



GUIDE FOR

POSITION MOORING SYSTEMS JULY 2019

**American Bureau of Shipping
Incorporated by Act of Legislature of
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Foreword

Mooring systems have been evolving in design, analysis, operating management and other areas to meet the challenges of safety and efficiency. ABS Rules and Guides are developed and updated to keep pace with the industry. This has resulted in a complex library of Rules and Guides. Many requirements are repeated throughout ABS Rules and Guides making use and maintenance of Rules/Guides more challenging. To address the duplication of requirements and provide a set of Rules/Guides that is easier to navigate, this Guide consolidates the latest classification requirements for position mooring systems.

In addition to the consolidation of the current requirements, this Guide also includes updates in the following areas based on the latest industry knowledge and experiences:

- Vortex Induced Motion (VIM) effect (8/3.7, 8/5.13)
- Bending-tension fatigue of mooring chains (3/7.5)
- Fiber rope mooring criteria (3/7.3)
- Mooring systems in squalls (3/3.5, 8/3.1, 8/5.11)
- Dynamically installed anchors (3/7.9, 6/5.7)
- Anchor holding capacity (6/5.7)
- Mooring analysis methodology (Section 8)
- Thruster-Assisted Mooring (Section 4)

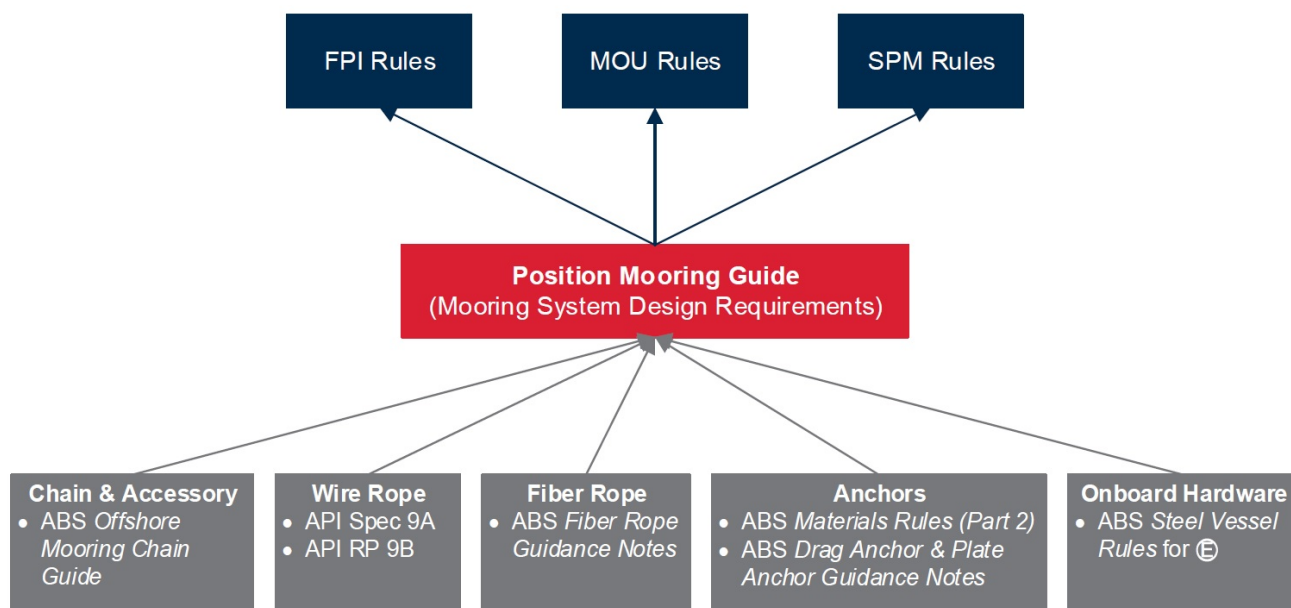
This Guide supplements the following ABS Rules and Guides for issuing classification Notations relevant to position mooring systems:

- *ABS Rules for Building and Classing Floating Production Installations (FPI Rules)*
- *ABS Rules for Building and Classing Mobile Offshore Units (MOU Rules)*
- *ABS Rules for Building and Classing Single Point Moorings (SPM Rules)*
- *ABS Guide for Building and Classing Floating Offshore Liquefied Gas Terminals (FLGT Guide)*
- *ABS Rules for Building and Classing Marine Vessels (MVR Rules)*
- *ABS Guide for the Classification Notation Thruster-Assisted Mooring (TAM, TAM-R, TAM (Manual)) For Mobile Mooring Systems (TAM Guide)*
- *ABS Guide for the Classification Symbols Pre-Laid Position Mooring Systems and Equipment for Mobile Offshore Units (Pre-Laid Guide)*

The following figure shows the relationship between this Guide and other ABS Rules/Guides/Guidance Notes:

This Guide focuses on design aspect of position mooring systems. Survey requirements remain in relevant Rules/Guides and are referenced in this Guide. The design requirements for position mooring systems will be removed from above mentioned Rules/Guides and replaced with references to this Guide on 1 July, 2019.

Before 1 July 2019, designers can choose to use this Guide or applicable Rules/Guides mentioned above. On 1 July 2019, *TAM Guide* and *Pre-Laid Guide* will be withdrawn and only this Guide will remain for the design of position mooring system.



Users are advised to check periodically on the ABS website www.eagle.org to verify that this version of this Guide is the most current.

We welcome your feedback. Comments or suggestions can be sent electronically by email to rsd@eagle.org.



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SECTION 1 Introduction

1 Objectives

This Guide provides criteria, technical requirements, and guidance on the design and analysis of position mooring systems. It supplements the following ABS Rules for issuing classification notations relevant to position mooring systems:

- *ABS Rules for Building and Classing Floating Production Installations (FPI Rules)*
- *ABS Rules for Building and Classing Mobile Offshore Units (MOU Rules)*
- *ABS Rules for Building and Classing Single Point Moorings (SPM Rules)*
- *ABS Guide for Building and Classing Floating Offshore Liquefied Gas Terminals (FLGT Guide)*
- *ABS Rules for Building and Classing Marine Vessels (MVR Rules)*

3 Scope and Application

The mooring system provides position keeping to support the production and operation in the context of Rules and Guides mentioned above, and may be a part of the mandatory classification such as in the *FPI Rules*, or have a separate optional classification notation requested by the owner. This Guide provides detailed classification requirements for the mooring systems. The Guide is applicable to offshore position mooring systems including, but not limited to:

- Spread mooring systems
- Turret mooring systems (internal turret and external turret)
- Catenary anchor leg mooring (CALM) systems
- Single anchor leg mooring (SALM) systems
- Disconnectable mooring systems
- Pre-laid mooring systems
- Thruster-assisted mooring systems

The Guide does not cover the tendon systems for Tension Leg Platforms (TLP).

The main components of the mooring system include:

- Mooring line
 - Chain, wire rope, synthetic rope, or a combination
 - Clump weight
 - Spring buoy
 - Connecting hardware (shackle, swivel, other connectors)
- Winching equipment
 - Windlass
 - Chain jack

- Drum-type winch
 - Linear winch
 - Traction winch
 - Fairlead and stopper
- iii) Anchoring system
- Drag Embedment Anchors
 - Pile Anchors (driven, jetted, drilled and grouted)
 - Dynamically installed piles
 - Suction pile and Suction Caisson
 - Gravity Anchor
 - Plate Anchor (drag embedded and direct embedded)
 - Suction embedded plate anchor (SEPLA)
- iv) Where applicable, the mooring system may also include the following
- Turret for turret mooring systems
 - Disconnection system for disconnectable mooring systems
 - Thrusters and thruster control systems for thruster-assisted mooring systems

5 ABS Rules and Guides References

In addition to this Guide and the ABS Rules and Guides listed in Subsection 1/1, the following ABS Rules and Guides are applicable to related components of the position mooring systems:

- *ABS Guide for the Certification of Offshore Mooring Chain (Offshore Mooring Chain Guide)*
- *ABS Guidance Notes on the Application of Fiber Ropes for Offshore Mooring (Fiber Rope Guidance Notes)*
- *ABS Rules for Building and Classing Offshore Installations (Offshore Installations Rules)*
- *ABS Guide for Fatigue Assessment of Offshore Structures*
- *ABS Guide for Dynamic Positioning Systems (DPS Guide)*

Following two Guidance Notes provide recommendations and best practices for anchors:

- *ABS Guidance Notes on Design and Installation of Dynamically Installed Piles*
- *ABS Guidance Notes on Design and Installation of Drag Embedment Anchor and Plate Anchor*

7 References of Industry Standards and Guidelines

The Industry standards and Guidelines given below, as well as other recognized standards, may provide acceptable methods for fulfilling the requirements in this Guide provided that the methods can achieve the same or a higher level of safety required in this Guide.

- API RP 2SK: Recommended practice for design and analysis of Station Keeping systems for floating structures.
- API RP 2SM: Design, Manufacture, Installation, and Maintenance of Synthetic Fiber Ropes for Offshore Mooring.
- API RP 2FPS: Recommended Practice for Planning, Designing, and Constructing Floating Production Systems

- API RP 2MET: Derivation of Metocean Design and Operating Conditions
- API RP 2GEO: Geotechnical and Foundation Design Considerations
- API Spec 9A: Specification for Wire Rope
- API RP 2I: Recommended Practice for In-service Inspection of Mooring Hardware for Floating Structures.
- ISO 19901-7:2005: Stationkeeping systems for floating offshore structures and mobile offshore units.
- ISO 19904-1: Floating Offshore Structures – Part 1: Monohulls, Semi-submersibles and Spars
- ISO 1704:2008: Shipbuilding - Stud-link anchor chains
- ISO 2232:1990: Round drawn wire for general purpose non-alloy steel wire ropes and for large diameter steel wire ropes – Specifications.
- ISO 10425:2003: Steel wire ropes for the petroleum and natural gas industries – Minimum requirements and terms of acceptance.
- ISO 18692: Fibre ropes for offshore stationkeeping – Polyester.
- ISO/TS 17920: Fibre ropes for offshore stationkeeping -- Aramid
- ISO TS 14909: Fibre ropes for offshore stationkeeping – High modulus polyethylene (HMPE)
- ISO/TS 19336: Fibre ropes for offshore station keeping – Polyarylate
- NORSOK N-001: Integrity of Offshore Structures
- NORSOK N-005: Condition Monitoring of Load Bearing Structures
- HSE Offshore Installation Moorings (IS 4/2013): UK HSE Offshore Information Sheet No. 4/2013
- HSE Research Report 444: Floating Production System (FPS) Joint Industry Project (JIP) FPS Mooring Integrity
- HSE FPSO-Mooring Inspection (SN-3/2005): Floating Production Storage and Offloading (FPSO) – Mooring Inspection
- UK Mooring Integrity Guidance (MIG): UK Mooring Integrity Guidance
- NOPSEMA: Offshore Petroleum and Greenhouse Gas Storage (Safety) Regulations 2009
- BSEE NTL 2008-G09: Guidelines for Moored Drilling Rig Fitness Requirements for Hurricane Season
- BSEE NTL 2009-G03: Synthetic Mooring Systems
- OCIMF: Mooring Equipment Guidelines, Oil Companies International Marine Forum

9 Terms and Definitions of Mooring Systems

A mooring system can be of several types, such as single point mooring or spread mooring, and can be used for different operations, such as offshore production, storage, off-loading, or mobile drilling. Design requirements vary for different applications. This Section provides a basic introduction and definitions of different mooring systems.

Anchor Leg. Mooring element connecting the floating structure or unit to the seabed at the anchor point, and is essential for station keeping of the system.

Automatic Thruster Assisted Mooring (ATAM). A floating unit or structure which maintains its position by means of a mooring system assisted by automatically controlled thruster.

Catenary Mooring. A mooring system where the restoring action is provided by the distributed weight of mooring lines.

CALM. Catenary Anchor Leg Mooring system. It consists of a large buoy anchored by catenary mooring lines. The installation is moored to the buoy by soft hawser(s) or a rigid yoke structure.

Damaged Condition. Loss of single component of the mooring system, such as a mooring line, or a thruster, a single engine/generator in case of Thruster Assisted (TA) mooring system. It is possible that one component failure in the TA system could result in the failure of more than one thruster.

Design Environmental Condition (DEC). The extreme condition with a specific combination of wind, waves and current for which the system is to be designed. For permanent mooring systems, the return period of the DEC is specified by this Guide. For mobile mooring systems, the DEC is the most severe design environmental conditions specified by the Owner or designer.

Design Installation Condition (DIC). The limiting environmental condition that would require suspension of installation operations. Specific limits on environmental conditions affecting safe operation during the installation are to be established and documented.

Design Operating Condition (DOC). The limiting environmental condition that would require suspension of normal operations specified by the Owner or designer. For permanent mooring systems, the return period associated with the DOC is to the larger of: a) the value as specified by the Operator, or b) one-year return environment.

Discharge Terminal. The recipient of liquefied gas from trading liquefied gas carriers and stores it. In such terminals, the stored liquefied gas is normally vaporized in a re-gasification facility and discharged ashore.

Disconnectable Mooring. A mooring system that can be disconnected from and reconnected to the installation at specified environmental conditions.

Floating Offshore Liquefied Gas Terminal. Provides liquefied gas storage and receives and/or offloads liquefied gas. There are two major variations of offshore liquefied gas terminal: Load Terminals and Discharge Terminals, with various configurations of each.

Hawser. Mooring line between a production installation, or mooring terminal, and a trading vessel.

Installation (Noun). A floating structure and the machinery, equipment and systems necessary for safety, propulsion (if fitted) and auxiliary services. The structural configurations of these installations may be ship-shaped or barge-shaped (with or without propulsion), column stabilized or any other configuration of a purpose-built floating installation.

Load Terminal. Receives gas directly from one or more wells or from another offshore facility where it may or may not have been processed. The gas is liquefied in an onboard liquefaction facility and stored for offloading as liquefied gas to a trading liquefied gas carrier. Alternatively, a Load Terminal may receive liquefied gas from a liquefaction plant via a pipeline.

Manual Thruster Assisted Mooring (MTAM). A floating unit or structure which maintains its position by means of a mooring system assisted by manually controlled thrusters.

Mobile Mooring. A mooring system, generally retrievable, intended for deployment at a specific location for a short-term operation, such as those for mobile offshore drilling units (MODUs), tenders moored next to another platform such as floatels, drilling tender, and service vessels.

Mobile Offshore Drilling Units. A mobile offshore structure or vessel capable of engaging in drilling operation for the exploration for or exploitation of resources beneath the seabed.

Mobile Offshore Units. A mobile offshore unit of self-elevating or column-stabilized type, not fitted with drilling equipment, production facilities, hydrocarbon storage, or any other system onboard handling hydrocarbons.

Mobile Units. Both Mobile Offshore Drilling Units and Mobile Offshore Units

Mooring Terminal. A mooring system normally used to secure a floating structure that is designed for temporarily holding loading/offloading vessels or vessels of other activities.

Offset. The horizontal excursion of a floating structure from the intended location.

Offshore Support Vessels. Refer to vessels intended for support services to offshore installations.

Permanent Mooring. A mooring system normally used to secure floating structures deployed for long-term operations, such as floating units for production and/or storage, through their design life.

Pre-laid Mooring. Mooring components and accessories other than those carried onboard the unit. It typically consists of anchors, piles, chain, cable, buoys and other appurtenances that are installed at the offshore location ahead of the arrival of the unit.

Position Mooring System. A system that keeps the floating offshore structure/unit on station. The system includes mooring lines, connectors, hardware, winches, and anchors. For a single point mooring system, the turret, turntable, disconnecting system, buoy, etc., are also part of the system.

Position (pre-laid) Mooring System. A position mooring system without the complete set of mooring equipment, anchors, chains or wire rope being carried onboard the unit. Typically mooring equipment and components carried onboard a unit designed for position (pre-laid) mooring will be the winches/windlasses and top chain or wire rope.

Recognized Consultant. A person or organization recognized by ABS as being capable of providing specialized knowledge or assistance.

SALM. Single Anchor Leg Mooring system. An anchoring structure with built-in buoyancy at or near the water surface and is itself anchored to the seabed by an articulated connection.

SPM. Single Point Mooring system. A mooring system that allows the floating structure to which it is connected to vary its heading so that the floating structure may weathervane. One example of a single point mooring is a turret mooring system where a number of mooring lines are attached to a turret, which possesses bearings to allow the floating structure to rotate.

Soliton. A solitary wave that propagates with little loss of energy and retains its shape and speed.

Specified Maximum Environmental Conditions. The specified wind speed, current speed, and wave height under which the floating structure is designed to carry out intended operations.

Specified Operating Envelope. The area within which the floating structure is required to stay in order to satisfactorily perform the intended operations under the specified maximum environmental conditions.

Spread Mooring. A system with multiple mooring lines anchored to piles or drag anchors at the sea bed. The other end of each line is individually attached to winches or stoppers on the floating structure through fairleads as necessary. A typical spread mooring system could hold a stable heading of the floating structure regardless of the direction of the environment.

Squall. A wind event with a rapid increase in speed of 8m/s, sustained above 11m/s for at least 1 minute.

Squall Direction. The direction at which the wind speed is peaked.

Swing Circle. The area swept by the moored vessel as it revolves about the mooring point.

Taut-line Mooring. A mooring system where the restoring action is provided by elastic deformation of mooring lines.

Thruster Assisted Mooring. A mooring system assisted by onboard thrusters and thruster control systems to provide position keeping for a floating structure. The thrusters may be used to control the heading of the floating structure and reduce mooring load.

Turret Mooring. A system consisting of a number of mooring legs attached to a turret, which includes bearings to allow the floating structure to rotate around the anchor legs so that the installation may weathervane. The turret may be mounted internally within the installation or externally from the installation bow or stern. Typically, a spread mooring arrangement connects the turret to the seabed.

Yoke Arm. A structure at the end of the installation that only allows angular relative movement between the installation and the mooring attachment to the seabed.

11 Abbreviations

ABS: American Bureau of Shipping

ALS: Accidental limit state

API: American Petroleum Institute

CALM: Catenary anchor leg mooring

DIN: Dissolved nitrogen

DEC: Design Environmental Condition

DIC: Design Installation Condition

DISEC: DISconnecting Environmental Condition

DOC: Design Operating Condition

DOFs: Degree-of-freedom

DPS: Dynamic Positioning Systems.

FEM: Finite element method

FLS: Fatigue limit states

FMEA: Failure modes and effects analysis

FOS: Factor of safety

FPIs: Floating production installations

FPS: Floating production system

FPSO: Floating production storage and offloading

HMPE: High modulus polyethylene

IPB: In-plane bending

JIP: Joint Industry Project

MBS: Minimum breaking strength

MIC: Microbiologically influenced corrosion

MIG: Mooring integrity guidance

MODU: Mobile Offshore Drilling Units

MOU: Mobile Offshore Unit

NDT: Nondestructive testing

OCIMF: Oil Companies International Marine Forum

OPB: Out-of-plane bending

ORQ: Oil rig quality

OSV: Offshore supply vessel

SALM: Single anchor leg mooring

SCFs: Stress concentration factors

SPM: Single point mooring

SEPLA: Suction embedded plate anchor

TAM: Thruster-assisted mooring

TAM (Manual): Manual thruster control system

TAM-R: Automatic thruster control system with redundancy

TLP: Tension leg platform

TT Tension-tension

UHC: Ultimate holding capacity

ULS: Ultimate limit states

UPS: Uninterruptible power system

VIM: Vortex Induced Motion

VLAs: Vertically loaded anchors



SECTION 2 Classification of Mooring Systems

1 General

ABS classifies mooring systems based on the function types of the floating structure/unit that the mooring system is designed for. The floating structures/units can be categorized into three types:

- *Production Installation*: An installation for production, storage and offloading
- *Mobile Unit*: A floating structure intended to be frequently relocated to perform a particular function, such as mobile drilling units, offshore construction support vessels, accommodation units, service floating units etc.
- *Mooring Terminal*: A floating structure, such as a buoy, that provides temporary offshore mooring to a variety of visiting vessels, such as shuttle tankers for loading or offloading gas or liquid products, by means of a hawser or yoke from the buoy.

This Section describes the ABS classification notations for these three types of mooring systems and the ABS Rules and Guides that provide relevant classification requirements.

3 Classification Notation

3.1 Mooring System for Floating Production Installations

For Floating Production Installations (FPIs), there is no separate class notation for the mooring system. The installation's class notations cover a position mooring system that meets the requirements of the *FPI Rules* and this Guide. Examples are:

Floating Production, Storage and Offloading System (*hull type*)

Floating Production (and Offloading) System (*hull type*)

Floating Storage and Offloading System (*hull type*)

In addition, ABS also provides the classification notation (**Disconnectable**) to indicate that a floating installation system has a propulsion system and a means of disengaging the installation from its mooring and riser systems to allow the installation to ride out severe weather or seek refuge under its own power for a specified design environmental condition.

3.3 Mooring System for Floating Offshore Liquefied Gas Terminals

For a Floating Offshore Liquefied Gas Terminals, there is no separated class notation for the mooring system. Vessel's class notations, such as **F(LPG)**, **F(LNG/LPG)**, etc., cover the position mooring system that meets the requirements of the *FLGT Guide* and this Guide.

3.5 Mooring System for Mobile Offshore Drilling Units, for Mobile Offshore Units, for Offshore Supply Vessels

For a Mobile Offshore Drilling Unit (MODU), a Mobile Offshore Unit (MOU), and an Offshore Support Vessel (OSV), the following optional notions for the mooring system can be provided if requested by the owner.

(M): Indicates that the mooring equipment, anchors, chain or wire rope which have been specified by the Owner for position mooring have been tested in accordance with the specifications of the Owner and in the presence of a Surveyor.

(P): Indicates that the mooring system has the position mooring capability of the unit under owner specified environmental conditions and meets the requirements specified in this Guide.

TAM: Indicates that the combined mooring and thruster systems is capable of automatically maintaining the position and heading of the unit under owner specified maximum environmental conditions and meets the requirements specified in this Guide.

TAM-R: Indicates that the combined mooring and thruster systems is capable of automatically maintaining the position and heading of the unit under owner specified maximum environmental conditions, thruster system meets the requirements specified in this Guide including redundancy.

TAM (Manual): Indicates the combined mooring and thruster system is capable of maintaining the position and heading of the unit under owner specified maximum environmental conditions, thruster system is manually controlled and meets the requirements specified in this Guide.

(P-PL): Indicates that the mooring equipment and components carried onboard a unit and designed for the pre-laid position mooring system has the positioning mooring capability of the unit, when hooked up with pre-laid mooring components, under owner specified environmental conditions and meets the requirements specified in this Guide.

(M-PL): Indicates that the mooring equipment, chain or wire rope (carried onboard the unit) which has been specified by the Owner for position (pre-laid) mooring have been tested in accordance with the specifications of the Owner and in the presence of a Surveyor.

TAM-PL (Manual): Indicates a pre-laid systems fitted with a TA system that is manually operated by a TA operator. The system is capable maintaining the position and heading of the unit under specified maximum environmental conditions and meet the requirements of this Guide.

3.7 Mooring System for Mooring Terminals

For a mooring terminal, there is no separated notation for the mooring system. The terminal's class notation of **Single Point Mooring** covers the mooring system that meets the *SPM Rules* and this Guide.

5 Documentation

The submitted documents for review are to include all design data, system components, analysis reports, and other documents that are sufficiently detailed to demonstrate the adequacy of the mooring design.

The design documentation for the mooring system is to include the following, when applicable:

- i) Mooring arrangement or pattern
- ii) Details of winching equipment
- iii) Details of anchoring system
- iv) Details of mooring line segments
- v) Connections at anchors and between mooring line segments
- vi) Details of in-line (spring) buoys
- vii) Details of buoy for CALM system
- viii) Details of SALM structures
- ix) Details of turret system to show turret structure, swivel, turntable and disconnecting device

- x)* Details of yoke (hard or soft) connecting the installation to the CALM/SALM structure
- xi)* Anchoring system showing the size of anchor, holding capacity of piles, pile sizes, and capacity
- xii)* Environmental Report
- xiii)* Mooring Analysis describing method of load calculations and analysis of dynamic system to determine the mooring line design loads
- xiv)* Mooring fatigue analysis report
- xv)* Mooring installation/hook-up procedures
- xvi)* Model Test report when the design loads are based on model tests in a wave basin
- xvii)* General arrangements of the thruster(s) installation, its location of installation, together with its supporting auxiliary machinery systems, fuel oil tanks, foundations, and watertight boundary fittings
- xviii)* Thruster specifications and calculations of a system with dynamic positioning system for thruster forces and power to counteract environmental forces
- xix)* For class Notation **TAM-R**, FMEA analysis report for thruster system
- xx)* Operations manual for mooring system and for thruster assist system

SECTION 3 Mooring System Design

1 General

This Section provides requirements related to the design of a mooring system for the class notations described in Subsection 2/3 of this Guide. Requirements as specified in the Rules and Guide given in Subsections 1/1, and 1/5 are also applicable. This Section includes design criteria for the mooring systems and the methodology for evaluation and verification of the mooring systems.

3 Environmental Criteria

3.1 General

The environmental criteria, in general, are established based on the following:

- i) The type of structure being designed
- ii) The phase of development (e.g., construction, transportation, installation, drilling, or production)
- iii) The performance considered
- iv) The design environmental conditions for restricted exposure levels, when appropriate, are based on the consequences of failures of a mooring system. In this Guide, mooring systems are categorized into following three groups according to their intended operations:
 - Mooring systems for floating production, storage, and offloading installations
 - Mooring systems for mobile offshore units, mobile offshore drilling units, and offshore support vessels
 - Mooring systems for floating mooring terminals

3.3 Design Environmental Conditions

3.3.1 General

For a position mooring system, where applicable, the following environmental conditions are to be considered:

- i) *Design Environmental Condition (DEC)*. The extreme condition with a specific combination of wind, waves and current for which the system is to be designed.
- ii) *Design Operating Condition (DOC)*. The limiting environmental condition that would require suspension of normal operations.
- iii) *Design Installation Condition (DIC)*. The limiting environmental condition that would require suspension of installation operations.

3.3.2 Mooring Systems for Floating Production Installations

3.3.2(a) *Design Environmental Condition (DEC)*.

The DEC is to be one of the following combinations that results in the most severe loading case:

- i) 100-year waves with associated wind and current
- ii) 100-year wind with associated waves and current

- iii) 100-year current with associated waves and wind

In areas where the maximum mooring system responses are governed by squalls, 100-year squalls with the following combination are also to be included for the DEC:

- iv) 100-year squalls with associated wind seas and 1-year current.

In areas with high current, additional design environmental load cases may require consideration.

A minimum return period of 50 years will be specially considered if it is accepted by the coastal state. Any environmental combinations with return periods shorter than that of the 100-year DEC which may induce larger mooring load responses are also to be used in the design.

For a Floating Installation with a Disconnectable notation, the Disconnecting Environmental Condition (DISEC) of the mooring system is the limiting extreme environmental condition at which the installation is to be disconnected from the mooring system. The DISEC condition is not to be taken as less severe than the environmental condition based on 10-year return period. In tropical revolving storm areas, the 100-year “sudden” tropical cyclone (hurricane or typhoon) which may form near the site of the installation may be considered instead of a fully developed storm for this evaluation. The permanent mooring system (i.e., the mooring system alone (without the installation)), is to be designed to withstand an environmental condition based on a 100-year return period. An acceptable monitoring system is to be provided for tracking environmental conditions or mooring line tensions in order to assist in the decision to disconnect the installation from the mooring system.

3.3.2(b) Design Operating Condition (DOC).

The return period associated with the DOC is to be the larger of:

- i) The value as specified by the Operator
- ii) One year

3.3.2(c) Design Installation Condition (DIC).

Specific limits on environmental conditions affecting safe operation during the installation phases are to be established and documented.

3.3.2(d) Fatigue Environmental Condition.

For the long term fatigue analysis, a set of environmental states, such as wave scatter diagram data of wave height/period joint occurrence distribution, are to be specified, to cover the range of conditions and allow the calculation of fatigue damage with adequate accuracy.

3.3.3 Mooring Systems for Mobile Offshore Units (MOUs), Mobile Offshore Drilling Units (MODUs), Offshore support Vessels (OSVs)

For MOUs, MODUs, and OSVs, the Owner is to specify the environmental conditions for which the plans for the unit are to be approved. These design environmental conditions are to be recorded in the Operations Manual. The following environment conditions are to be specified:

3.3.3(a) Design Operating Condition (DOC).

The most severe design environmental conditions for normal operations specified by the Owner or designer.

3.3.3(b) Design Environmental Condition (DEC).

The most severe design environmental conditions for survival specified by the Owner or designer.

3.3.4 Floating Mooring Terminals

3.3.4(a) Design Environmental Condition (DEC).

The Design Environmental Condition for a mooring system of a floating mooring terminal is defined as the environmental condition with maximum wind, waves, and associated currents based on a 100-year return period. In this condition, no vessel is moored to the mooring terminal, unless the system is specifically designed for this situation. Alternatively, the DEC's for Floating Production Installations can be used.

3.3.4(b) Design Operating Condition (DOC).

The Design Operating Condition for a mooring system of a floating mooring terminal is defined as the maximum sea state in which a vessel is permitted to remain moored to the terminal. Wind, waves, and the associated currents used in the design are specified by the owner or designer.

3.5 Environmental Data

3.5.1 General

The environmental conditions for various design conditions described in Subsection 3/3 of this Guide are to be submitted with adequate data for the specific site of operation. Statistical data and mathematical models that describe the range of expected variations of environmental conditions are to be employed. All data used are to be fully documented with the sources and estimated reliability of data noted.

An *environmental report* describing methods employed in developing available data into design criteria is to be submitted in accordance with Subsection 2/5 of this Guide. Probabilistic methods for short-term, long-term and extreme-value prediction are to employ statistical distributions appropriate to the environmental phenomena being considered, as evidenced by relevant statistical tests, confidence limits and other measures of statistical significance. Hindcasting methods and models are to be fully documented.

For areas where the design is governed by special weather events, which may not be well represented by typical return period statistics, such as squalls, such special weather events are also to be taken into consideration when determining the environmental conditions.

Generally, data and analyses supplied by recognized consultants will be accepted as the basis of design. Relevant published design standards and data, if available, may be cited in documentation.

For mobile mooring systems, the design environment conditions are specified by the owners. The required information specified in 3/3.5 may not be applicable to mobile mooring systems.

3.5.2 Waves

Extreme wave events of Design Environmental Condition (DEC) and Design Operation Condition (DOC) are to be provided, including both winter storms and tropical cyclones (hurricanes or typhoons) where applicable. The environmental report is to provide the following wave statistics for the site of installation:

- i) Significant wave height
- ii) A range of associated wave periods is to be considered for each specified significant wave height
- iii) Long period swell and direction, where applicable
- iv) Wave spectral shape formulation
- v) Wave height/period joint occurrence distribution (wave scatter diagram data with equal annual probability of occurrence for each data point)
- vi) Long-term wave statistics by direction

For each design sea state, a long-crested sea without spectral energy spreading is normally considered in the mooring analysis.

3.5.3 Wind

The wind conditions for various design conditions are to be established from collected wind data and are to be consistent with other environmental parameters assumed to occur simultaneously. In general, the wind speed is to be based on a return required for the DEC.

The environmental report is to present wind statistics for the site of installation and operation. The statistics are to be based on the analysis and interpretation of wind data by a recognized consultant. The report is to 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 is to be identified. Extreme wind events of Design Environmental Condition (DEC) and Design Operation Condition (DOC) of following are to be provided where applicable. The following wind statistics for the site of installation are to be provided:

- i) Wind speed of 1-minute average at 10m above sea level
- ii) Steady wind speed of 1-hour mean wind at 10m above sea level
- iii) Suitable wind gust spectrum
- iv) Long-term wind direction statistics

3.5.4 Squall

A squall is a strong transient wind event characterized by sudden rapid increases in wind speed and sudden shifts in wind direction. The environmental report is to present squall statistics for the site of installation and operation. The statistics are to be based on the analysis and interpretation of squall data by a recognized consultant. Extreme squall events of Design Environmental Condition (DEC) of the following are to be provided where applicable.

- i) Squall events and its time history of wind speed and wind direction
- ii) Statistics of squall direction. The squall direction is defined as the direction at which the wind speed is peaked

When the information on extreme squall events of Design Environment Condition with a 100-year return period are not available, the following method can be used to determine the characteristics of a 100-year squall.

3.5.4(a) 100-year Squalls.

100-year squalls can be established by scaling the wind speeds of selected squall events as given in below. The maximum wind speed of a squall event is to be scaled to the wind speed associated with 100-year return period of a given metocean site.

$$V_{100}(t_i) = \frac{V_{100}}{V_{\max}} V(t_i) \quad \text{m/s} \quad (\text{ft/s})$$

where

$V_{100}(t_i)$ = wind speed at time i of scaled 100-year squall, in m/sec (ft/s)

$V(t_i)$ = wind speed at time i of a squall record, in m/sec (ft/sec)

V_{100} = wind speed with 100-year return period, in m/sec (ft/sec)

$V_{\max}$ = maximum wind speed of a squall record, in m/sec (ft/sec)

The method can be applied to other number of years return squalls, say N -year squall.

3.5.4(b) Squall Direction.

The wind direction of one minute mean of a squall time record can be in any direction. The direction of a squall in this Guide is defined as the wind direction corresponding to the maximum wind speed in a squall time record. If there is no information on squall direction, it can be assumed that the squall can come from any direction. The critical squall directions given in 3/3.3.6 should be considered in mooring analysis.

3.5.5 Current

For the extreme current events of Design Environmental Condition (DEC) and Design Operation Condition (DOC), the following data is to be provided where applicable. The following current statistics for the site of installation are to be presented:

- i) Current speed and directional variation through the water depth
- ii) Long-term current direction statistics

The vector sum of the currents may include following components:

- i) Tidal currents (associated with astronomical tides)
- ii) Circulation currents (loop and eddy currents)
- iii) Storm-generated currents
- iv) Soliton currents

3.5.6 Angular Separation of Wind, Current and Waves

For single point mooring systems, which allow the moored floating structure to weathervane, both collinear and non-collinear directions among wind, current and waves are to be considered. Proper angular separation for the DEC of wind, current and waves is to be determined based on the site-specific environmental study. If this information is not available, the following two angular combinations for non-collinear environments can be considered as a minimum:

- i) Wind and current are collinear and both at 30 degrees to waves.
- ii) Wind at 30 degrees to waves and current at 90 degrees to waves. For wave condition dominated design, the angular separation between current and waves may be reduced from 90 degrees, but is to be no less than 45 degrees.

Section 3, Figure 1 illustrates one example of wind, wave and current directions.

For spread mooring systems with limited change in installation heading angles (less than 20 degrees) under design environmental loads, the design can be based solely on the collinear environments of wind, current and waves, which are generally controlling.

For a squall-dominated environment, the following conditions are to be considered.

Squall directions, as well as current and wave directions of site specific information can be used for the mooring analysis. If such information is not available, below guidelines can be followed.

For a spread mooring system, a co-linear condition, (squall, current and waves are in same direction), can be considered. Mooring analysis should include following directions as minimum:

- i) Squall direction in each mooring line group

- ii) Squall direction is beam-on a moored unit

For a single point mooring, in addition to the co-linear condition, following additional conditions are also to be considered.

- i) Current and waves are collinear and both at 30 degrees to squall.
 ii) Waves at 30 degrees to squall and current at 90 degrees to squall.
 iii) Waves at 180 degrees, current 90 degrees, squall initial direction (direction at the initial time step of a squall) in 0-degree, 30-degree and 60-degree from stern, respectively

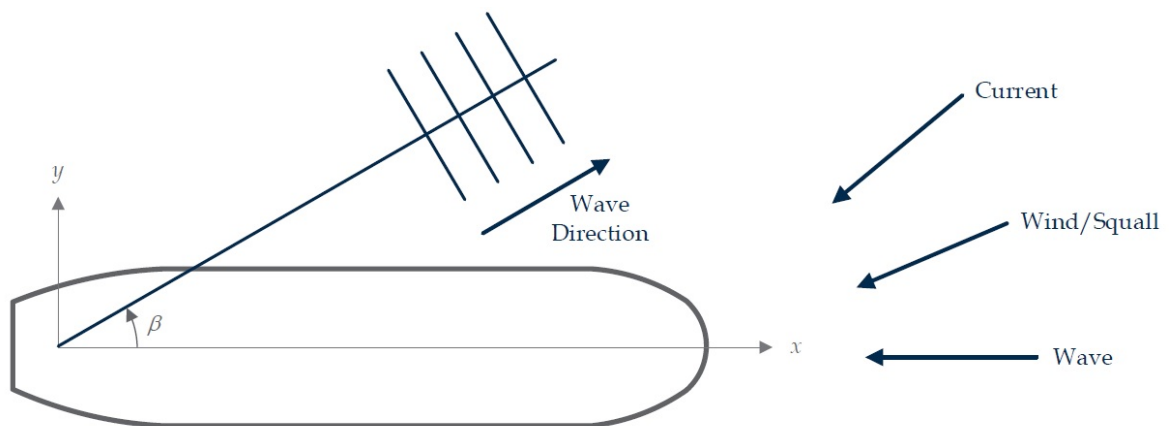
The initial squall direction for the analysis case considered should be shifted accordingly as follows.

$$\theta_i(t_0) = \theta(t_0) - \theta(t_{\max}) - \beta_i \text{ degrees}$$

where

- $\theta_i(t_0)$ = initial squall direction for the analysis case i , degrees
 $\theta(t_0)$ = initial squall direction at first time step, degrees
 $\theta(t_{\max})$ = squall direction defined as at the maximum wind speed of a squall, degrees
 β_i = specified direction for analysis case i , such as the direction of a mooring line group, etc.

FIGURE 1
Direction of Wave Wind and Current Illustration



3.5.7 Water Depth

The design water depth for the mooring system is to account for sea level variations due to tides, storm surges, and seafloor subsidence, if applicable.

Tidal data is to be based on astronomical tides and storm surge. The astronomical tidal extremes and tidal means for the mooring site are to be established. Sufficient data is to be submitted to establish the validity of the tide data. Tide levels may preferably be determined from records of a tide gauge in the vicinity of the site or from published tide tables for a location in the vicinity of the site. If the location from which the tide data is obtained is from a remote mooring site, a transformation of the tide data to the mooring site is to be performed by a recognized consultant. The seasonality of extreme tidal variations should be considered when considering the combination of astronomical tide and storm surge.

The maximum storm surge for the mooring site is to be established if the mooring is in a coastal or estuary location. Sufficient data is to be submitted to establish the validity of this storm surge.

Maximum storm surge may preferably be determined from tide records taken near the location. If the location from which the tide data is obtained is remote from the mooring site, a transformation of the tide data to the mooring site is to be performed by a recognized consultant. Storm surge hindcasts for design (extreme) storms performed by a recognized consultant may be submitted.

3.5.8 Seiche

The location of the mooring site in relation to seiche nodal points is to be investigated by a recognized consultant if the site is in a basin or other area known for seiche action. Seiche is defined as a standing wave in a basin or partially enclosed body of water due to wind, waves, atmospheric pressure, or earthquake. Mooring sites located at or near seiche nodal points may be influenced by currents not otherwise predicted. If the mooring site is at or near a seiche nodal point, currents induced by seiche are to be reflected in the operating current and maximum current, and the influence of the period of the current on the dynamic response of the moored vessel is to be considered.

3.5.9 Temperatures and Ice

Where drift ice may be a hazard to a mooring or to a vessel navigating to or moored at a mooring or to floating hoses at a mooring, an analysis of the nature and degree of this hazard is to be submitted.

When air temperature and precipitation, spray, or tidal action may combine to cause substantial ice formation on the mooring, an analysis of the degree to which ice may form and how this ice may affect the performance of the mooring is to be submitted.

The structure, equipment, hoses/flexible risers, component parts and their respective material which may be affected by low temperatures are to be examined.

3.5.10 Marine Growth

The type and accumulation rate of marine growth at the design site can affect mass, weight, hydrodynamic diameters, and drag coefficients of floating structure members and mooring lines. Marine growth is to be taken into consideration for permanent mooring systems not subject to any regular marine growth removal.

3.7 Mooring Location

3.7.1 Site Chart

A complete chart of the mooring area is to be submitted. This chart is to show depth soundings and obstructions within the swing circle, the maneuvering area, and where applicable, the approach channel from deep water or an established navigation channel. The chart may be based on local charts published by government agencies or on hydrographic surveys conducted by a recognized consultant. In the case of charts based on hydrographic surveys, a survey report is to be submitted describing the surveying method, equipment, and personnel employed to conduct the survey.

The exact location and water depth of the mooring base and each anchor point, is to be indicated on the chart. If the mooring is associated with other SPMs in the area, or with a pumping or control platform, these features are to be indicated on the chart. All other features and water use areas which may present potential navigational hazards are to be identified. All existing and planned navigation aids such as lights, buoys, and shore markers which will be used in conjunction with the mooring are to be indicated and identified on the chart.

3.7.2 Swing Circle

For a loading/offloading mooring terminal, the swing circle as defined in Subsection 1/9 of this Guide is to be indicated and captioned on the site chart. The radius of the swing circle is the sum of the horizontal excursion of the mooring systems from its center position under operating hawser load and minimum tide, the horizontal projection of the length of the hawser under operating hawser load, the length overall of the largest vessel for which the mooring system is designed, with an additional safety allowance of 30 m (100 ft).

3.7.3 Water Depth Requirement

For a loading/offloading mooring terminal, the water depth at any place within the maneuvering area is to be such that no vessel using the mooring terminal system will make contact with the sea floor or any object on the sea bottom in any sea condition under which such a vessel is expected to be present as outlined in the design premises within the maneuvering area.

The designer may elect to specify limiting drafts for various vessel sizes when the proposed water depth is not sufficient to allow a vessel of the maximum size to be moored in the maneuvering area under the design operating environmental condition.

The determination of the required water depth is to be based upon calculations, data from model tests or full scale trials, designers' experience, or other available sources of information.

The designer is to submit evidence to demonstrate to the satisfaction of ABS that in determining the required water depth, the following factors have been considered:

- i) Vessel's dimensions and other relevant characteristics
- ii) Wave height, wave period, and compass direction with respect to the vessel
- iii) The prevailing wind and astronomical tides
- iv) The expected vessel's heaving, rolling and pitching and vessel under keel clearance of at least 1 meter (3.3 feet)
- v) The consistency of the sea bottom material or the character of any protrusion from the sea bottom
- vi) The level of accuracy of the depth survey data
- vii) Predicted variation of seabed profile due to sediment transport during the design life, where applicable.

3.7.4 Soil Condition

In general, site investigation is to be in accordance with Section 3-2-5 of the *Offshore Installations Rules*. Soil data is to be taken from the vicinity of the foundation system site. An interpretation of this data is to be submitted by a recognized geotechnical consultant. To establish the soil characteristics of the site, foundation system borings or probings are to be taken at all foundation locations to a suitable depth. This depth is to be of at least the anticipated depth of any piles or anchor penetrations plus a consideration for the soil variability. As an alternative, sub-bottom profile runs may be taken and correlated with at least two borings or probings in the vicinity of anchor locations and an interpretation may be made by a recognized geotechnical consultant to adequately establish the soil profile at all anchoring locations.

5 Mooring System Design Requirements

5.1 Design Requirement

5.1.1 Functional Requirement

A mooring system is to be designed to restrict the offset of a floating structure/unit within prescribed limits, as well as to maintain the directionality when the structure's orientation is important for safety or operational considerations.

The limiting criteria for offset and orientation are generally established either by the owner of the floating structure/unit or directly derived from design requirements including those related to:

- i) Safety of personnel
- ii) Stability of the floating structure
- iii) Serviceability of the floating structure, and intended operations
- iv) Drilling riser and production riser requirements
- v) Access to and clearances with respect to nearby installations
- vi) Any other special positioning requirement

Other mooring system design requirements, to include:

- i) Contact of connectors with soil
- ii) Contact of synthetic rope with soil
- iii) Uplift at anchor where applicable
- iv) Clashing of mooring lines
- v) Synthetic rope minimum tension, where applicable

5.1.2 Strength and Fatigue Capacity Requirement

The mooring system and its components are to be designed to withstand environmental and other external forces under the environmental conditions specified in Subsection 3/3 of this Guide. They are to be designed with consideration given to the following limit states.

- i) *Ultimate Limit States (ULS)*. The mooring system and its components are to be designed to have adequate strength to withstand the load resulted from extreme environmental conditions.
- ii) *Fatigue Limit States (FLS)*. The mooring system and its components, where applicable, are to be designed to have adequate capacity to withstand the cyclic load due to exposure environments.
- iii) *Accidental limit state (ALS)*. The mooring system and its components, where applicable, are to be designed to have adequate capacity to withstand the load resulting from extreme environmental conditions when the mooring system loses any one of the mooring lines, or thrusters for thruster assisted mooring systems.

5.3 Design Analysis

The design requirements given in 3/5.1 of this Guide for the excursion/offset of a moored offshore structure/unit and the strength and fatigue capacity of the mooring line components can be evaluated by engineering analysis with methodologies provided in this section. Other industry guidelines may be used provided those methods can achieve the same level of, or better results, than the methods in this section. The detailed analysis considerations and procedures are provided in Section 8 of this Guide.

5.3.1 Quasi-Static Method

In this approach, the load on the mooring lines are calculated by statically offsetting the structure by wave-induced motions. Dynamic actions on the mooring lines associated with mass, damping and fluid acceleration are not considered. Various conditions, such as the type of floating structures and mooring systems, mooring line configuration, and water depth are to be considered when selecting this method to evaluate the effect on the mooring load predictions.

5.3.2 Dynamic Analysis Method

Dynamic analysis includes the effects due to added mass, damping, fluid acceleration and relative velocity between the mooring system and the fluid.

Both frequency domain and time domain analyses methods can be used for mooring analysis. In the time domain method, nonlinear effects, such as line stretch, line stiffness, and nonlinear wave frequency load can be included in the analysis. For the mooring systems subject to squalls, time domain analysis methods are to be used to account for the variations of wind speed and directions.

In the frequency domain method, on the other hand, the loads, mooring line stiffness and responses are assumed linear as the linear principle of superposition is used. Methods of approximating nonlinear effects in the frequency domain and their limitations are to be investigated so that the analysis results are not compromised.

5.5 Loading and Mooring System Conditions

The mooring system analysis is to be carried out to cover various loading conditions of the moored floating structure/unit for the environmental conditions specified in Subsection 3/3. The design limit states specified in 3/5.1 are to be verified through mooring analysis.

5.5.1 Loading Conditions of Moored Floating Structure/Unit

The loading conditions for mooring analysis are to be selected from the loading manual or operations manual which could result in maximum mooring line load or maximum offset of the moored floating structures. The following loading conditions, where applicable, are to be included:

- i) Full load condition
- ii) Minimum load condition
- iii) Intermediate load condition
- iv) Survival load condition
- v) Largest vessel intended to dock with the floating structure or mooring terminal through hawsers, or other vessel of a smaller size if the smaller vessel is apt to impose higher loads

5.5.2 Mooring System Conditions

The following mooring system conditions, where applicable, are to be included in the mooring analysis as minimum.

- i) *Intact Condition.* A condition with all components of the mooring system and thruster assist system, where applicable, as designed.
- ii) *One Line Damage.* A condition with any one mooring line not in service that would cause maximum mooring line tension for the system. The mooring line subjected to the maximum tension at intact condition, when broken, might not lead to the worst broken mooring line case. The designer should determine the worst case by analyzing several cases of broken mooring line, including lead line broken and adjacent line broken cases (or thruster or propeller if the mooring is thruster-assisted).

For a disconnectable mooring system with a quick release system, the mooring analysis for a broken line case may not be required. For unusual (non-symmetric) mooring patterns, mooring analysis for the broken line case for the disconnectable environmental condition may be required.

For a system utilizing the SALM concept, the case with one broken mooring line is not relevant. A case considering loss of buoyancy due to damage of a compartment of the SALM structure is to be analyzed for position mooring capability.

- iii) *One Line Damage Transient.* A condition with one mooring line broken (usually the lead line) in which the moored installation exhibits transient motions (overshooting) before it settles at a new equilibrium position. The transient condition can be an important consideration when proper clearance is to be maintained between the moored installation and nearby structures. An analysis for this condition is required (see Section 3, Table 1). The effect of increased line tensions due to overshoot upon failure of one mooring line (or thruster or propeller if the mooring is thruster -assisted) is should also to be considered.
- iv) *Loading/Off-loading Condition.* Where applicable, the mooring line loads and the hawser load in the Design Operating Condition (DOC) are to be established for the condition with the vessel moored to the mooring system.

5.7 Summary of Mooring Analysis Conditions

The analysis of a mooring system includes the determination of environmental forces and the extreme response of the moored structures (excursion/offset), mooring line load, and hawser load, where applicable, in the Design Environmental Condition (DEC) and Design Operating Condition (DOC). Calculations of the maximum mooring system loading are to consider various relative directions of the wind, wave and current forces. The environmental conditions specified in 3/3.3 of this Guide are to be used in the mooring analysis. Section 3, Table 1 provides the summary of mooring analysis conditions.

TABLE 1
Mooring Analysis Conditions

<i>Type of Mooring</i>	<i>Environment Condition</i>	<i>Mooring System Condition</i>	<i>Limit State</i>
Mooring for FPI	DEC (3/3.3)	Intact	ULS
	DEC (3/3.3)	Intact	FLS
	DOC (3/3.3)	Intact	ULS (hawser)
	DEC (3/3.3)	One line damage (steady)	ULS
	DEC (3/3.3)	One line damage (transient)	ULS
Mobile Mooring ⁽¹⁾	DEC (3/3.3)	Intact	ULS
	DOC (3/3.3)	Intact	ULS
	DEC (3/3.3)	One line damage (steady)	ULS
	DOC (3/3.3)	One line damage (steady)	ULS
	DEC (3/3.3)	One line damage (transient)	ULS
	DOC (3/3.3)	One line damage (transient)	ULS
Mooring Terminal ^(2,3)	DEC (3/3.3)	Intact	ULS
	DOC (3/3.3)	Intact	ULS
	DOC (3/3.3) ⁽⁴⁾	One line damage	ULS