel will be accompanied by escort tug(s) and will assist the harbour tugs in the berthing (or unberthing) operation. The tugs will take their positions according to the pilot's direction and prepare to assist in the berthing operation by making lines fast and manoeuvring the tanker as required by the pilot.

Depending on whether a tanker arrives ballasted or fully laden, and the environmental conditions prevailing at the time of berthing, it may be preferable to turn the tanker either before it enters the berth or after it departs the berth (see Sections 4.3.2 and 4.3.3 below). Once the inbound tanker has been turned into the desired orientation, if required, and has been positioned approximately 200 to 300 m t of the berth, it is ready for the final manoeuvres into the berth. Using the dock monitoring system, as described below, and other aids, the pilot will direct the harbour tugs to manoeuvre the tanker alongside the dock and push the vessel against the berth's fender units. The vessel's approach speed and approach angle will be kept as low as practical to prevent damage to the dock structures (see Section 4.3.5).

When a tanker is ready to depart, tugs will be used to assist the vessel off the berth fenders and turn the vessel as required in the turning basin. Tethered tug escort will be provided for laden tankers throughout the Confined Channel sections in combination with a close escort tug from Kitimat Terminal to the Pilot boarding stations at, Browning Entrance and Caamaño Sound. A Close Escort tug will be provided for all ballasted tankers within the same confined channel sections, and will also escort laden and ballasted tankers to the Triple Island pilot station.

### 4.3.2 Condensate Tanker Manoeuvres

Under most conditions, inbound condensate tankers arriving in a loaded condition will normally berth with their port sides to the loading platform. This allows for a straight arrival course as the vessel approaches the terminal. In this orientation there will be no need for the tugs to turn the fully loaded tanker before it is manoeuvred into the berth. This is advantageous because turning a vessel is generally easier when the vessel is in a light or ballasted condition.

Upon departure, once the tugs have cleared the condensate tanker from the berth, the tanker will be required to make a 180 degree turn in the turning basin in order to transit back to the open ocean. However, since the condensate tanker will have discharged its cargo, this turning manoeuvre will be done in a light or ballasted condition as opposed to a fully loaded condition, allowing the tugs to manoeuvre the tanker more easily.

Starboard-side berthing may be required for the condensate tankers depending on meteorological conditions and preferences of the pilots, in which case the arrival and departure approaches will be the reverse to that given above.

### 4.3.3 Oil Tanker Manoeuvres

Inbound oil tankers arriving in a ballasted condition will normally berth with their starboard sides to the loading platform. This means the oil tanker will be required to make a 180° turn in the turning basin first, before the tugs manoeuvre the tanker into the berth.

After the oil tanker has loaded its cargo and is ready to depart, the tugs will manoeuvre the tanker off the berth and the vessel will head under escort toward the open sea.

Port-side berthing may be required for the oil tankers depending on meteorological conditions and preferences of the pilots, in which case the arrival and departure approaches will be the reverse of that given above.

### 4.3.4 Docking Monitoring System

To assist the pilot and ship's crew, each tanker berth will be equipped with a computerized docking monitoring system. The system is designed to provide feedback information to the pilot and ship's crew by displaying the vessel's distance, approach speed and angle with respect to the dock. The system improves the safety of the berthing operation by helping the pilot and ship's crew manage the vessel's speed and approach vector.

### 4.3.5 Maximum Allowable Berthing Velocity

The berthing velocity is the most critical variable with respect to the berthing energy of a vessel. The berthing velocity is defined as the speed of the vessel at initial contact with the fenders, measured perpendicular to the berth. The vessel's maximum allowable approach velocity is influenced by many factors, including prevailing environmental conditions, navigational conditions, method and frequency of berthing, use of docking aid systems, type and size of vessel, use of tugs, condition of the berth, type of cargo, wind exposure area of the vessel, and the experience level of ship personnel.

The velocities for each design vessel were determined using the design approach velocities as recommended in PIANC [Ref 2]. These recommended values are a function both of the vessel size, the relative exposure of the berth to prevailing winds and waves, as well as the degree of difficulty of the navigational approaches. Conservatively assuming good but exposed berthing conditions at Kitimat Terminal, the maximum allowable berthing velocities for each design vessel class are given in Table 4-1.

**Table 4-1 Maximum Allowable Berthing Velocities**

| Design Vessel Class | Cargo Condition | Displacement | Maximum Berthing Velocity | Abnormal Impact Factor |
|---|---|---|---|---|
| VLCC | 50% Ballasted | 224,000 | 0.125 m / sec. | 1.25 |
| VLCC | Fully Loaded | 384,000 | 0.10 m / sec. | 1.25 |
| Suezmax | Fully Loaded | 200,000 | 0.13 m / sec. | 1.35 |
| Aframax | Fully Loaded | 117,000 | 0.16 m / sec. | 1.50 |

Based on these maximum allowable berthing velocities, the berthing energies for each design vessel class can be calculated. The governing berthing energy is used to select a fender type and the berthing structures are designed for the appropriate reaction force as given in Section 2.2.

Although every effort will be made to maintain the berthing velocities below the maximum allowable limits, there are occasions when abnormal berthing conditions occur and the maximum berthing velocities might be exceeded. These abnormal berthing situations can occur for a variety of reasons including vessel mishandling, vessel malfunction, or adverse environmental conditions. Typically a safety factor is used in the berthing energy calculations to account for these abnormal situations. Standard abnormal impact factors for tankers and bulk cargo vessels vary from 1.25 for the largest vessels to 1.75 for the smallest vessels [Ref. 2]. The abnormal impact factors for each design vessel class are given in Table 4-1.

# 4.4 Mooring Operations

## 4.4.1 Mooring Assistance Requirements

A vessel's mooring lines are typically deployed and secured with utility boats and mooring crews (line handlers). During the berthing manoeuvres, as the vessel approaches to a distance a few meters away from the fenders, the vessel's crew will pass mooring lines to the terminal's mooring personnel for connection to the mooring hooks. Depending on terminal operating procedures and the proximity of the mooring hooks to the ship, the line transfer can be done either directly from the ship's deck to terminal personnel on the berth structures or with the use of small utility boats. The utility boats transfer the mooring lines from the vessel to the shore-based personnel who then place the lines on the appropriate mooring hooks. The number and placement of the mooring lines will be determined for each size of vessel during the detailed design phase of the project.

Quick Release Hook hardware as described in TERMPOL Study 3.10 will be installed on the berth and mooring structures to provide a safe and efficient means of securing the vessel's mooring lines. Each hook unit typically includes an integrated capstan which is used to haul in the mooring line before it is placed on its corresponding hook. Once a mooring line is attached to a hook, the line is tensioned by the winch gear on the ship.

When all the mooring lines are connected and secured and the vessel is held against the dock, the mooring operations will be complete. The tugs and pilot will leave the vessel, terminal personnel will deploy the gangway and other preparations will be made for the cargo transfer operations, see TERMPOL Study 3.11. The entire mooring operation should take approximately 2 hours.

For departing vessels, the terminal's mooring crew, in coordination with the ship's deck crew, will release the mooring hooks in a manner as directed by the vessel's Master. Although the hooks are designed for quick release even when the lines are under full tension, it is typical practice to release the ship's winch brakes and reduce the line tension gradually before removing the line from the hook. This practice avoids any potentially dangerous recoil which may occur if the line were released under full tension. Once fully released, the mooring lines will be reeled in using the vessel's deck winches.

One safety feature of the Quick Release Hooks is their Remote Release System which allows mooring lines to be safely released from a control console located in the central control room. This reduces the need for terminal personnel to be on the berth structures in close proximity to highly tensioned mooring lines. Hooks will always be released in a controlled sequential fashion. The simultaneous release of all hooks should not be allowed, even in emergency situations, since this may allow the ship to drift uncontrollably and pose greater safety risks.

## 4.4.2 Mooring Line Load Limits

Six-strand wire rope, of the general type known as 6x37, is commonly used as winch mounted mooring lines on tankers and other merchant vessels. Typically, wire core construction, also called IWRC (independent wire rope core), is used, which is stronger and less elastic than the fibre core construction. The most common grades of steel used in the wire ropes are improved plow steel (IPS) and extra improved plow steel (XIPS).

Typically, steel wire rope mooring line has nylon tails at its ends. Tails are between 10 to 11 m in length with a breaking strength approximately 125 percent of the wire rope.

Once the mooring lines are fastened to the quick-release hooks, the lines are pre-tensioned using the ship's deck winches. As a general rule, pretension is set at approximately 10 percent of Minimum Breaking Load (MBL) of the wire rope. Details of the mooring lines are listed in Table 4-2.

## Table 4-2 Mooring Line Details

| Mooring Line Characteristics | | VLCC Tanker | Suezmax Tanker |
|---|---|---|---|
| **Number of Lines Assumed** | | 16 | 16 |
| **Wire Rope** | **Diameter (mm)** | 42 | 38 |
| | **MBL (tonne)** | 121 | 94 |
| **Nylon Tail** | **Diameter (mm)** | 91 | 80 |
| | **MBL (tonne)** | 152 | 117 |
| **Pre-Tension (tonne)** | | 12 | 9 |
| **Allowable Load* (tonne)** | | 67 | 52 |

Based on the preliminary mooring analysis as described in Section 2.3, the maximum mooring line forces premised on a 63.1 knot wind from any direction were found to be 618 kN (63.0 tonnes) for the VLCC mooring scenario and 482 kN (49.1 tonnes) for the Suezmax mooring scenario [Ref. 1]. These line tensions are acceptable since they fall below the allowable load limit of the mooring lines which is set at 55 percent of their Minimum Breaking Load (MBL). As indicated in Table 4-2, for the VLCC mooring scenario, 42 mm wire rope has an allowable load of 652 kN (67 tonnes), and for the Suezmax mooring scenario, 38 mm wire rope has an allowable load of 510 kN (52 tonnes).

A Mooring Load Monitoring system will be installed to ensure the mooring line tensions remain within the allowable range. The Mooring Load Monitoring System forms an integral part of the Quick Release Hook Hardware and monitors the forces in each mooring line in real time by using load cells installed in each hook. The system helps operators balance the mooring line pattern and helps prevent lines from becoming overstressed and breaking. The system can be installed with visual and audible alarms located at the hook and remotely at the control centre. The alarms can alert mooring personnel when line tensions become too high or too low. All mooring load information is sent to the marine monitoring station located in the control centre. The data can also be transmitted and displayed to the pilots and ship personnel via carry-on laptops or hand-held monitors.

## 4.5 Communications

Ship-to-shore communications will be maintained throughout the berthing and mooring operations with intrinsically-safe explosion-proof radios. Typically UHF and VHF radio transceivers are used for two way communications between the ship, tugs, mooring utility boats and mooring crew. Handheld units can be used by the individual mooring crew members as well as other personnel not stationed at a vessel bridge or control center.

## 4.6 Effects of Metocean Conditions

Environmental and oceanographic conditions can have a significant effect on vessel handling during the berthing and un-berthing manoeuvres. These conditions can also cause vessel movements while the vessel is moored at the berth. The environmental and oceanographic effects on the berthing and mooring operations are discussed below.

### 4.6.1 Effects of Current Flow

Historical current data indicate that near-surface current speeds in the manoeuvring area at the terminal site, and Douglas Channel in general, can vary from 15 to 30 cm / s (0.3 to 0.6 knots) with maximum near-surface currents being as high as 50 to 60 cm / s (1.0 to 1.2 knots) [Ref. 5]. The highest maximum current speed measured directly at the surface and near the terminal site was 78 cm / s (1.5 knots).

A more recent study conducted between Sept. 2005 and Jan. 2006 [Ref. 3] deployed an Acoustic Doppler Current Profiler (ADCP) unit in the manoeuvring area approximately 200 m from shore at a depth of 179 m. The results from this study indicate average near surface current speeds of 8 cm / s (0.15 knots) with a maximum near surface current speed of 51 cm / s (1.0 knot). Overall, the results of this recent study appear to confirm the historical data.

To determine the currents precisely at the berth locations an ADCP unit was deployed in 30 m deep water, at the fender line of the proposed berths, from January to April 2006 [Ref. 4]. The average and maximum near surface currents speeds recorded at the berth locations were 10 cm / s (0.2 knots) and 66 cm / s (1.3 knots) respectively. These results are in general agreement with those from the manoeuvring area.

Due to the confined nature of the inland waterways, the currents typically flow in the direction of the channel, with cross channel flow being minimal. The currents at the proposed marine terminal flow in a NNE to SSW direction in alignment with the channel at this location.

While navigating Douglas Channel and while moored at the marine terminal the vessels will be aligned with the channel sides and the direction of current flow. In such an orientation the effects of the currents on vessel handling will be at a minimum.

The most pronounced current effects will occur during the berthing manoeuvres when the tankers make a 180° turn either before they enter the berth or after they leave the berth. It is easier and preferable to turn the tankers when they are in a lighter ballasted condition. As such, the tankers will have less draught which will help minimize the effects of current forces on vessel handling. The most critical situation for current forces will occur when, for various reasons, a pilot decides to turn the vessel when it is fully loaded and is in its deepest draught condition. In this situation the current forces will be at their maximum half way through the turn when the vessel is broadside to the direction of the channel and current flow. Preliminary environmental force analysis results indicate the maximum current forces acting on the broad side of a fully loaded VLCC can be over double that of a vessel in the ballasted condition. The effects of current regardless of whether the vessel is in a ballasted or fully loaded condition can be effectively counteracted by proper positioning of the harbour tugs during the berthing manoeuvres.

### 4.6.2 Effects of Tidal Variations

The tides along the central coast of BC are classified as mixed, mainly semi-diurnal (i.e. two high tides and two low tides per day) with successive highs and lows of unequal heights. The tides in the area also have a spring-neap cycle where the tidal ranges that occur during the spring tides are approximately double the tidal ranges that occur during the neap tides. For the Kitimat area the spring tide range is 6.5 m, while the neap tide range is only 3.0 m. The tide levels given in Table 4-3 are measured from the local Hydrographic Tide and Chart Datum at Kitimat, BC, as published in the Canadian Tide and Current Tables, Volume 7.

**Table 4-3 Tide Levels**

| Tide Level | Elevation (m) (Chart Datum) | Elevation (m) (Geodetic Datum) |
|---|---|---|
| Recorded Extreme High Tide: | 6.7 | 3.47 |
| Higher High Water Level (Large Tide): | 6.5 | 3.27 |
| Higher High Water Level (Mean Tide): | 5.3 | 2.07 |
| Mean Sea Level: | 3.3 | 0.07 |
| Lower Low Water Level (Mean Tide): | 1.0 | -2.23 |
| Lowest Normal Tide (Chart Datum): | 0.0 | -3.23 |
| Lower Low Water Level (Large Tide): | -0.1 | -3.33 |
| Recorded Extreme Low Tide: | -0.2 | -3.43 |

The historical data and more recent water level studies conducted from Sept. 2005 to Jan. 2006 [Ref. 3] and from Jan. 2006 to April 2006 [Ref. 4] show that the recorded tidal ranges conform to the tide levels given by the Canadian Hydrographic Services.

Where the tide enters coastal waterways such as those leading to Kitimat, the tendency is for the tidal variations to increase towards the head of the inlet as compared to those near the entrance. Tidal ranges also increase as the tide moves northward. The published tidal current velocities indicated on the CHS Marine Chart No. 3743 for Douglas Channel are 0.5 knots for flood conditions and 1 knot for ebb conditions. These published values are in general agreement with the measured current velocities given in the previous section.

The predicted times and heights of successive high and low tides are used by mariners to ensure adequate underkeel clearances in shallow water areas, for anchoring, and for planning of transits. With the exception of the current effects as given in the previous section, the tidal effects on vessels transiting to Kitimat Terminal should be minimal considering the depth of water and relatively large width of the navigational channels.

While moored at the berth, changes in tide levels can affect mooring line forces if the line tensions are not adjusted. However, a preliminary mooring analysis [Ref. 1] has indicated that the effects on mooring line tension from changes in tide level were small compared to the much larger changes in the ship's draught while loading or discharging cargo. Overall the tidal effects on berthing and mooring operations should be minimal.

### 4.6.3 Effects of Wind

The recorded wind data from the Nanakwa Shoal marine buoy was selected as the most relevant data for Kitimat Terminal and was used exclusively for determining the design wind speed at the project site, refer to TERMPOL Study 3.10. The processed wind data from the Nanakwa Shoal records is summarized in Table 4-4, in a bi-variate histogram format. The frequency of the wind speeds and directions are also shown graphically in the wind rose in Figure 4-1.

**Table 4-4 Wind Speed versus Wind Direction**

| Frequency Distribution (Count) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Wind Speed (m / s)** | **N** | **NE** | **E** | **SE** | **S** | **SW** | **W** | **NW** | **Total** |
| 0.5-1.8 | 3,258 | 2,113 | 627 | 720 | 1,899 | 2,602 | 3,488 | 2,639 | 17,346 |
| 1.8-3.3 | 2,252 | 2,869 | 204 | 260 | 2,433 | 3,954 | 3,189 | 1,325 | 16,486 |
| 3.3-5.4 | 1,318 | 3,983 | 76 | 142 | 4,151 | 5,334 | 584 | 271 | 15,859 |
| 5.4-8.5 | 917 | 5,132 | 83 | 45 | 4,103 | 7,185 | 132 | 48 | 17,645 |
| 8.5-11.1 | 700 | 3,796 | 60 | 5 | 952 | 2,297 | 10 | 2 | 7,822 |
| 11.1-14.2 | 651 | 2,938 | 53 | 4 | 169 | 410 | 2 | 0 | 4,227 |
| 14.2-17.2 | 120 | 1,083 | 2 | 0 | 4 | 28 | 1 | 1 | 1,239 |
| >17.2 | 2 | 131 | 0 | 0 | 0 | 1 | 0 | 0 | 134 |

| Frequency Distribution (Count) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Wind Speed (m / s)** | **N** | **NE** | **E** | **SE** | **S** | **SW** | **W** | **NW** | **Total** |
| Total | 9218 | 22045 | 1105 | 1176 | 13711 | 21811 | 7406 | 4286 | 80758 |
| Frequency of Calm Winds: 4508<br>Average Wind Speed: 4.68 m / s | | | | | | | | | |

Source: Nanakwa Shoal Ocean Data Acquisition System (ODAS) Buoy, Atmospheric Environment Services Canada, Marine Environmental Data Services (MEDS) Station ID # C46181

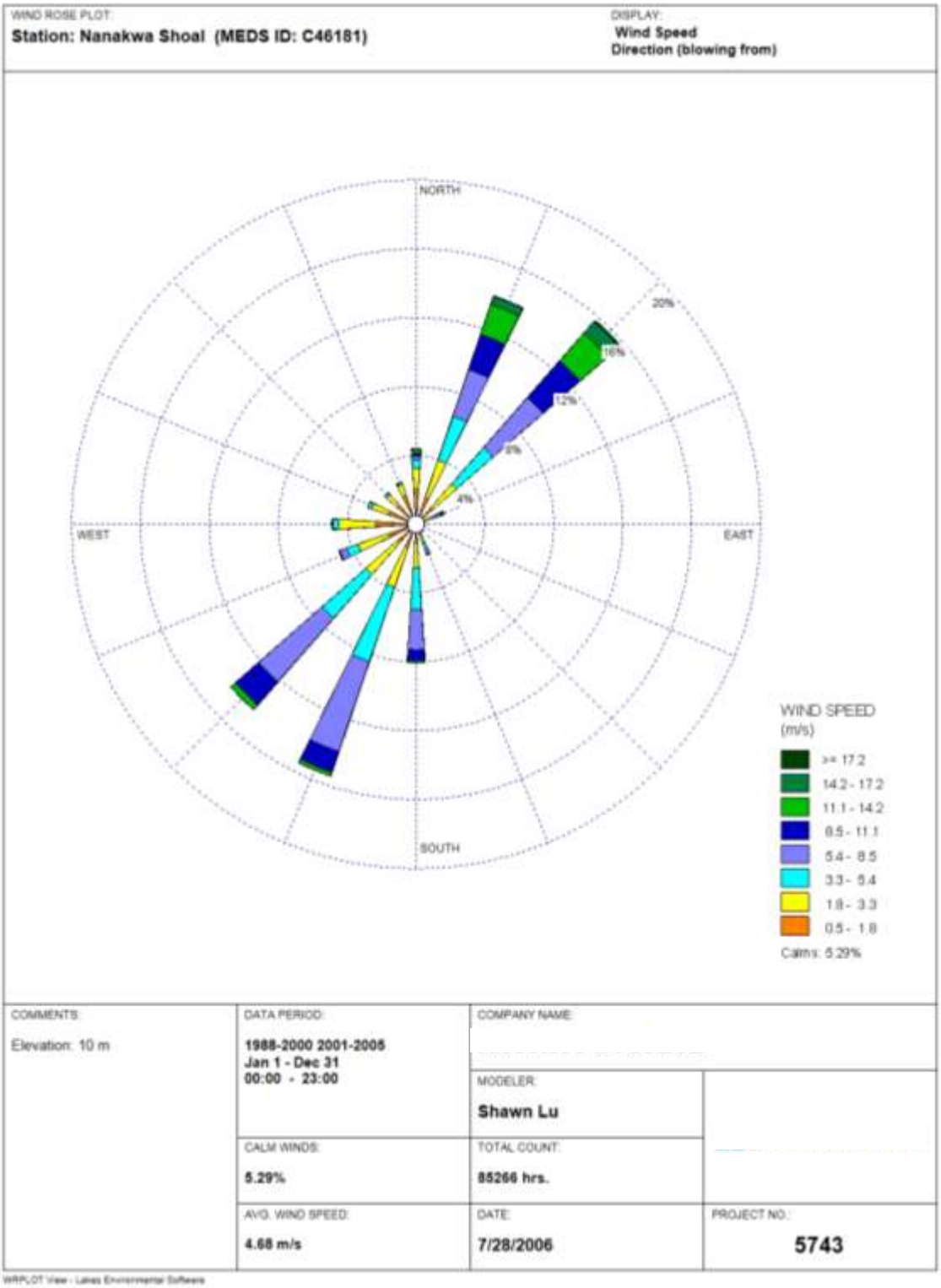


**Figure 4-1 Nanakwa Shoal Wind Rose**

The results of the wind analysis indicated the maximum measured sustained winds were from the northeast with a speed of 20.3 m / s (73 km / hour) (39.4 knots) and the maximum measured sustained winds from the southwest were 18.4 m / s (66 km / hour) (35.8 knots). The predominant winds from the northeast and southwest are essentially aligned with the direction of the channel indicating that the local winds are influenced by the surrounding mountains and principally blow up and down the channels in the local fjord system. Since the project site is relatively exposed to winds along the Douglas Channel, it will likely be most affected by the predominant winds. This wind data formed the basis of a computer-based mooring analysis that was carried out as part of the preliminary design work.

While navigating Douglas Channel and while moored at the marine terminal the vessels will be aligned with the channel sides and the predominant wind direction. Since the vessel has a smaller exposed area when oriented with the wind, the wind effects will be at a minimum.

The most pronounced wind effects will occur during the berthing manoeuvres when the tankers make a 180° turn either before they enter the berth or after they leave the berth. Although it is generally preferable to turn the tankers when they are in a lighter ballasted condition, the ballasted condition is the most critical condition for wind forces since the vessel sits higher in the water and has a greater wind exposure area. In this situation the wind forces on the vessel will be at their maximum half way through the turn when the vessel is broadside to the predominant wind direction. Preliminary environmental force analysis results indicate the maximum wind forces acting on the broad side of a ballasted VLCC can be more than double the wind forces acting on a fully loaded VLCC. The effects of wind forces regardless of whether the vessel is in a ballasted or fully laden condition can be effectively counteracted by proper positioning of the harbour tugs during the berthing manoeuvres.

### 4.6.4 Effects of Waves

Wave conditions at Kitimat Terminal were estimated using the wind data from the Nanakwa Shoal dataset and fetch data specific to the terminal site. The wave analysis showed that the wind blowing from SSW with duration of 2 to 2.5 hours resulted in the maximum waves for all return periods. The predicted significant wave height Hs (i.e. the average of the highest 33 percent of the waves) , and the peak wave periods for the associated return periods of 2, 5, 10, 25, 50, and 100 years are summarized in Table 4-5.

**Table 4-5 Estimated Wave Height and Period at Project Site**

| Return Period (Years) | Wind Direction ($^{o}$N) | Wind Speed, $U_{10}$ (m / s) | Wind Duration (Hrs) | Effective Fetch, F (km) | Significant Wave Heights, Hs (m) | Wave Period, $T_p$ (s) |
|---|---|---|---|---|---|---|
| 2 | 202 | 13.8 | 2.5 | 16.2 | 1.08 | 3.8 |
| 5 | 202 | 16.4 | 2.0 | 16.2 | 1.33 | 4.3 |
| 10 | 202 | 17.9 | 2.0 | 16.2 | 1.53 | 4.6 |
| 25 | 202 | 19.5 | 2.0 | 16.2 | 1.68 | 4.7 |

| Return Period (Years) | Wind Direction ($^oN$) | Wind Speed, $U_{10}$ (m / s) | Wind Duration (Hrs) | Effective Fetch, F (km) | Significant Wave Heights, Hs (m) | Wave Period, $T_p$ (s) |
|---|---|---|---|---|---|---|
| 50 | 202 | 20.6 | 2.0 | 16.2 | 1.81 | 4.8 |
| 100 | 202 | 21.6 | 2.0 | 16.2 | 1.92 | 4.9 |

The results show that for a 50-year return period the significant wave height at Kitimat Terminal is approximately 1.8 m. Waves of this nature are expected to have negligible effect on the moored vessels due to their relatively short period and wavelength compared to the natural frequency of the design vessels. The preliminary mooring analysis [Ref. 1] confirmed that the effects of wave forces on a vessel in Douglas Channel are very small compared to the forces caused by wind. The effects of waves should be minimal with respect to the berthing and mooring operations. The design wave may have some impact on tug operations, but if this is considered problematic, the ship will delay berthing or de-berthing operations.

### 4.6.5 Effects of Ice

The ocean waters of Douglas Channel are not subjected to freezing and remain open all year round. As such there are no ice effects with respect to berthing and mooring operations other than the potential safety issues for mooring personal regarding the build-up of ice and snow on the berth decks and mooring hardware due to freezing sea spray and snow fall. During periods of heavy snowfall or ice build-up, the snow and ice will be manually cleared from the decks and hardware of the marine structures.

### 4.6.6 Effects of Bathymetry

Bathymetric surveys confirm that within the vicinity of the marine terminal, the navigational channel is characterized by steep-sloped sides where the seabed quickly drops off from the shoreline and achieves depths within the manoeuvring area of approximately 100 to 160 m. Further from the shoreline towards the middle of the channel the seabed becomes relatively flat and achieves depths of 190 m and deeper. These depths easily meet the minimum manoeuvring-area underkeel clearance requirements of 27.1m as given in the Special Underkeel Clearance Survey (TERMPOL Study 3.6).

These significant depths essentially eliminate any shallow water effects in the turning basin manoeuvring area. Shallow water effects are also expected to be minimal at the terminal berths due to large underkeel clearances available from the steeply sloped channel sides. As a result, the bathymetry should have minimal to no effect on the berthing and mooring operations.

### 4.6.7 Metocean Monitoring System

Meteorological and oceanographic sensors will be installed at Kitimat Terminal to monitor local environmental conditions at the tanker berths. These sensors will provide real time data including wind speed, wind direction, barometric pressure, temperature, visibility, tidal changes, wave height, wave direction, current speed, and current direction. For a detailed list of environmental sensors, see TERMPOL Study 3.10.

All environmental information from the sensors is sent to the marine monitoring station located in the control centre for display and logging. The data can also be transmitted and displayed to the pilots and ship personnel via carry-on laptops or hand-held monitors.

### 4.6.8 Maximum Environmental Operating Conditions

Oil and condensate tankers operating near the facility within Douglas Channel will be tug assisted. Estimates of the limiting environmental operating values are given below:

- Maximum Wind Speed, Tug Assisted Berthing for smaller tankers: 20 m / s (40 knots) sustained
- Maximum Wind Speed, Tug Assisted Berthing for larger tankers: 15 m / s (30 knots) sustained
- Maximum Wind Speed, Loading / Unloading Shutdown: 25 m / s (50 knots) sustained
- Maximum Wind Speed, Loading / Unloading Arm Disconnect: 30 m / s (60 knots) sustained
- Maximum Wind Speed for Vessel to Vacate the Berth: 32.4 m / s (63 knots) sustained
- Maximum Depth-averaged Current, Vessel Manoeuvring: 1.0 m / s (2 knots)
- Minimum Visibility, Tug Assisted Berthing: 1.0 km

The above estimated values are considered preliminary and are subject to change in consultation with pilots and pending detailed operational mooring analyses which will be conducted during the detailed design phase of this project.

# 5 References

The following documents are referenced by number as (Ref. No.) in the report.

1. Moffatt & Nichol, 2006 "Static Mooring and Berthing Analysis" final report prepared for Enbridge Gateway Pipelines. Inc., December 1, 2006.
2. Permanent International Association of Navigation Congresses (PIANC): Guidelines for the Design of Fender Systems.
3. Gateway Environmental Management Team (GEM), 2006. "Marine Physical Environment TR-ASL-004: "Water Levels and Waves".
4. Gateway Environmental Management Team (GEM), 2006. "Marine Physical Environment Report TR-ASL-007: "GEM Oceanography Program, Sept. 2005 to Jan. 2006".
5. Gateway Environmental Management Team (GEM), 2006. "Marine Physical Environmental Report TR-ASL-008: "GEM Oceanography Program, January to April 2006".
6. Moffatt & Nichol, 2006 "Wind and Wave Analysis" final report prepared for Enbridge Gateway Pipelines. Inc., August, 2006.
7. Moffatt & Nichol, 2006 "Vessel Wake Study" final report prepared for Enbridge Gateway Pipelines. Inc., August, 2006. (Included in Termpol submission Volume 2)
8. National Research Council of Canada, 2005, "User's Guide – National Building Code 2005 Structural Commentaries (Part 4 of Division B)", 2nd ed., 2006.
9. International Tsunami Research, Inc. and Coastal and Ocean Resources Inc. 2009, "Numerical Modeling of the Landslide-Generated Tsunami of 27 April 1975 in Kitimat Arm, British Columbia", Report prepared for AMEC Engineering on behalf of Enbridge Northern Gateway Pipelines Limited Partnership, April 29, 2009.

# Appendix A Structural Load Combinations

## Table A-1 Load Combinations for Design of Loading Platforms and Access Trestles

| Load Combinations | Load Factors | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Dead | Live** | Snow, Rain, & Ice | Wind on Structure | Berthing | Mooring* | | Wave on Structure | Current on Structure | EQ |
| | | | | | | MBL | Analysis Forces | | | |
| **Vacant Condition:** | | | | | | | | | | |
| Load Combination 1 (NBCC Case 1) | 1.4 | | | | | | | 1.5 | 1.5 | |
| Load Combination 2 (NBCC Case 2) | 1.25 | 1.5 | | 0.4 | | | | 1.5 | 1.5 | |
| Load Combination 3 (NBCC Case 2) | 1.25 | 1.5 | 0.5 | | | | | 1.5 | 1.5 | |
| Load Combination 4 (NBCC Case 3) | 1.25 | 0.5 | 1.5 | | | | | 1.5 | 1.5 | |
| Load Combination 5 (NBCC Case 3) | 1.25 | | 1.5 | 0.4 | | | | 1.5 | 1.5 | |
| Load Combination 6 (NBCC Case 4) | 1.25 | 0.5 | | 1.4 | | | | 1.5 | 1.5 | |
| Load Combination 7 (NBCC Case 4) | 1.25 | | 0.5 | 1.4 | | | | 1.5 | 1.5 | |
| Load Combination 8 (NBCC Case 4) | 0.9 | | | 1.4 | | | | 1.5 | 1.5 | |
| Load Combination 9 (CHBDC - ULS 1) | 1.25 | 1.7 | | | | | | 1.5 | 1.5 | |
| Load Combination 10 (CHBDC - ULS 7) | 1.25 | | 1.3*** | 0.9 | | | | 1.5 | 1.5 | |
| **Earthquake Condition:** | | | | | | | | | | |
| Load Combination 11 (NBCC Case 5) | 1.0 | | | | | | | | | 1.0 |
| Load Combination 12 (NBCC Case 5) | 1.0 | 0.5 | 0.25 | | | | | | | 1.0 |

**Notes:** * For mooring loads use the governing condition of either:

a) 1.0 x $F_d$ (Line Minimum Breaking Load (MBL) Force); or,

b) 1.5 x Mooring Analysis Force.

** Live Use and Occupancy loads shall have a load factor of 1.5 as per the load combinations in the National Building Code of Canada (NBCC), and live vehicle loads shall have a load factor of 1.7 as per the load combinations in the Canadian Highway Bridge Design Code (CHBDC).

*** A load factor of 1.3 shall be used for the "Ice Accretion Load" on equipment and topsides as per the Canadian Highway Bridge Design Code (CHBDC).

## Table A-2 Load Combinations for Design of Berthing Structures

| Load Combinations | Load Factors | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Dead | Live** | Snow, Rain, & Ice | Wind on Structure | Berthing | Mooring* | | Wave on Structure | Current on Structure | EQ |
| | | | | | | MBL | Analysis Forces | | | |
| **Vacant Condition:** | | | | | | | | | | |
| Load Combination 1 (NBCC Case 1) | 1.4 | | | | | | | 1.5 | 1.5 | |
| Load Combination 2 (NBCC Case 2) | 1.25 | 1.5 | | 0.4 | | | | 1.5 | 1.5 | |
| Load Combination 3 (NBCC Case 2) | 1.25 | 1.5 | 0.5 | | | | | 1.5 | 1.5 | |
| Load Combination 4 (NBCC Case 3) | 1.25 | | 1.5 | 0.4 | | | | 1.5 | 1.5 | |
| Load Combination 5 (NBCC Case 3) | 1.25 | 0.5 | 1.5 | | | | | 1.5 | 1.5 | |
| Load Combination 6 (NBCC Case 4) | 1.25 | 0.5 | | 1.4 | | | | 1.5 | 1.5 | |
| Load Combination 7 (NBCC Case 4) | 1.25 | | 0.5 | 1.4 | | | | 1.5 | 1.5 | |
| Load Combination 8 (NBCC Case 4) | 0.9 | | | 1.4 | | | | 1.5 | 1.5 | |
| Load Combination 9 (CHBDC – ULS 1) | 1.25 | 1.7 | | | | | | 1.5 | 1.5 | |
| Load Combination 10 (CHBDC – ULS 7) | 1.25 | | 1.3*** | 0.9 | | | | 1.5 | 1.5 | |
| **Mooring Condition:** | | | | | | | | | | |
| Load Combination 11 | 1.25 | 1.5 | | 0.4 | | 1.0* | 1.5* | 1.5 | 1.5 | |

| Load Combinations | Load Factors | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Dead | Live** | Snow, Rain, & Ice | Wind on Structure | Berthing | Mooring* | | Wave on Structure | Current on Structure | EQ |
| | | | | | | MBL | Analysis Forces | | | |
| (NBCC Case 2) | | | | | | | | | | |
| Load Combination 12 (NBCC Case 2) | 1.25 | 1.5 | 0.5 | | | 1.0* | 1.5* | 1.5 | 1.5 | |
| Load Combination 13 (NBCC Case 3) | 1.25 | 0.5 | 1.5 | | | 1.0* | 1.5* | 1.5 | 1.5 | |
| Load Combination 14 (NBCC Case 3) | 1.25 | | 1.5 | 0.4 | | 1.0* | 1.5* | 1.5 | 1.5 | |
| Load Combination 15 (NBCC Case 4) | 1.25 | 0.5 | | 1.4 | | 1.0* | 1.5* | 1.5 | 1.5 | |
| Load Combination 16 (NBCC Case 4) | 1.25 | | 0.5 | 1.4 | | 1.0* | 1.5* | 1.5 | 1.5 | |
| Load Combination 17 (NBCC Case 4) | 0.9 | | | 1.4 | | 1.0* | 1.5* | 1.5 | 1.5 | |
| **Berthing Condition:** | | | | | | | | | | |
| Load Combination 18 (NBCC Case 3) | 1.25 | 0.5 | 1.5 | | 1.5 | | | 1.5 | 1.5 | |
| Load Combination 19 (NBCC Case 3) | 1.25 | | 1.5 | 0.4 | 1.5 | | | 1.5 | 1.5 | |
| Load Combination 20 (NBCC Case 4) | 1.25 | 0.5 | | 1.4 | 1.5 | | | 1.5 | 1.5 | |
| Load Combination 21 (NBCC Case 4) | 1.25 | | 0.5 | 1.4 | 1.5 | | | 1.5 | 1.5 | |
| Load Combination 22 (NBCC Case 4) | 0.9 | | | 1.4 | 1.5 | | | 1.5 | 1.5 | |
| **Earthquake Condition:** | | | | | | | | | | |
| Load Combination 23 (NBCC Case 5) | 1.0 | | | | | | | | | 1.0 |
| Load Combination 24 (NBCC Case 5) | 1.0 | 0.5 | 0.25 | | | | | | | 1.0 |

**Notes:** * For mooring loads use the governing condition of either:

a) 1.0 x $F_d$ (Line Minimum Breaking Load (MBL) Force); or

b) 1.5 x Mooring Analysis Force.

** Live Use and Occupancy loads shall have a load factor of 1.5 as per the load combinations in the National Building Code of Canada (NBCC), and live vehicle loads shall have a load factor of 1.7 as per the load combinations in the Canadian Highway Bridge Design Code (CHBDC).

*** A load factor of 1.3 shall be used for the "Ice Accretion Load" on equipment and topsides as per the Canadian Highway Bridge Design Code (CHBDC).

## Table A-3 Load Combinations for Design of Mooring Structures

| Load Combinations | Load Factors | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Dead | Live | Snow, Rain, & Ice | Wind on Structure | Berthing | Mooring* | | Wave on Structure | Current on Structure | EQ |
| | | | | | | MBL | Analysis Forces | | | |
| **Vacant Condition:** | | | | | | | | | | |
| Load Combination 1 (NBCC Case 1) | 1.4 | | | | | | | 1.5 | 1.5 | |
| Load Combination 2 (NBCC Case 2) | 1.25 | 1.5 | | 0.4 | | | | 1.5 | 1.5 | |
| Load Combination 3 (NBCC Case 2) | 1.25 | 1.5 | 0.5 | | | | | 1.5 | 1.5 | |
| Load Combination 4 (NBCC Case 3) | 1.25 | | 1.5 | 0.4 | | | | 1.5 | 1.5 | |
| Load Combination 5 (NBCC Case 3) | 1.25 | 0.5 | 1.5 | | | | | 1.5 | 1.5 | |
| Load Combination 6 (NBCC Case 4) | 1.25 | 0.5 | | 1.4 | | | | 1.5 | 1.5 | |
| Load Combination 7 (NBCC Case 4) | 1.25 | | 0.5 | 1.4 | | | | 1.5 | 1.5 | |
| Load Combination 8 (NBCC Case 4) | 0.9 | | | 1.4 | | | | 1.5 | 1.5 | |
| **Mooring Condition:** | | | | | | | | | | |
| Load Combination 9 (NBCC Case 3) | 1.25 | 0.5 | 1.5 | | | 1.0* | 1.5* | 1.5 | 1.5 | |
| Load Combination 10 (NBCC Case 3) | 1.25 | | 1.5 | 0.4 | | 1.0* | 1.5* | 1.5 | 1.5 | |
| Load Combination 11 (NBCC Case 4) | 1.25 | 0.5 | | 1.4 | | 1.0* | 1.5* | 1.5 | 1.5 | |
| Load Combination 12 (NBCC Case 4) | 1.25 | | 0.5 | 1.4 | | 1.0* | 1.5* | 1.5 | 1.5 | |
| Load Combination 13 | 0.9 | | | 1.4 | | 1.0* | 1.5* | 1.5 | 1.5 | |

| Load Combinations | Load Factors | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Dead | Live | Snow, Rain, & Ice | Wind on Structure | Berthing | Mooring* | | Wave on Structure | Current on Structure | EQ |
| | | | | | | MBL | Analysis Forces | | | |
| (NBCC Case 4) | | | | | | | | | | |
| **Earthquake Condition:** | | | | | | | | | | |
| Load Combination 14 (NBCC Case 5) | 1.0 | | | | | | | | | 1.0 |
| Load Combination 15 (NBCC Case 5) | 1.0 | 0.5 | 0.25 | | | | | | | 1.0 |

Notes: * For mooring loads use the governing condition of either:

a) 1.0 x $F_d$ (Line Minimum Breaking Load (MBL) Force); or

b) 1.5 x Mooring Analysis Force.