GUIDANCE NOTES ON

NEARSHORE POSITION MOORING
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Foreword

These Guidance Notes provide direction for the design and analysis of nearshore position mooring systems used for floating structures such as Floating Offshore Liquefied Gas Terminals (FLGTs), Floating Storage and Regasification Units (FSRUs), Floating Production Storage and Offloading Installations (FPSOs) and accommodation barges. Nearshore position mooring in these Guidance Notes is intended to provide long-term solutions for stationkeeping for these floating structures.

These Guidance Notes are applicable to the position mooring system and mooring equipment onboard the floating structures. The design of jetties or similar bottom supported structures used for the mooring of floating structures is generally the responsibility of the Owner. These structures should be designed in accordance with relevant industry guidelines and standards, and they should be able to provide required holding capacity to the mooring systems.

Nearshore position mooring in these Guidance Notes cover the following types of mooring configurations:

i) Jetty Mooring

ii) Tension Pile Mooring

These Guidance Notes should be used in conjunction with the ABS *Rules for Building and Classing Floating Production Installations (FPI Rules),* ABS *Guide for Building and Classing Floating Offshore Liquefied Gas Terminals (FLGT Guide)* and ABS *Guide for Building and Classing LNG Regasification Vessels*.

These Guidance Notes become effective on the first day of the month of publication.

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SECTION 1 Introduction

1 General *(1 February 2019)*

These Guidance Notes provide direction for the design and analysis of nearshore position mooring systems used for floating structures such as Floating Offshore Liquefied Gas Terminals (FLGTs), Floating Storage and Regasification Units (FSRUs), Floating Production Storage and Offloading Installations (FPSOs) and accommodation barges.

The nearshore mooring system in this document is intended to provide a long-term permanent stationkeeping solution, in that it is designed to keep the floating structure on position throughout its design life.

Position mooring systems should be designed in accordance with applicable rules or guides with a level of safety that matches the intended service. Special characteristics of the nearshore mooring systems are provided in 1/3.9. Where applicable, the ABS *Guide for Position Mooring Systems* and *Mooring Equipment Guidelines*, published by Oil Companies International Marine Forum (OCIMF) may be used for nearshore position mooring systems.

These Guidance Notes primarily focus on:

i) Jetty mooring or tension pile mooring

ii) Design environment considerations

iii) Operating conditions

iv) Environmental Loads and bearing capacity of the mooring systems

v) Emergency release of the mooring system

vi) Mooring equipment qualification

vii) Maintenance, monitoring and inspection

The design of bottom fixed structures, such as a jetties, piers, quays, sea islands, wharfs, or dolphins, which serve as holding foundations for the mooring systems, is generally the responsibility of the Owner. Those structures should be designed in accordance with relevant industry guidelines and standards, and they should be able to provide the required holding capacity for the mooring systems.

3 Overview of Nearshore Position Mooring Systems *(1 February 2019)*

Nearshore position mooring systems have close proximity to the shoreline, and the access to the mooring system is relatively simple. In most cases, they can be accessed directly from structures that are connected to shore. They are normally located in areas where currents and wave motions are influenced by seabed bathymetry.

Similar to the position mooring systems defined in the ABS *Guide for Position Mooring Systems*, a nearshore position mooring system can be designed based on one of the following two types:

i) Non-disconnectable. The floating structure stays at the location, even in severe weather. The mooring system is designed for extreme events with the floating structure connected.

ii) Disconnectable. The floating structure can be disconnected from the mooring system and depart to avoid severe weather. The mooring system alone is designed for extreme events, if applicable.

Nearshore position mooring in these Guidance Notes covers the following types of mooring configurations:

i) Jetty Mooring (see 1/3.1)

ii) Tension Pile Mooring (See 1/3.3)

iii) Other Alternative Mooring Systems (See 1/3.5)

3.1 Jetty Mooring

Jetty mooring is a mooring system that affixes the floating structure alongside a jetty structure. In a jetty mooring system, the anchoring points of the mooring system are either connected to onshore structures or nearshore structures such as a jetty (a pier, quay, sea island, wharf, or dolphins). A jetty mooring system consists of:

- Mooring lines (fiber ropes, chain, and/or wire ropes)
- Mooring end fitting and accessories (thimbles, shackles)
- Fenders
- Quick release hooks
- Mooring equipment onboard the floating structure (mooring winch, fairlead, chain stoper, chocks, bitts, rollers, and etc.)
- Jetty structure (mooring bollards, cleats, and/or other mooring equipment)

3.3 Tension Pile Mooring *(1 February 2019)*

A tension pile mooring system is similar to the tendon system used for a Tension Leg Platform (TLP). In such a system, the position of the floating structure is maintained by the tension of several vertical piles fixed to the seabed. The floating structure is connected at the piles using pins and hooks or other connection hardware. The piles are uplifted in tension with the buoyancy of the floating structure. A tension pile mooring system consists of:

- Piles and foundation of the piles
- Hooks on the top of piles
- Pins/extended pins on the hull of the floating structure

Tension piles are within the scope of ABS classification, and should comply with the requirements in 6/5 of the ABS *Guide for Position Mooring Systems*.

3.5 Other Alternative Mooring Systems *(1 February 2019)*

There are other alternative mooring systems such as:

- Guide pile mooring
- Hinged stiff leg restraint mooring

Unconventional mooring arrangements are either in-use or proposed at a small number of terminals. Examples are:

- Vacuum pads
- ITB-style (Integrated Tug/Barge) hydraulic pins and matching slot

Nearshore position mooring technology is currently evolving. For innovative designs, reference can be made to ABS *Guidance Notes on Review and Approval of Novel Concepts* and the principles contained in these guidance notes.

3.7 Mooring Arrangement for Loading/Unloading Operations

For FLGTs or FSRUs, an LNGC is usually used to load/unload cargoes from the FLGT or FSRU. The arrangement of FLGT/FRSU, LNGC and sometimes a jetty structure can be one of the following configurations:

i) *Side-by-side Mooring*. The LNGC alongside FLGT/FSRU, and FLGT/FSRU may be moored alongside a jetty structure in the case of jetty mooring, or with other types of mooring.

ii) *Tandem Mooring.* The LNGC is moored behind the FLGT/FSRU, both may be moored alongside a jetty structure in the case of jetty mooring, or with other types of mooring.

iii) *Cross Dock Jetty Structure*. The LNGC and the FLGT/FSRU are moored on either side of the jetty structure.

3.9 Comparison with other Mooring Systems

There are many commonalities between nearshore position mooring and offshore mooring in terms of environmental load analysis and strength assessment of the mooring system.

Nearshore position mooring also has similarities to temporary berthing systems in terms of surrounding environment, shore accessibility and mooring system arrangements.

1/3.9 Table 1 provides a comparison between nearshore position mooring, offshore mooring, and temporary berthing. The list in the table highlights the differences that should be taken into consideration in the design of nearshore position mooring systems.

Table 1
Comparison of Mooring Systems

	Offshore Mooring for FPI	*Temporary Berthing*	*Nearshore Mooring*
Moored Floating Structure Types	Production facility/Terminal	Ocean going/trading vessels	Production facility/ Terminal
Design Life	20 years or more	N/A	In accordance with the moored facility
Distance to Shore	No direct access to shore	Direct access to shore	Direct access to shore
Water Depth	In general water depth has no significant impact on wave and current load on the moored floater	No specific requirement for the return period for the high and low water level	Water depth has impact on wave and current load, as well as clearance. Should consider 100-year high and low water level in the analysis
Environmental Conditions	Open ocean cOpen ocean condition, Site specific wave statistics are normally available ondition, Site specific wave statistics are normally available	Site-specific wave data may be derived from the record of deep water location. Bathymetry and bottom effect may be important. Increased current load due to small bottom clearance.	Similar to temporary berthing

	Offshore Mooring for FPI	*Temporary Berthing*	*Nearshore Mooring*
Mooring Arrangement	No easy access to the mooring components. Mooring lines are submerged and relatively long. The natural period of the mooring systems is relatively long.	Mooring lines are in the air. Fenders attached to the terminals contact the moored vessels. Mooring lines are short and the natural period of the mooring systems is short.	For jetty mooring, similar to temporary berthing.
Equipment	Mooring equipment onboard the facility and controlled on the facility	Mooring equipment onboard the mooring terminals or on the vessel	Similar to offshore mooring
Mooring Line Adjustment and Replacement	Should be avoided if possible. Replacement is expensive and not easy.	Often adjusted, wear and tear could be high. The replacement is relatively easy.	Jetty mooring is similar to temporary berthing, however, replacement may disrupt the operation and the cost may be high.
Operational Considerations	Continuous production operation for a relatively long period of time	Loading/Offloading in a relatively short period of time	Similar to offshore mooring
Monitoring Systems	Not often used during normal operation	Often used during mooring line adjustment, and berthing/ unberthing	Should be used for mooring line adjustment and for disconnecting
Inspection Methods	Divers and ROV	Easy access for visual inspection and measurement	Similar to temporary berthing
Analysis Method	Coupled dynamic analysis method including motions and line dynamic effects	Uncoupled quasi-static method where dynamic effects are often not included	Recommend the coupled dynamic analysis method
Strength Assessment	100-year return period environment for strength assessment	No specific return period.	Recommend using 100-year return period environment and also include the values for maximum high water and minimum low water levels
Fatigue Assessment	Required	Not required	Required in general if the components are designed for long-term use. If the components are designed for periodical replacement, fatigue assessment may not be necessary

SECTION 2 Design Considerations

1 Design Life (1 February 2019)

The design life for the nearshore position mooring system is defined as its intended service life . The design life of the mooring system may be different from the design life of the floating structure to which it is connected. The design life for a nearshore position mooring should generally be 20 years, or in accordance with the intended onsite service time of the floating structure that uses the mooring system for position keeping. This applies to mooring line components, fenders and equipment that are not intended to be replaced within the design life.

Depending on the inspection and maintenance program, the actual design life of the mooring line components, fenders and equipment can vary if they are designed for easy retrieval, repair or replacement. Some mooring line components such as rope tails may be designed for temporary use. Such components should be periodically inspected during their service life and replaced if necessary.

3 Operational Considerations

Operational considerations, such as offset and accelerations, may set design limits to the nearshore position mooring system, and should be considered in the mooring system design.

Operational considerations for the nearshore position mooring include but are not limited to:

- Berthing and un-berthing of the LNGC or other carriers
- Loading and offloading of gas or other products
- Disconnection and departure of the floating structure, as applicable
- Operations for production, regasification, or other activities, as applicable
- Operations of systems and equipment on board the floating structure that can be affected by the mooring system and the floating structure

5 Mooring Design Conditions

The design of a nearshore position mooring system should address the conditions described below.

5.1 Design Environmental Condition (1 February 2019)

During Design Environmental Condition (DEC), the floating structure is moored alone without loading/ offloading carriers attached. Normal operations are suspended and loading devices (such as rigid loading arm or flexible hoses) are disconnected.

During DEC, for a disconnectable nearshore position mooring, the mooring system stands alone without floating structure if applicable.

For the DEC, the mooring system should be designed based on design limits for strength and fatigue, where applicable.

5.3 Operation Condition

During the operation condition, the moored floating structure carries out production activities. The limiting environmental conditions for operations should be specified by the owner/operator. The limiting conditions could be determined from the floating structure's motions, onboard equipment and loading devices. Under the operation condition, the mooring system should be designed to not exceed the following limits:

i) Maximum allowable mooring tensions and loads under the owner specified operation environmental conditions

ii) Maximum allowable offsets under the the limits of the loading devices, such as rigid loading arms or flexible hoses, or owner specified operation environment conditions, where applicable

iii) Fatigue strength, where applicable

5.5 One Compartment Damage Condition *(1 February 2019)*

A one component damage condition occurs when one component, (such as a mooring line component) which could affect the position holding capability of the mooring system, is damaged.

Under this condition, the mooring system should be designed to not exceed the following limits:

i) Maximum mooring tensions and loads

ii) Maximum offsets, where applicable

Where the spare components are available for a mooring system and the replacement can happen quickly and it can be assumed that there is no effect on the position holding capability due to the damage of the component, the damage condition for such a component may be excluded. The details of the spare components, replacement, and the failure analysis should be documented. Fenders may be considered as a no-fail component.

5.7 Disconnecting Conditions *(1 February 2019)*

For a disconnectable nearshore position mooring system with a **Disconnectable** notation, the disconnecting condition should be included in the design. A disconnecting condition occurs when the mooring system is disconnected under specified limiting environment conditions.

Under this condition, the mooring system should be designed to not exceed the following limits:

i) Maximum mooring tensions and loads under specified disconneting environment conditions

ii) Maximum offsets under specified disconneting environment conditions, where applicable

7 Environmental Conditions *(1 February 2019)*

Site-specific environmental conditions include:

- Wind (speed, direction and wind profile)
- Wave, swell and seiche (wave heights, periods and directions)
- Current (speed, direction and current profile)
- Water depth (tides, storm surge, bathymetry, etc)
- Air and sea temperature
- Ice and snow
- Marine growth
- Seismicity
- Sea ice
- Soil data, if applicable

Environmental criteria for the mooring systems includes:

- Design Environmental Condition (DEC), or DISconneting Environmental Condition (DISEC)
- Design Operating Condition (DOC)
- Long term statistics for fatigue analysis

The mooring system should be designed to survive the Design Environmental Condition (DEC) and, if applicable, the Disconnecting Environmental Condition (DISEC). The mooring system should remain operational under the specified Design Operating Condition (DOC).

The DEC should be selected, in general, based on 100-year return period conditions for wind, wave, and current, as specified in 3/3 of the ABS *Guide for Position Mooring Systems*. For nearshore position mooring, especially in shallow water where water elevation (tide, etc.) plays an important role, a 100-year return period of Maximum High Water (MHW) level and Minimum Low Water (MLW) should be considered.

For the Design Operating Condition, the following conditions are typically considered:

- One-year return period conditions for wind, current and wave, at the Lowest Astronomical Tide and Highest Astronomical Tide, with the maximum unit loading condition and the ballast-only unit loading condition.
- LNGCs designed for worldwide trading should be provided with mooring equipment capable of resisting a 60 knot wind from any direction, simultaneous with 3 knots of current at 0° or 180° relative heading, or 2 knots current at 10° or 170° relative heading, or 0.75 knot current from the direction of maximum beam current loading.

7.1 Wind, Waves and Current *(1 February 2019)*

Nearshore locations may be exposed to adverse swell and long-period swell which imposes additional cyclic loads on the mooring system. Currents may be tidal and reverse direction every few hours, or they may be relatively steady, as in a river. Wind loads may be steady or sudden in a frontal passage or thunderstorm. It is important to gather basic metocean data at the specific site and design the mooring system according to the maximum environmental conditions encountered while the floating structure remains moored.

Nearshore wind, wave and currents may be different from those in open oceans. Conditions such as tsunami, swell, and seiche may be critical for nearshore position mooring system design based on the site location. Care should be taken when assessing this data.

7.1.1 Wind

The wind conditions for various design conditions should be established from collected wind data and should be consistent with other environmental parameters assumed to occur simultaneously.

The environmental report should present wind statistics for the installation site. The statistics should be based on the analysis and interpretation of wind data by a recognized consultant. The report should include a wind rose or table showing the frequency distributions of wind velocity and direction and a table or graph showing the recurrence period of extreme winds. The percentage of time for which the operational phase limiting wind velocity is expected to be exceeded during a year and during the worst month or season should be identified.

7.1.2 Waves

The wave height versus wave period relationships for the design sea state should be accurately determined from oceanographic data for the area of operation. The period can significantly affect wave drift forces and vessel motions, and therefore a range of wave periods should be examined.

For fatigue analysis, the long-term joint distribution of wave heights and periods (scatter diagram) is required. For some locations, swell may also be important and should be considered for mooring system design.

The penetration of long period, low amplitude waves into a harbor can result in resonant standing waves, when the wave forcing frequency coincides with a natural frequency of the harbor. The resonant standing waves can result in large surge motions if this frequency is close to the natural frequency of the mooring system.

7.1.3 Current

The most common categories of currents are:

i) Tidal currents (associated with astronomical tides)

ii) Circulation currents (loop and eddy currents)

iii) Storm-generated currents

iv) Soliton currents

The vector sum of the currents applicable to the site is the total current for each associated sea state. The speed and direction of the current at different elevations should be specified. In certain areas, current force can be the governing design load. Consequently, a selection of the appropriate current profile requires careful consideration.

7.3 Water Depth

The consideration of water depth should take into account the following factors:

- Water level variation due to tides and storm surge
- Bathymetry
- Seafloor subsidence, if applicable

7.5 Directions of Wind, Wave and Current *(1 February 2019)*

The mooring system should be assessed under the most unfavorable combination of wind/wave/current directions that can be reasonably assumed to occur. Direction combinations of wind, wave and current other than those specified in 3/3.5.6 of the ABS *Guide for Position Mooring Systems* may be considered for the nearshore position mooring system design based on site specific environmental data. The ability of the floating structure to change heading in response to changing environmental conditions may be considered.

7.7 Site Specific Environmental Data

The design values of wind, wave and current with required return periods should be based on site specific environmental data.

9 Environmental Loads

The environmental loads should be calculated and submitted for review. General guidelines are given in this Subsection.

9.1 Wind Loads *(1 February 2019)*

Wind loads should be calculated for all design conditions. Two methods are generally used to assess effects of wind for design:

i) Wind is treated as constant in direction and speed, which is taken as the 1-minute average.

ii) Fluctuating wind is modeled by a steady component, based on 1-hour average velocity, plus a time-varying component calculated from a suitable empirical wind gust spectrum.

For the final design of permanent moorings, Method ii) should be used. However, Method i) may be used if it can be shown to be more conservative.

Wind speeds are normally given at a reference height of 10 meters (33 feet) above sea level. To convert the wind velocity at a reference height for a given time average to velocity of a different height and time average, the relationship should be derived based on site-specific conditions.

Wind loads can be calculated based on wind profiles and windage areas. The total wind force is obtained by summing up the wind forces on each windage area.

For ship-type floating structures with relatively small superstructures (e.g., LNGCs), wind forces can be calculated by using the coefficients presented in *Mooring Equipment Guidelines* by OCIMF. Additional forces due to superstructures and equipment can be calculated for each windage area and added to the total wind forces.

Wind forces may be determined by using wind tunnel or towing tank model test data. Model test data may be used to predict wind loads for mooring system design provided that a representative model of the unit is tested, and that the condition of the model in the tests, such as draft and deck cargo arrangement, closely matches the expected conditions that the unit will see in service. Care should also be taken so that the character of the flow in the model test matches the character of flow for the full-scale unit.

9.3 Current Loads *(1 February 2019)*

Current loads should be calculated with considerations of current direction and current profiles. Analytical methods, model test data or full-scale measurements can be used for calculation. Current profiles used in the design should be representative of the expected conditions at the installation site.

The effect of underkeel clearance on current force should be included. Where appropriate, flutter and dynamic amplification due to vortex shedding should be taken into account.

Current forces can be calculated for ship-type floating structures (e.g., LNGC) using the coefficients presented in *Mooring Equipment Guidelines* by OCIMF.

9.5 Wave Loads *(1 February 2019)*

Calculation of wave loads is normally based on a radiation/diffraction analysis up to the second order. The main output of a radiation/diffraction analysis gives first-order excitation forces, hydrostatics, potential damping, added mass, first-order motions in 6 Degrees-of-Freedom (DOFs) and second-order wave forces/ moments.

Hydrodynamic interactions between multiple (*n*) floating structures in close proximity may also be solved using radiation/diffraction analyses, where the floating structures are normally solved in an integrated system with motions in n x 6 DOFs.

For structures consisting of slender members that do not significantly alter the incident wave field, semi-empirical formulations, such as Morison's equation, may be used. For calculation of wave loads on structural configurations that significantly alter the incident wave field, appropriate methods which account for both the incident wave force (e.g., Froude-Krylov force) and the forces resulting from wave diffraction should be used. In general, application of Morison's equation may be used for structures comprising slender members with diameters (or equivalent diameters giving the same cross-sectional areas parallel to the flow) less than 20 percent of the wavelengths.

Special considerations for wave loads for nearshore position mooring design are listed below:

- Interaction effects between carrier, moored floating structure (vessel) and jetty structure especially for side-by-side mooring configuration (for example LNGC/FSRU/Jetty).

- Effect of bathymetry and the seefloor may need to be considered for the wave load calculation.
- A full quadratic transfer function (QTF) matrix is normally required for second-order wave drift forces in shallow water where wave load is a dominant environment condition.
- The change of the seafloor topography due to sedimentation and other factors during the life time of the floater may need to be considered.

9.7 Passing Vessel Effects *(1 February 2019)*

In locations with passing vessels, the passing vessel may induce considerable loads on the moored floating structure. Those loads should be considered in the design.

When calculating the passing vessel induced loads, the sway and surge forces, as well as yaw moment, on a moored floating structure should be established considering the following factors:

- Distance from the passing vessel to the moored floating structure.
- Size of passing vessel (ratio of length of moored floating structure to length of passing vessel, ratio of midship section areas of the moored floating structure and passing vessel)
- Passing vessel speed
- Underkeel clearance of the moored floating structure and passing vessels
- Draft and trim of the moored floating structure and draft of the passing vessel
- Mooring line tension (tension distribution between lines, snap loads for slack lines)

Normal operating wind and current conditions can be assumed when calculating forces due to passing vessels. Methodologies used to determine forces/moments on a moored floating structure are primarily:

- Field measurements
- Model tests
- Empirical equations
- Conventional hydrodynamic analysis
- Advanced analysis based on computational fluid dynamics (CFD) techniques

9.9 Effect of Piers

The effect of piers is one of the key design considerations . Consideration should be given to:

- Hydrodynamic interaction between the moored floating structure/pier/carrier
- Shielding for wind and current loads of the pier to the moored floating structure

Piers constructed on piles are effectively transparent to waves, but solid piers can have a significant influence by reflecting the waves, and interaction with the waves generated by the motions of the floating structure.

9.11 Multi-Body Dynamics

When two or more floating structures operate in close proximity, multi- body dynamics should be considered. Model test results should be used if available. The hydrodynamics related to multi-body dynamics are complex. This relates to the:

- Interaction in the first-order wave forces, added mass and damping, wave drift forces.
- Viscous damping of the surge, sway, yaw and roll motion of the vessel in close proximity of another structure
- Interaction effect in the wind and current forces

For a single body with 6 DOFs, the equations of motion can be written as:

$$\sum_{j=1}^{6}\left(M_{kj}+m_{kj}\right)\ddot{x}_j \quad + \quad B_{kj}\dot{x}_j \quad + \quad C_{kj}x_j \quad = \quad F_k$$

where

x_j	=	motion in j-direction
F_k	=	external forces in the k-mode of motion
M_{kj}	=	inertia matrix
m_{kj}	=	added inertia matrix
B_{kj}	=	matrix of restoring coefficients
C_{kj}	=	matrix of damping force coefficients
k, j	=	1-6, mode of motion

For multiple-bodies (number of bodies n), the integrated system will result in n x 6 DOFs coupled motion of equations. All n bodies can be subject to wave-induced forces, hydrodynamic reaction forces and other coupling effects (either linear or non-linear). The inertia and added inertia matrices are derived from multi body diffraction analysis in the frequency domain.

When hydrodynamic loads are calculated based on multi-body dynamics, the wave shielding of one body by another body is taken into account automatically. The wave exciting forces, the added mass and damping of a given body is calculated with the other bodies present. For cross coupling terms (off-diagonal coupling terms), when the bodies are in close proximity such as side-by-side, the hydrodynamic cross coupling should be included in the analysis. The fully coupled matrix with the cross coupling between the different bodies should be used for multi-body dynamic analysis.

11 Mooring Line and Fender Design Assessment

11.1 Mooring Line and Fender Load for Strength Analysis *(1 February 2019)*

A strength analysis should determine the maximum loads and maximum offsets for the design conditions. In a one-component damage condition, a transient analysis should be performed to determine the maximum offsets.

Results from the strength analysis are then checked against allowable values for the adequate strength of the system against overloading and the sufficient clearance to avoid interference with other structures.

Mooring lines should be designed with the factors of safety specified in 3/7.7 of the ABS *Guide for Position Mooring Systems*. They are also listed in 2/11.1 TABLE 1 below with respect to the breaking strength and fatigue characteristics of mooring lines. These factors of safety are dependent on the design conditions of the system, as well as the level of analyses. Allowances for corrosion and abrasion of a mooring line should also be taken into consideration where applicable.

TABLE 1
Factor of Safety for Anchoring Lines

		Factor of Safety
All Intact		
Dynamic Analysis	(DEC)	1.67

		Factor of Safety
Quasi-Static	(DEC)	2.00
One Broken Line (at New Equilibrium Position)		
Dynamic Analysis	(DEC)	1.25
Quasi-Static	(DEC)	1.43
One Broken Line (Transient)		
Dynamic Analysis	(DEC)	1.05
Quasi-Static	(DEC)	1.18
Mooring Component Fatigue Life w.r.t. Design Service Life		
Inspectable areas		3.00
Non-inspectable and Critical Areas		10.00

Active mooring line adjustment should not be considered in the mooring analysis for maximum design conditions. For a mooring system where the mooring line load could be significantly affected by the different loading conditions (e.g., full load and ballast conditions), the mooring line may be adjusted for different loading conditions. In such a case, they should be documented clearly in operations manual.

Fender loads should be calculated under the maximum environmental conditions in which the floating structure is to remain at the berth. Fenders should be selected in accordance with industry standards.

11.1.1 Strength Analysis for Jelly Mooring *(1 February 2019)*

For jetty mooring system strength analysis, methodologies and guidelines for position mooring as given in 8/5 of the ABS *Guide for Position Mooring Systems* and guidelines given in OCIMF MEG can be referenced where applicable.

The calculations of the mooring line tension and fender loads should be based on dynamic analysis methods. Where a different method is used, the assumptions and validations should be documented. To calculate mooring line tensions and fender loads, the following loads should be considered:

- Steady wind, current loads and mean wave drift forces
- First-order wave forces
- Slow wave drift forces
- Dynamic wind loads (for wind loads calculation method, see 2/9.1)

Due to the nonlinearity of the mooring and fender systems, a time-domain analysis is recommended. The following analysis procedure may be used:

i) Obtain mooring system configuration or pattern

ii) Obtain environmental conditions

iii) Set up dynamic load model

- Loading conditions, mass properties of each floating structures
- Distance between each floating structure where applicable
- Hydrodynamic panel models for wave load
- Wind load model
- Current load model

iv) Set up mooring line model

v) Set up fender model

vi) Calculate the hydrodynamic wave loads and hydrodynamic coefficients

- Consideration of effects from pier
- Consideration of passing by vessel effects
- Consideration of hydrodynamic interaction effects of multiple bodies
- Considerations of other loads, such as swell, tsunami or seiche

vii) Calculate wind and current load or load coefficients

- Consideration of floating structure draft, trim or list
- Consideration of floating structure under keel clearance

viii) Static analysis under steady wind, current and mean wave drift forces

ix) Perform time domain simulations

x) Obtain mooring line and fender loads

xi) Obtain vessel offsets where applicable

Normally, if the mooring system is designed to the maximum design wave, wind and current forces, reserve strength will be sufficient to resist other moderate forces that may arise. However, if other appreciable forces, such as passing vessel effects, tsunami, seiche or ice conditions exist, considerable loads can be developed in the mooring lines. These forces are difficult to analyze and should be usually determined through model testing, field measurements or advanced computer programs.

11.1.2 Strength Analysis for Tension Pile Mooring

Strength analysis is required for structures onboard the floating structure that are in the load bearing path of the mooring system. Load and motion analysis can be performed with the restrictions from the tension piles to the floating structure appropriately considered. These restrictions can be considered as additional stiffness that may be derived by a structural analysis using 3D finite element models. Guidelines for strength analysis can be found in 3-2-3/3 of the *FPI Rules* or other applicable industry standards.

For tension piles, guidelines for strength analysis can be found in Section 3-2-5 of the *Offshore Installations Rules.*

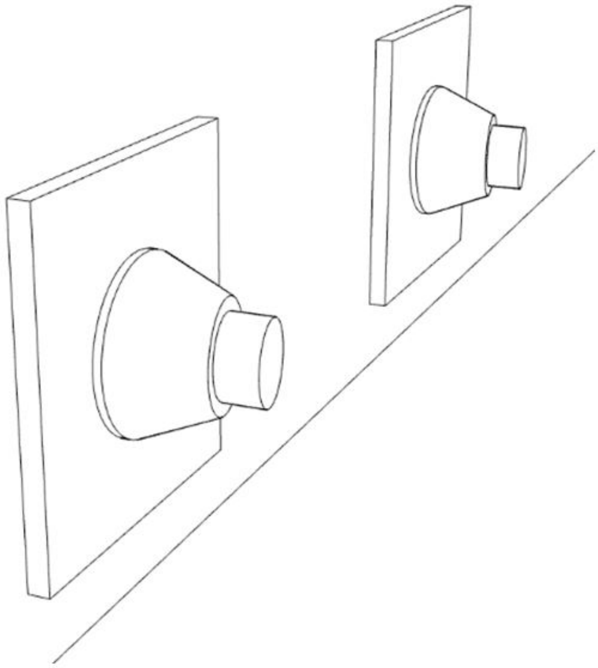
11.1.3 Strength Analysis for Other Nearshore Position Moorings

For nearshore position mooring with new features, the analysis methods should be submitted by the designer and reviewed by ABS on a case-by-case basis.

11.2 Assessment of Fender Load on the Contact Vessel *(1 February 2019)*

The jetty moored vessel should endure repetitive impact loads from fenders as the vessel oscillates due to environment loads. 2/11.2 FIGURE 1 depicts a typical fender used for a jetty mooring system. The strength of the shell plating of the vessel should be capable of withstanding these loadings. The pressure on the hull from the fender can be calculated directly using the rated fender force specified by the manufacturer. Alternatively, the pressure can be determined using maximum fender load obtained from mooring analysis with a safety factor of 1.25 in the design environmental condition (DEC) and with a safety factor of 1.67 in the Design Operation Condition (DOC).

FIGURE 1
Fender Contact



For the mooring analysis, the fender and vessel contact modeling should include the nonlinear stiffness and the contact surface area of the fender. The friction coefficient on the fender surface should be set based on manufacturer specification. Appendix 1 provides procedures for a jetty mooring analysis.

11.3 Mooring Line Fatigue Load Analysis *(1 February 2019)*

Fatigue analysis should be performed for mooring line components where applicable. For mooring line components designed to be repairable and replaceable, fatigue analysis may not be necessary. The replacement schedule should be submitted for review.

Fatigue life estimates are made by comparing the long-term cyclic loading in a mooring line component with the fatigue capacity of that component. The factors of safety for fatigue life should be in accordance with the requirement in the ABS *Guide for Position Mooring Systems* and are also listed in 2/11.1 TABLE 1.

11.3.1 Fatigue Analysis for Jetty Mooring *(1 February 2019)*

For jetty mooring system fatigue analysis, methodologies and guidelines for position mooring as given in 8/5 of the ABS *Guide for Position Mooring Systems* can be referenced.

Mooring line fatigue loads should be calculated for each fatigue sea state based on long-term statistics. The calculations of the mooring line fatigue loads should be based on the dynamic analysis methods. To calculate mooring line fatigue loads the following loads should be considered:

- Steady wind, current loads and mean wave drift forces
- First-order wave forces
- Slow wave drift forces

The following approaches can be used for the analysis:

11.3.1(a) Static and Frequency-Domain Analysis Approach

i) Static Analysis under steady Wind, Current and Mean Wave Drift Forces. Mooring line loads are calculated based on the principle of static equilibrium. The change of mooring system geometry due to elasticity of the line components should be considered in the analysis.

ii) Frequency-Domain Analysis for First-Order Wave Loads Induced Mooring Line Fatigue Loads. The first-order wave induced motions can be treated as independent of the mooring properties. The motions should be estimated from model tests, calculated using suitable computer software or measured from field observations at the site. Effects of pier and multibody dynamics should be considered. The properties of local winds, seas and swell are generally different and independent. Their effects on floating structure motions should be estimated separately and then combined by taking the root of the sum of the squares of the two motions induced by waves and swell. The additional mooring line tensions due to wave motions are calculated by superimposing these motions onto the equilibrium position. When mooring line dynamic effects are significant, these effects can be considered through applying a line tension amplification factor.

iii) Frequency-Domain Analysis for Dynamic Wind Load and Second-Order Wave Load Induced Mooring Line Fatigue Load. The low frequency motions can be calculated based on linearized motion equations under the dynamic wind loads and second-order wave loads in the frequency domain. The motion induced mooring line loads then can be calculated based on the calculated motions.

11.3.1(b) Time-Domain Analysis Approach

- For each fatigue sea state, time-domain analysis can be performed based on the method as given in 2/11.1.1.
- Tension cycles can be obtained based on rain-flow counting
- Fatigue life calculation is based on given mooring line fatigue capacity model

Due to the nonlinearity of the jetty mooring system, it is recommended that a time-domain approach be used in the fatigue analysis. However, the frequency-domain dynamic analysis method may be used in the fatigue analysis provided the nonlinear effects are appropriately linearized. For further guidance on combination of the fatigue damage of wave frequency and low frequency components in the fatigue analyses in the frequency domain, reference can be made to API RP 2SK.

11.3.2 Fatigue Analysis for Tension Pile Mooring

Fatigue analysis is required for structures on board the floating structure that are in the load bearing path of the mooring system. Guidelines for fatigue analysis can be found in Section 5B-2-4 of the *FPI Rules* or other applicable industry standards.

For tension piles, guidelines for fatigue analysis can be found in Section 3-2-5 of the *Offshore Installations Rules.*

11.3.3 Fatigue Analysis for Other Nearshore Position Moorings

For nearshore position mooring with new features, the analysis methods should be submitted by the designer and reviewed by ABS on a case-by-case basis.

11.5 Mooring Line Fatigue Capacity

When fatigue analysis is required, the appropriate fatigue capacity models (S-N curves or T-N curves) for mooring line components of chain, wire rope and fiber rope should be used. As given in API RP 2SK, the T-N curve approach is used to determine the number of cycles to failure for a specific mooring component as a function of a constant normalized tension range. The T-N curve for a specific type of mooring component is established based on experimental results.

The equation for a representative T-N curve is:

$$N \;.\; T^{m} = K$$

where

N	=	number of permissible cycles of tension range ratio, T
T	=	ratio of tension range (double amplitude) to the reference breaking strength of the component (see guidance given below)
m	=	inverse slope of the T-N fatigue curve
K	=	constant coefficient or mean load dependent coefficient

When determining the reference breaking strength of the mooring chain or connecting links, the diameter for different periods of service life can be established if the corrosion and wear rate can be predicted. If the corrosion and wear rate is uncertain, a conservative approach using the nominal diameter minus the corrosion and wear allowance should be considered for the fatigue analysis. The reference breaking strength for a wire rope should be its Minimum Breaking Strength (MBS).

For mooring line components with no standard fatigue capacity models (S-N curve or T-N curve), fatigue testing should be performed to determine the mooring line fatigue capacity.

For the mooring components that could experience a much more complicated loading pattern, such as those in a jetty mooring system, in comparison with that in offshore mooring leg (bending, tension, etc.), and may experience high level of wear and tear, ultraviolet, heat and other harsh environments, traditional Tension-Tension fatigue analysis may not yield reliable prediction of the fatigue life of these components. Those components should be designed for easy inspection, maintenance and replacement.

11.7 Design Life and Replacement

Mooring line components and fender system components can be designed so as to not to require replacement during their design life or service life (see2/1 for design life of permanent components). Mooring line components and fender system components may also be designed to be repairable and replaceable when needed during service life based on planned inspection and maintenance. The design life of components intended for use on a temporary basis can be lower than 20 years and should be regularly inspected and replaced when necessary based on material degradation.

For mooring line components that are not intended to be replaced during design life, the replacements of such permanent components should depend on the inspection results from scheduled surveys required as conditions for class. Replacement should be performed when required by the inspection results.

For mooring line components, such as rope tails and fender system components that are intended to be regularly inspected and may be repaired and replaced periodically, the inspection plan including inspection methods and inspection intervals of such temporary components should be in place and specified in the Operations Manual.

13 Other Design Considerations *(1 February 2019)*

Mooring equipment should be reviewed in accordance with published ABS requirements for such equipment or applicable recognized industry standards. Applicable ABS references and industry standards are:

- Chain: ABS *Guide for the Certification of Offshore Mooring Chain*
- Fiber Ropes: ABS *Guidance Notes on the Application of Fiber Rope for Offshore Mooring*
- Wire Rope: API Spec 9A and API RP 9B

- *Mooring Equipment Guidelines*, OCIMF

The *Mooring Equipment Guidelines* provides detailed sources for the design considerations of mooring hardware, inspections, maintenance and operations. It also provides items to consider regarding the human factor elements in mooring design.

13.1 Clearance

Clearance (ship-to-unit, unit-to-jetty, unit bottom clearance, mooring lines to other adjacent structures) should be considered in the design.

Sufficient bottom clearance of the floating structure should be maintained for water level variations due to tides and draft, trim, and motions of the floating structures for all design conditions.

Clearance between an LNGC or other carrier to the floating structure (vessel-unit) and between the floating structure to the jetty when applicable (unit-to-jetty) should be considered in the design.

The mooring system should be designed with sufficient clearance to avoid interference with other adjacent structures for all design conditions.

13.3 Mooring Supporting Structure

Structures supporting anchoring equipment, fairleads and winches should be designed to the expected design loads. Structural strength, bulking and fatigue of mooring supporting structures onboard the floating structure as applicable should be considered in the design. Design and analysis criteria should conform to the structural design requirements specified in 5A-1-4/3, 5B-1-2/7.3, 5B-2-4/5.3, and 5B-3-4/1.1 of the *FPI Rules* and 3-7/3 of the *FLGT Guide*.

Considerations concerning the strength for mooring supporting structures and all mooring fittings (such as chain stopper, fairleads, chocks, bitts, rollers, etc.) should be based on the principle of mooring line failure before fitting failure and fitting failure before hull structure or foundation failure.

13.5 Mooring Holding Foundation

Structural strength, bulking and fatigue of mooring holding foundations for winches, fairleads and other mooring equipment on board the FLGT, FSRU, and other floating structure as applicable, should be considered in the design. The design and analysis criteria should conform to the structural design requirements specified in Section 5A-1-3, 5B-1-2/7.3, 5B-2-3/1.13, and 5B-3-3/1.13 of the *FPI Rules* and 3-7/5.3 of the *FLGT Guide*.

13.7 Corrosion, Wear and Rope Creep *(1 February 2019)*

Corrosion, wear and rope creep should be considered in the design. Chain and wire rope will be degraded due to corrosion and wear. Special attention should be paid to the components that often go through chocks, sheaves, and bend shoes. In addition to wear or abrasion of the fiber ropes, ropes may creep and experience creep rupture due to sustained and cyclic loads. Creep rupture can be a failure mode of fiber rope, such as HMPE (high modulus polyethylene), due to continuous creep over time under a specific load and temperature.

When chain is designed as a permanent component of the mooring lines, the allowance for corrosion and wear should be included in the design. It should be noted that corrosion rate depends on type of steel and seawater environment, and is often significantly accelerated in the first few years of service.

Corrosion protection can be provided by galvanizing individual wires. Corrosion of wire rope at connections to sockets can be excessive due to the galvanized wire acting as an anode for adjacent components. For permanent systems it is recommended that either the wire be electrically isolated from the socket or that the socket be isolated from the adjacent component. Additional corrosion protection can be achieved by adding sacrificial anodes to this area. Applying sheathing could be helpful to maintain the long-term integrity of the wire especially for submerged wire ropes. However, sheathing may make inspection of components difficult especially when they subject to bending.

For polyester mooring ropes, line adjustments may be needed during design service life due to rope creep, and sufficient upper chain or wire segment length should be retained to allow future line adjustments where applicable. Estimate of future line adjustments can be carried out using the creep rates at the creep plateaus from the quasi-static stiffness test.

A main concern with HMPE (high modulus polyethylene) is its tendency to creep and the potential for failure via creep rupture, which should be addressed in the design of permanent moorings. As an HMPE rope creeps under tension, eventually it stretches to the point of complete failure. Another concern is the need for re-tensioning because of HMPE's high creep rate. A creep analysis should be performed for an intact mooring to estimate the total creep strain during the design service life. A creep rupture analysis should be performed for an intact mooring to estimate the creep rupture life.

Aramid rope has better resistance to creep than polyester and HMPE rope, and therefore creep and creep rupture analysis are not required for mooring design utilizing Aramid rope.

13.9 Safety Considerations *(1 February 2019)*

Safety considerations, such as snap-back should be taken into account in the design.

Snap-back is the sudden release of the energy stored in a tensioned mooring line when it parts as the mooring line reverts to its original length. The two ends of the line recoil or snap-back towards or past their secured ends. When a synthetic mooring line breaks, the snap-back effect can be extremely powerful and the rope ends may reach a high velocity as they recoil. Anyone within the snap-back zone at either end of the line risks serious injury or death.

It is to be noted that the most likely snap-back zones depend on actual mooring arrangements onboard. Sometimes, a synthetic tail is added to a mooring line to provide additional elasticity in the mooring system and serve to reduce peak dynamic loads. As a result of the tail's elasticity, the elongation of the total mooring line under tension is increased; this introduces significant stored energy that will be released if the mooring line fails. When connecting synthetic tails to HMSF (High Modulus Synthetic Fiber) and wire mooring lines, the energy introduced due to the elasticity of the tails can significantly increase the snap-back hazard.

It is also important to consider the effects of fire / blast and the resulting thermal effects on nearshore mooring systems which are not submerged. Mooring systems are normally located at the extremities of the vessel, but due considerations should be made for impact of congested topsides (e.g. FLNG, and later generation of FPSO topsides) and possible ignition of gas clouds as a result of LNG leakage. Accordingly, fire and blast studies together with gas dispersion/thermal analyses should be used to recommend safety zones for the mooring system location (noting that high temperatures can also adversely affect certain synthetic ropes). The Sections 5C-13-11 and 5C-13-12 of the ABS *Marine Vessel Rules* can be referred on fire safety and explosion preventions, respectively.

13.11 Bend Radius and Bending Fatigue of Mooring Line

Bending fatigue of mooring line components, such as chain and wire rope, should be considered in the design. The strength and life expectancy of fiber rope and wire are directly related to the anticipated bend radius in service. The rope manufacturer's guidelines on acceptable minimum bend radius and industry guidelines, such as OCIMF and API RP 2SK, should be consulted for each specific application. For some applications in a permanent mooring, location of fiber rope segments should be designed to be away from fairlead and seafloor to avoid excessive bending by using segments of chains at the top and bottom. Allocating the winches toward the deck edge can also reduce the bending of the mooring lines.

The strength of wire rope decreases when bent over a radius. An acceptable minimum bend ratio should be determined based on different application.

At the moment, publically available data for bending-tension fatigue of chain, wire and fiber rope are insufficient for generating design curves. In the absence of a fatigue design, precautionary measures should be taken to avoid mooring failure due to bending-tension fatigue. For example, the fairlead to line diameter ratio (D/d) should be large enough to minimize bending. The portion of mooring line in direct contact with a fairlead should be regularly inspected. Also, this portion should be periodically shifted to avoid constant bending in one area.

Industry experience indicates that chain links in direct contact with fairleads, bending shoes, chain stoppers, or hawser pipes can be subjected to additional stress concentrations, which in turn can cause premature fatigue failure. Stress concentrations under these conditions should be carefully evaluated by finite element analysis, especially for permanent moorings. Fatigue analysis should account for the additional stress concentration in these areas.

It is recommended that fairleads used in position mooring system should provide sufficient sheave to rope diameter ratio to minimize tension-bending fatigue. It is recommended that sheaves for wire rope have diameter (D/d) ratios of 16-25 for relatively short-term mobile mooring and 40-60 for long-term permanent mooring. Typically 7 to 9 pocket wildcat sheaves are recommended for chain. Other constructions which provide similar or better support may be considered.

It is also recommended that all the winches and related mooring equipment be located to the side of the unit to avoid bending over side and snap back effects.

13.13 Axial Compression Fatigue of Fiber Rope

Axial compression fatigue of fiber rope should be considered in the nearshore position mooring design when fiber ropes are used as the mooring line components.

Axial compression degradation is a failure mode for fiber rope under low tension or compression. Axial compression fatigue for aramid ropes should be properly addressed. Individual filaments may suffer compression fatigue if the bending of the rope is severe.

13.15 Mooring Load Monitoring

A mooring load monitoring system or other acceptable monitoring system should be provided for tracking environmental conditions or mooring line tensions in order to assist in the decision to disconnect the floating structure from the mooring system for a disconnectable nearshore position mooring, as well as tracking line life and stopping operations for non-disconnectable mooring system.

When mooring line adjustment is required in the design, moored floating structures should be equipped with a calibrated system for measuring mooring line tensions if the operation requires mooring line adjustment, and line tensions should be continuously displayed at each winch. For floating structures that do not require a tension measurement device, a device for detecting mooring failure should be considered if the mooring lines of the mooring system are not visually inspectable for line failure.

It should be noted that upon completion of mooring line adjustment, line tensions should be set to the design values. The mooring system should be set back to its original approved design configuration. The winch brake should be applied and winch motor put out of gear, if applicable.

13.17 Mooring Equipment

If the mooring lines are terminated and secured by winch brakes, the winch brakes should be able to render at 60% Minimum Breaking Load (MBL). Since brakes may deteriorate in service, it is recommended to design new equipment to hold 80% of the line's MBL, but have the capability to be adjusted down to 60% of the line's MBL. If the mooring system is designed to be terminated and secured by a chain stopper for a long-term operation, the chain stopper should be designed to the MBL of the mooring line.

13.19 Inspection and Replacement

For nearshore mooring systems, the mooring components are generally accessible. Mooring system design should consider easy inspection and replacement of the mooring components.

SECTION 3 Documentation

1 Mooring Arrangement and Equipment

i) Mooring arrangement or pattern

ii) Details of mooring line components

iii) Details of connections between mooring segments

iv) Details of connections at anchors to mooring line segments, if applicable

v) Details of mooring line end fitting and accessories

vi) Details of clump weight and in-line (spring) buoy, if applicable

vii) Details of buoy for Catenary Anchor Leg Mooring (CALM) system, if applicable

viii) Details of Single Anchor Leg Mooring (SALM) structures, if applicable

ix) Details of Turret System to show turret structure, swivel and turntable, if applicable

x) Details of yoke (hard or soft) connecting the floating structure to CALM/SALM structure, if applicable

xi) Details of anchoring system and/or pile foundation, if applicable

xii) Details of onboard mooring equipment

xiii) Details of mooring disconnection devices, if applicable

xiv) Details of monitoring systems, if applicable

xv) Specifications for mooring line components, connections, fittings and accessories

xvi) Specifications for onboard mooring equipment

3 Analysis Reports

The following analysis reports should be submitted for review:

i) Environmental report

ii) Site condition for soil data, if applicable

iii) Environmental loads calculation

iv) Model Test report when the design loads are based on model tests in a wave basin

v) Hydrodynamic and motion analysis report

vi) Mooring strength and fatigue analysis reports

vii) Sedimentation study, where applicable

5 Operations Manual

An operations manual with following information on the nearshore position mooring should be submitted for review:

i) Limiting environmental conditions for design operation conditions.

ii) Limiting environmental conditions for mooring disconnecting conditions, if applicable.

iii) Disconnecting Procedure, if applicable.

iv) Inspection interval of rope tails and mooring line components and fenders, if applicable.

v) Rope and rope tail replacement interval, if applicable. Supporting documents for recommended replacement interval may be required.

APPENDIX 1 Sample Jetty Mooring Analysis *(1 February 2019)*

1 General

This Appendix provides an example of a jetty mooring analysis to illustrate the analysis procedures. This example of a jetty mooring is for a nearshore permanently moored floating storage unit subject to wind, wave and current loads. It is applicable to any nearshore jetty mooring for a permanently moored floating production unit.

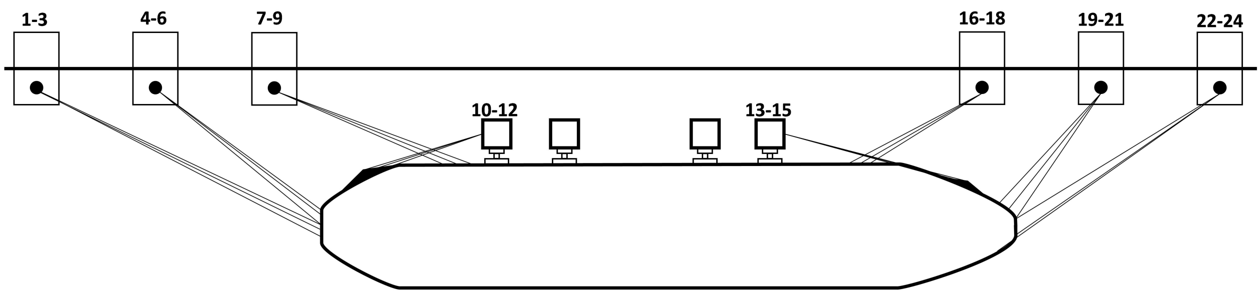
The analysis is performed for a typical vessel with assumed load cases. The data provided is for reference only and should not be used for any specific project.

2 Jetty Mooring Configuration

Appendix 1, Figure 1 is a common jetty mooring arrangement. In this configuration, the vessel is tied to the jetty using several mooring lines, with the line pretension balanced by fender counter force. This arrangement provides a very stiff mooring system with minimal vessel motions, which is essential for LNG offloading operations.

In this particular case study, the vessel is moored with 24 mooring lines and 4 fenders. The lines are composed of two sections, one being steel wire and connecting to the vessel, and a polyester rope tail connecting to the berthing facility. The fenders are cone shaped with a rectangular plate attached at the front that comes in contact with the vessel. Fender geometry is shown in A1/4 FIGURE 9. The arrangement of the lines and fenders are shown in A1/2 FIGURE 1.

FIGURE 1
Jetty Mooring Configuration



3 Environmental Conditions

Site-specific environmental data from metocean report should be used and should contain the following:

i) Meteorological data

- Wind (speed, direction, profile)
- Temperature (air, sea)

ii) Oceanographic data

- Bathymetry
- Water levels (tides, storm surge)
- Currents (speed, direction, profile)
- Waves (height, period, direction)

Loading due to these environmental factors should be carefully considered and analysis should be performed considering relevant vessel loading conditions for:

- Design Environmental Condition (DEC)
- Design Operating Condition (DOC)
- Disconnecting Environmental Condition (DISEC)

The mooring system should survive the design environmental condition without disconnecting. For this study, environmental parameters corresponding to a 1-year return period were used for the operational condition and a 100-year return period were used for the design environmental condition, see A1/3 TABLE 1.

TABLE 1
Environmental Conditions

Return Period (years)	*Wind Speed (m/s)*	*Current Speed (m/s)*	*Significant Wave Height (m)*	*Peak Period (s)*
1	8.5	1.39	1.5	5.6
100	10.7	1.53	3.2	8.3

Directions of the environmental loads are also provided. Specific modeling details for wind, waves and currents are given below.

3.1 Wind Load Calculation

The wind load is calculated based on the OCIMF wind coefficients for prismatic LNG type tanks and illustrated in A1/3.1 FIGURE 2 and A1/3.1 FIGURE 3. Note that those coefficients can be obtained through wind tunnel tests. The effective windage area in the longitudinal and lateral directions are obtained for particular loading conditions. The yaw wind moment area is calculated using the OCIMF guideline.

FIGURE 2
Wind Load Coefficients for Surge and Sway

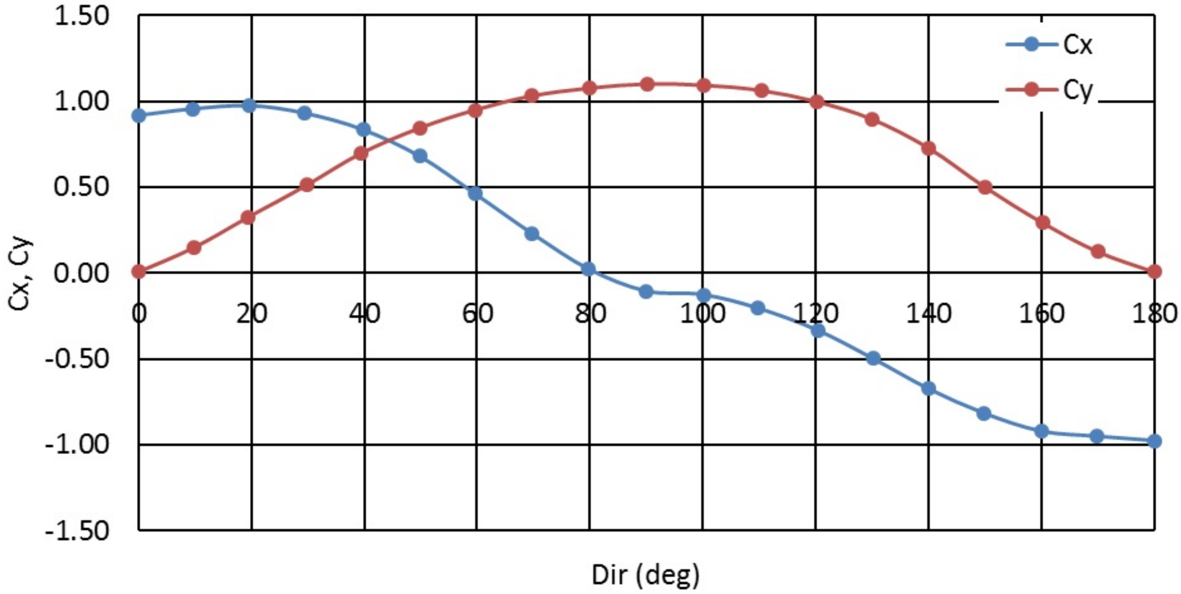
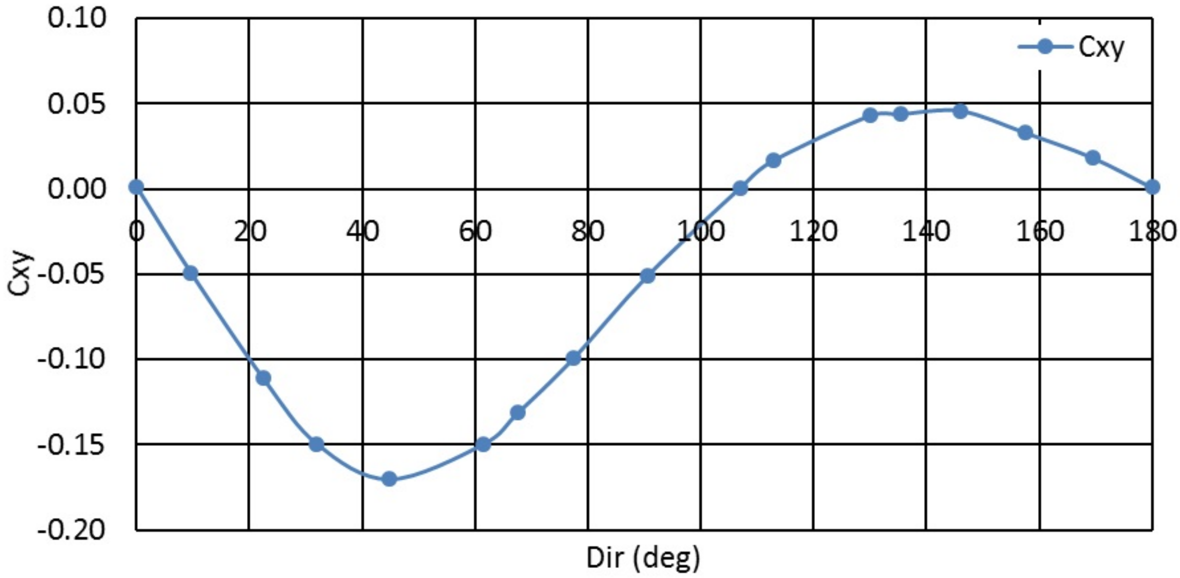


FIGURE 3
Wind Load Coefficients for Yaw



The resultant wind forces/moment acting on the moored vessel are calculated using the following Equations. The resultant forces/moment refer to the center of the vessel.

$F_{xw} = \frac{1}{2} C_x \rho_w V_w^2 A_T$

$F_{yw} = \frac{1}{2} C_y \rho_w V_w^2 A_L$

$M_{zw} = \frac{1}{2} C_{xy} \rho_w V_w^2 A_L L_{BP}$

where

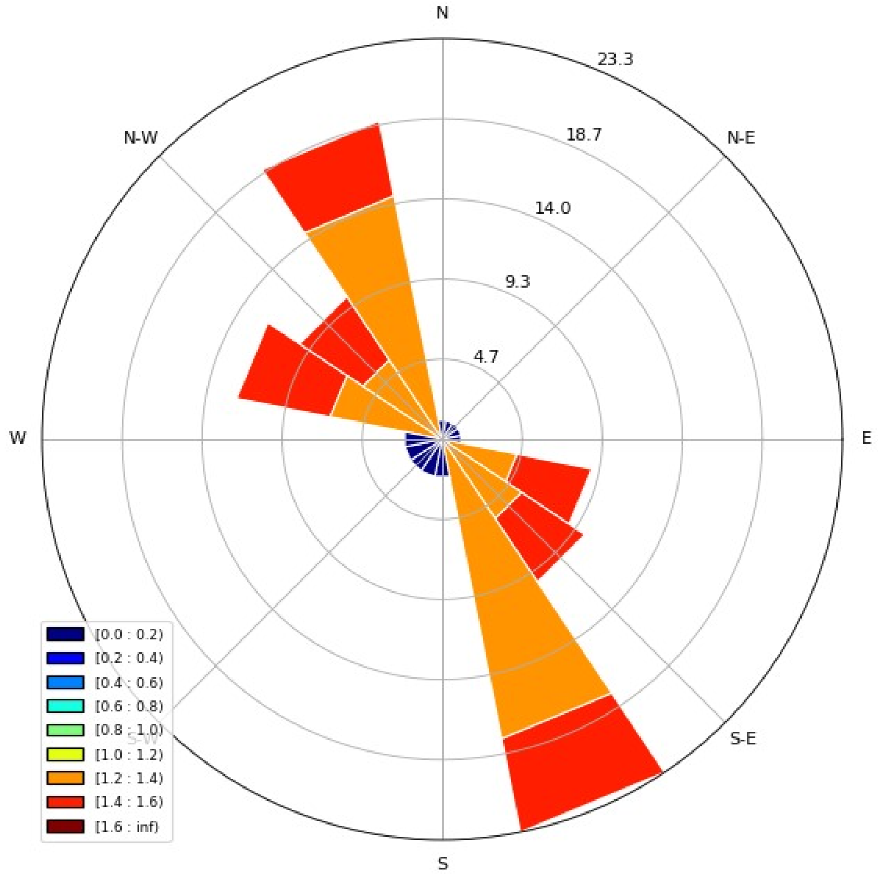
F_{xw}	=	wind force in longitudinal direction, KN (lbf)
F_{yw}	=	wind force in lateral direction, KN (lbf)
M_{zw}	=	wind moment in yaw direction, KN-m (lbf-ft)
ρ_w	=	air density, tonnes/m^3 (slugs/ft^3)
V_w	=	wind speed, m/s (ft/s)
A_T	=	windage area in the longitudinal direction, m^2 (ft^2)
A_L	=	windage area in the lateral direction, m^2 (ft^2)
L_{BP}	=	vessel's length between perpendiculars, m (ft)

3.2 Current Load Calculation

The current load is calculated using the OCIMF coefficients. The current force area in longitudinal and lateral are obtained for particular loading conditions. The yaw moment area is calculated using the OCIMF guideline.

For the nearshore environment, the current is typically stronger along the shoreline and weaker perpendicular to the shoreline. A1/3.2 FIGURE 4 depicts the current speed and direction as an example, where the high current speed is along the shoreline. The current profile also varies with depth, thus surface, mid depth and near seabed values were used to define the current profile.

FIGURE 4
Current Speed and Direction



The current load coefficients for the vessel are obtained from the OCIMF recommendation (see A1/3.2 FIGURE 5, A1/3.2 FIGURE 6 and A1/3.2 FIGURE 7). Two water depth to draft ratios are considered corresponding to fully loaded vessel in low tide (WD/T = 1.69) and ballast vessel in high tide (WD/T = 2.14).

FIGURE 5
Current Load Coefficients in Longitudinal Direction

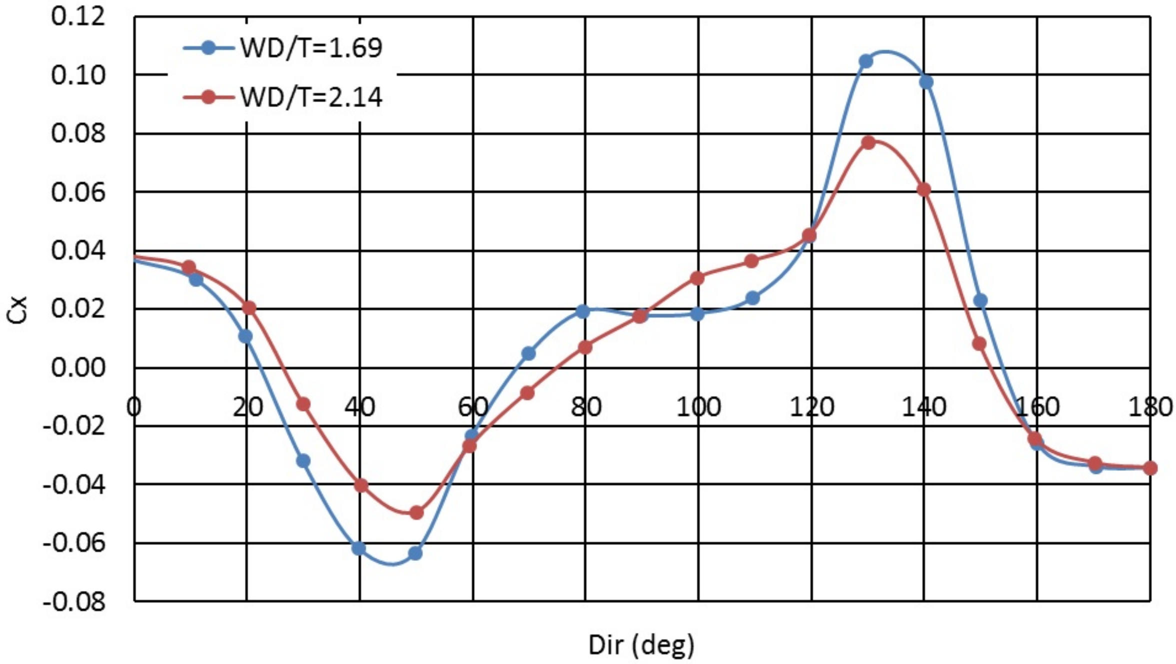


FIGURE 6
Current Load Coefficients in Lateral Direction

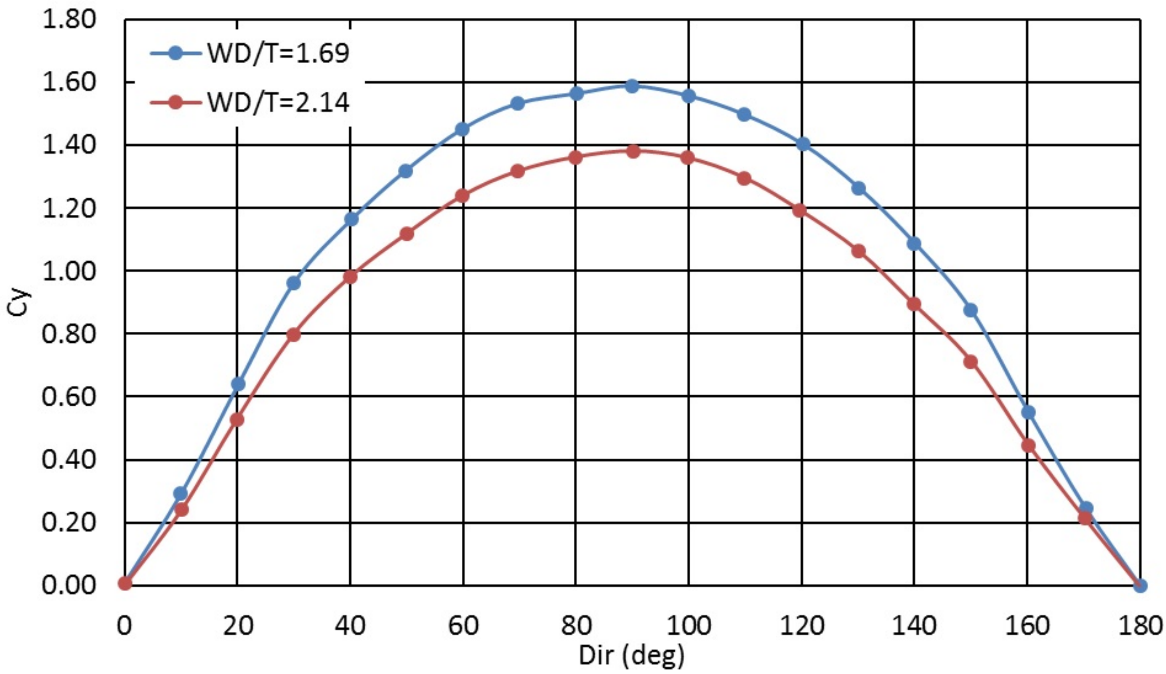
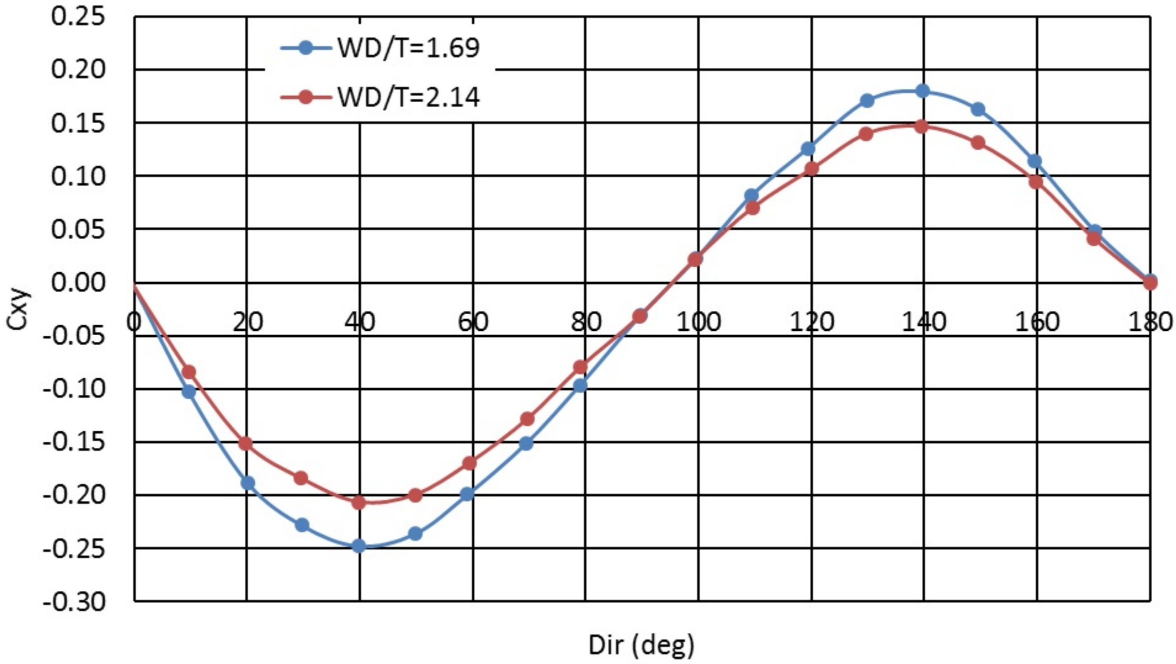


FIGURE 7
Current Moment Coefficients for Yaw



The resultant current forces/moment acting on the moored vessel are calculated using the following Equations. The resultant forces/moment refer to the center of the vessel.

$$F_{xc} = \frac{1}{2} C_x \rho_c V_c^2 L_{BP} T$$
$$F_{yc} = \frac{1}{2} C_y \rho_c V_c^2 L_{BP} T$$
$$M_{zc} = \frac{1}{2} C_{xy} \rho_c V_c^2 L_{BP}^2 T$$

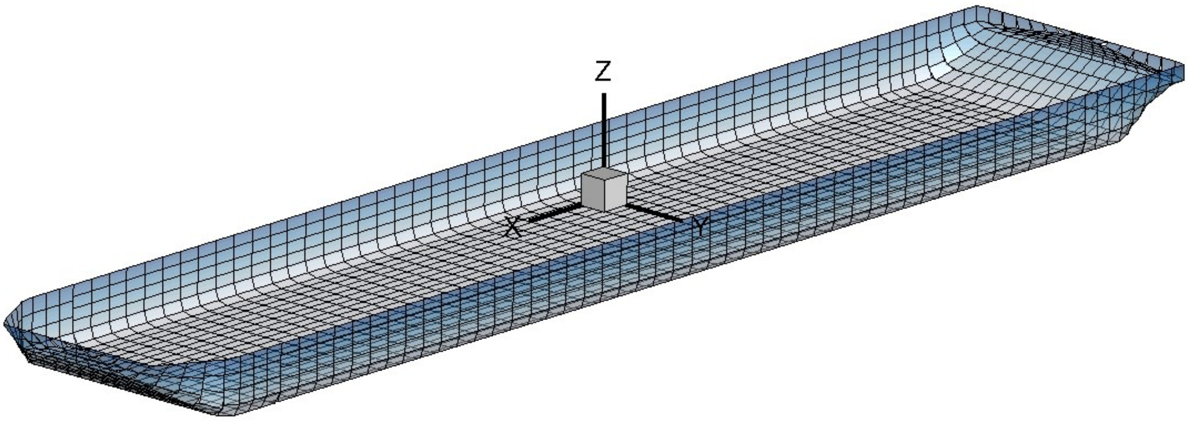
where

F_{xc}	=	current force in longitudinal direction, KN (lbf)
F_{yc}	=	current force in lateral direction, KN (lbf)
M_{zc}	=	current moment in yaw direction, KN-m (lbf-ft)
ρ_c	=	seawater density, tonnes/m^3 (slugs/ft^3)
V_c	=	current speed, m/s (ft/s)
L_{BP}	=	vessel's length between perpendiculars, m (ft)
T	=	draft, m (ft)

3.3 Wave Load Calculation

The wave load is calculated for site-specific sea state data. A diffraction analysis is performed for the freely floating vessel to obtain the wave forces of first order and second order drift forces. Commercial software for the wave forces predictions are available and can be used to obtain the wave forces. A1/3.3 FIGURE 8 illustrates a hydrodynamic panel model for wave forces calculations.

FIGURE 8
Hydrodynamic Model for Wave Load Calculation



4 Mooring Analysis

The mooring analysis includes the modeling of mooring lines, fenders and the moored vessel, and predicts motions of the moored vessel and mooring line and fender load. The inputs include geometry, dimensions, main particulars, stiffness properties and environment conditions and environment load coefficients. A1/4 TABLE 2 lists the properties of the fender selected for this case study and A1/4 FIGURE 9 and A1/4 FIGURE 10 illustrate fender's geometry and stiffness property.

The mooring analysis model is plotted in A1/4 FIGURE 11. The hydrodynamic loads calculated from load analysis are utilized for the mooring analysis. In this case study, the mooring line and fender loads are obtained through 3-hour time domain simulation. The most probable extreme value of the line tension and fender reaction forces in design environment conditions and operating conditions are obtained from the mooring analysis.

TABLE 2
Fender Information

Geometry		
Height	H	2 m
	$\emptyset\ W$	3.2 m
	$\emptyset\ U$	1.955 m
	Weight	9560 kg
Rated Energy Performance Data (RPD)		
Rated Energy	E_R	3800 KN-m
Rated Reaction	R_R	3680 KN

FIGURE 9
Illustration of Fender Geometry

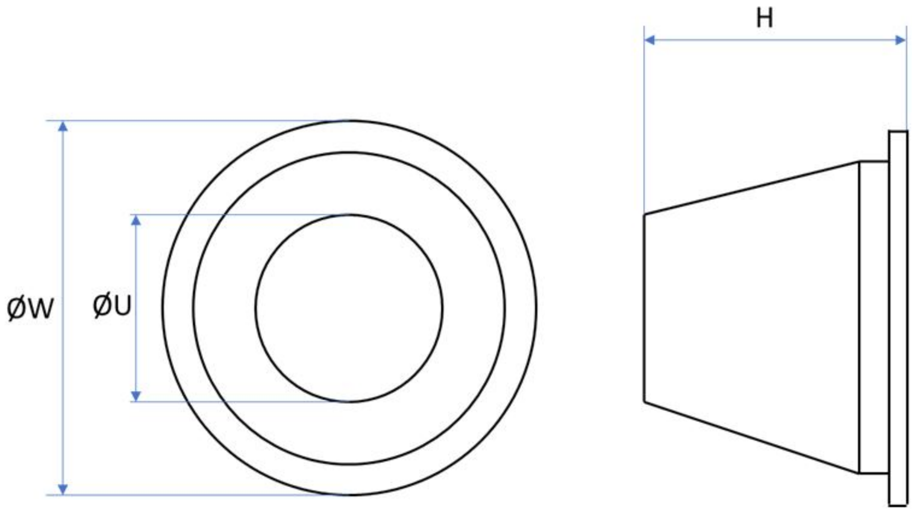


FIGURE 10
Fender Stiffness Curve

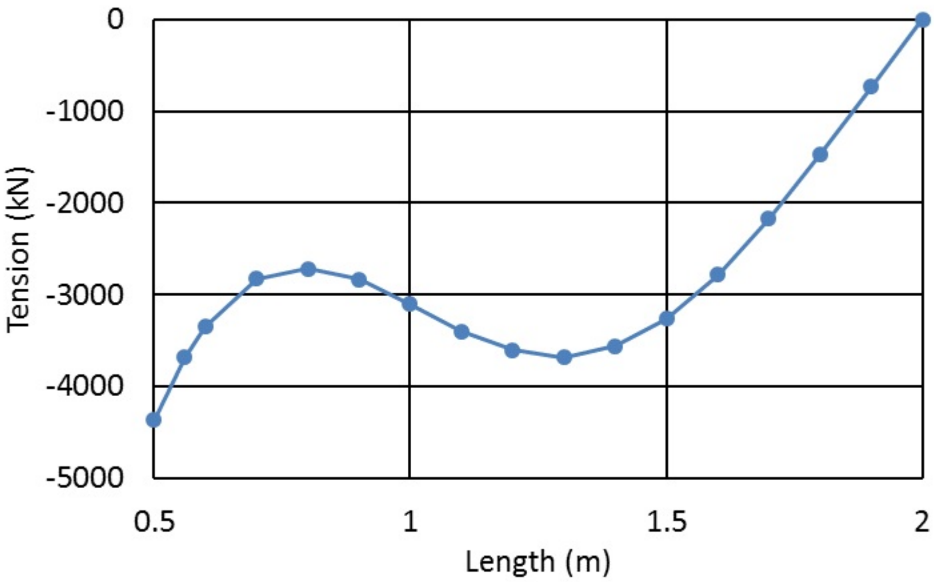
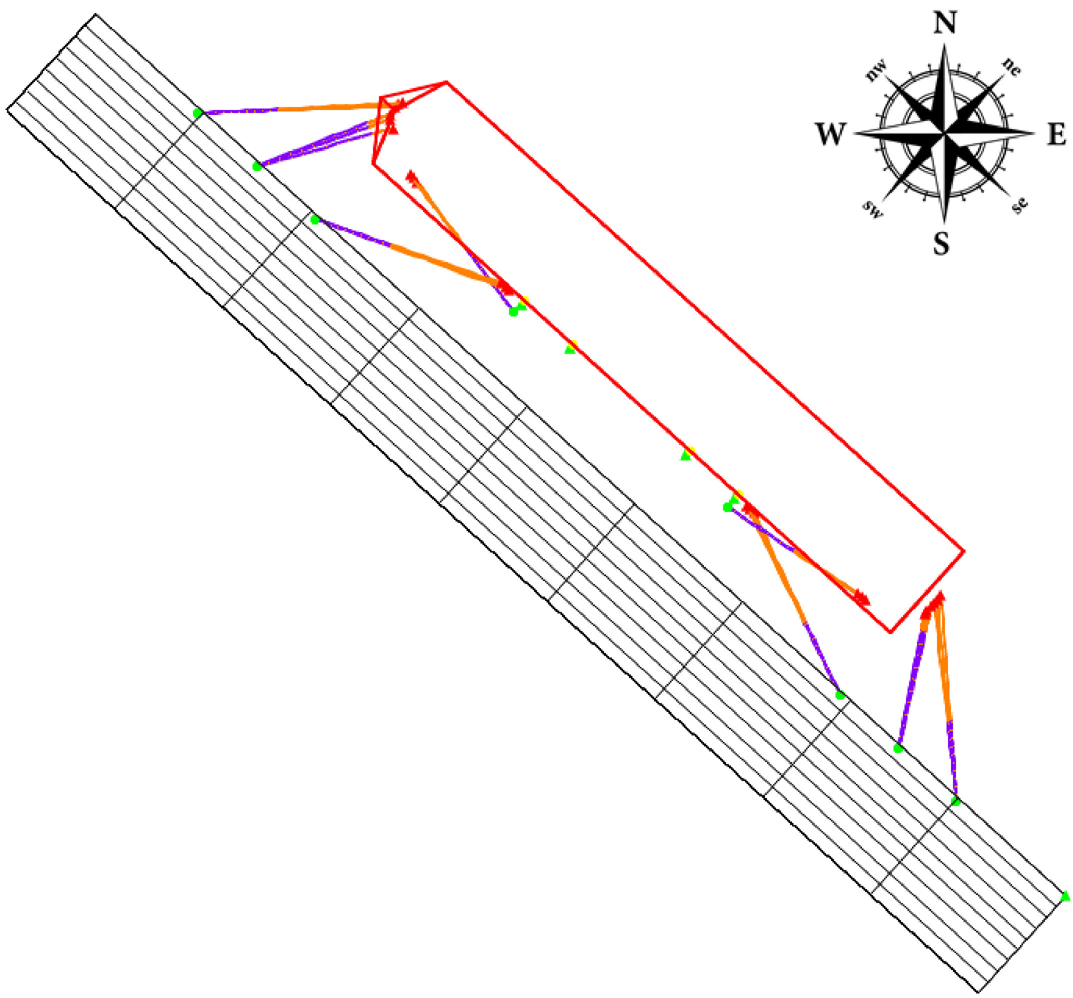


FIGURE 11
Mooring Analysis Model



5 Extreme Value Selection

The extreme values of mooring line tension and fender loads are determined from the most probable extreme values of the 3-hour time domain simulations. For the mooring lines, these maximum values are checked against the allowable maximum tension with the safety factors given in this Guidance Notes which are 1.67 for intact mooring condition and 1.25 for one-line damage condition.

For the fenders, the compression limits of the fenders provided by the manufacturers can be followed.

APPENDIX 2 Abbreviations

1 Abbreviations *(1 February 2019)*

ABS: American Bureau of Shipping

API: American Petroleum Institute

CALM: Catenary Anchor Leg Mooring

CFD: Computational Fluid Dynamics

CNG: Compressed Natural Gas

DEC: Design Environmental Condition

DIC: Design Installation Condition

DISEC: Disconnecting Environmental Condition

DOC: Design Operating Condition

DOFs: Degrees-of-Freedom

FLGT: Floating Offshore Liquefied Gas Terminals

FPI: Floating Production Installations

FPSO: Floating Production Storage and Offloading

FSRU: Floating Storage and Regasification Unit

HMPE: High Modulus Polyethylene

HMSF: High Modulus Synthetic Fiber

LNG: Liquefied Natural Gas

LNGC: Liquefied Natural Gas Carrier

LPG: Liquefied Petroleum Gas

MBL: Minimum Breaking Load

MBS: Minimum Breaking Strength

MEG: Mooring Equipment Guidelines

OCIMF: Oil Companies International Marine Forum

QTF: Quadratic Transfer Function

ROVs: Remotely Operated Vehicles

SALM: Single Anchor Leg Mooring

TLP: Tension Leg Platform

APPENDIX 3 Reference Standards and Guidelines

1 ABS Rules, Guides and Guidance Notes *(1 February 2019)*

The ABS *Guidance Notes on Nearshore Position Mooring* are intended for use in conjunction with the *FPI Rules* and the *FLGT Guide* or other applicable ABS Rules and Guides as listed below:

i) ABS *Rules for Building and Classing Floating Production Installations (FPI Rules)*

ii) ABS *Guide for Building and Classing Floating Offshore Liquefied Gas Terminals (FLGT Guide)*

iii) ABS *Guide for Building and Classing LNG Regasification Vessels*

iv) ABS *Rules for Building and Classing Single Point Moorings (SPM Rules)*

v) ABS *Guide for the Certification of Offshore Mooring Chain*

vi) ABS *Guidance Notes on the Application of Fiber Rope for Offshore Mooring*

vii) ABS *Guide for Building and Classing Gravity-Based Offshore LNG Terminals*

viii) ABS *Rules for Building and Classing Offshore Installations (Offshore Installations Rules)*

ix) ABS *Guide for Building and Classing Liquefied Gas Carriers with Independent Tanks*

x) ABS *Guide for Liquefied Gas Carrier Storage Service*

xi) ABS *Guide for LNG Bunkering*

xii) ABS *Guide for Automatic or Remote Control and Monitoring Systems for Vessels in Port*

xiii) ABS *Guide for Position Mooring Systems*

3 Industry Standards and Guidelines *(1 February 2019)*

References issued by other industry organizations are listed as below:

i) References issued by other industry organizations are listed as below:

ii) API RP 2SK, *Recommended Practice for Design and Analysis of Stationkeeping Systems for Floating Structures*

iii) API RP 2SM, *Recommended Practice for Design, Manufacture, Installation, and Maintenance of Synthetic Fiber Ropes for Offshore Mooring*

iv) API RP 2T, *Recommended Practice for Planning, Designing, and Constructing Tension Leg Platforms*

v) API RP 2I, Recommended Practice for In-Service Inspection of Mooring Hardware for Floating Drilling Units

vi) API Spec 9A, *Specification for Wire Rope*

vii) API RP 9B, *Recommended Practice on Application, Care, and Use of Wire Rope for Oil Field Service*

viii) ISO 19901-7, *Petroleum and natural gas industries - Specific Requirements for Offshore Structures, Part 7: Stationkeeping Systems for Floating Offshore Structures and Mobile Offshore Units*

ix) OCIMF MEG, *Mooring Equipment Guidelines*, by Oil Companies International Marine Forum

x) OCIMF, *The Hazards of Snap-back,* Oil Companies International Marine Forum