

# **MOORING SYSTEMS**

## FOR OFFSHORE UNITS

**NR493 R05**

EDITION MARCH 2026



# BUREAU VERITAS MARINE & OFFSHORE RULE NOTE

## **NR493 R05 March 2026**

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NR493 DT R05 March 2026 replaces the former edition July 2021.

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These rules are provided within the scope of the Bureau Veritas Marine & Offshore General Conditions, enclosed at the end of Part A of NR467, Rules for the Classification of Steel Ships. The latest version of these General Conditions is available on the Bureau Veritas Marine & Offshore website.

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## RULE NOTE NR493

# MOORING SYSTEMS FOR OFFSHORE UNITS

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Section 1	General
Section 2	In-service Surveys
Section 3	Design of Mooring System
Section 4	Components of Mooring System
Section 5	Mooring of Mobile Units
Section 6	Mooring at a Jetty
Appendix 1	Characterisation of the Line Response
Appendix 2	Combination of Metocean Parameters
Appendix 3	Structural Strength Criteria
Appendix 4	Permanent Mooring Design in Squall Conditions

# Table of Content

<b>Section 1</b>	<b>General</b>	
1	<b>General</b>	<b>8</b>
	1.1 Application	
	1.2 Exclusion	
2	<b>Classification</b>	<b>8</b>
	2.1 Scope	
	2.2 Class notations	
	2.3 Construction mark	
	2.4 Limits of notations POSA and POSA-HR and interfaces with Class	
	2.5 Survey of installation and deployment	
	2.6 Assignment of the class notation	
	2.7 Maintenance of Class	
3	<b>Documents to be submitted</b>	<b>10</b>
	3.1 Design data	
	3.2 Components of mooring system	
	3.3 List of documents to be submitted	
4	<b>Definitions and references</b>	<b>12</b>
	4.1 Definitions	
	4.2 Reference documents	
<b>Section 2</b>	<b>In-service Surveys</b>	
1	<b>General</b>	<b>14</b>
	1.1 Application	
	1.2 Permanent mooring	
	1.3 Mobile mooring	
	1.4 Units moored at a jetty	
2	<b>Annual surveys</b>	<b>15</b>
	2.1 All units	
3	<b>Intermediate surveys</b>	<b>15</b>
	3.1 All units	
4	<b>Class renewal surveys</b>	<b>16</b>
	4.1 Permanent units	
	4.2 Mobile units	
	4.3 Units moored at a jetty	
5	<b>Survey summary</b>	<b>17</b>
	5.1 Intermediate and renewal surveys	
6	<b>Renewal criteria for chains, steel wire and fibre ropes of permanent installations</b>	<b>18</b>
	6.1 General	
	6.2 Chains	
	6.3 Wire ropes	
	6.4 Fibre ropes	
<b>Section 3</b>	<b>Design of Mooring System</b>	
1	<b>General</b>	<b>19</b>
	1.1 Scope	
	1.2 Review of design	
	1.3 General methodology	

# Table of Content

<b>2</b>	<b>Methods of evaluation</b>	<b>19</b>
2.1	Purpose	
2.2	Quasi-static analysis	
2.3	Quasi-dynamic analysis	
2.4	Dynamic analysis	
2.5	Fully coupled analysis	
2.6	Model tests	
<b>3</b>	<b>Environmental conditions, actions and unit response</b>	<b>21</b>
3.1	Environmental conditions	
3.2	Actions	
3.3	Unit response	
<b>4</b>	<b>Mooring system</b>	<b>26</b>
4.1	Mooring pattern and initial tensions	
4.2	Mooring response	
4.3	Mooring stiffness	
<b>5</b>	<b>Line response</b>	<b>27</b>
5.1	Static line response	
5.2	Dynamic line analysis and response	
5.3	Evaluation of the line response model	
5.4	Selection of windows for dynamic line maximum tension	
<b>6</b>	<b>Design tension</b>	<b>29</b>
6.1	Application	
6.2	Design tension in intact condition	
6.3	Design tension in one-line damaged condition	
6.4	Design tension in one-line failure (transient) and thruster failure condition	
6.5	Design tension in two-line damaged condition	
6.6	Design tension in line components	
6.7	Minimum design tension	
<b>7</b>	<b>Offset calculations</b>	<b>32</b>
7.1	Intact conditions	
<b>8</b>	<b>Fatigue analysis</b>	<b>33</b>
8.1	General	
8.2	Tension range	
8.3	In-Plane Bending/Out-of-Plane Bendings (IPB/OPB)	
<b>9</b>	<b>Strength of line</b>	<b>33</b>
9.1	General	
9.2	Breaking strength of line components	
9.3	Corrosion and wear	
9.4	Tension-tension fatigue endurance	
9.5	In-plane/out-of-plane bending endurance	
<b>10</b>	<b>Selection of design conditions</b>	<b>36</b>
10.1	General	
10.2	Unit state configuration	
10.3	Mooring system state conditions	
10.4	Metocean conditions	
10.5	Extreme metocean conditions	
10.6	Operating conditions	
10.7	Fatigue analysis	
10.8	Sensitivity studies	
<b>11</b>	<b>Criteria</b>	<b>40</b>
11.1	Mooring lines strength	
11.2	Anchors	
11.3	Minimum clearance	
11.4	Fatigue life	
11.5	Load testing of anchors and mooring lines	

# Table of Content

12	Installation and service conditions	43
12.1	General	
12.2	Chains and standard fittings	
12.3	Steel wire ropes	
12.4	Fibre ropes	
12.5	Anchoring devices	
12.6	Ancillary components	
12.7	Transit	
<b>Section 4</b>	<b>Components of Mooring System</b>	
1	General	44
1.1	Scope	
1.2	Application	
2	General requirements	44
2.1		
3	Chains and standard fittings	45
3.1	General	
3.2	Designation	
3.3	Design	
3.4	Manufacturing and testing	
4	Steel wire ropes	46
4.1	General	
4.2	Designation	
4.3	Design of steel wire ropes	
4.4	Design of terminations	
4.5	Manufacturing and testing	
5	Fibre ropes	48
5.1	General	
5.2	Design	
5.3	Manufacturing and testing	
6	Non standard fittings	49
6.1	General	
6.2	Design	
6.3	Manufacturing and testing	
7	Anchoring devices	50
7.1	General	
7.2	Design	
7.3	Manufacturing	
8	Items at the unit-side end	52
8.1	General	
8.2	Design	
8.3	Manufacturing and testing	
9	Ancillary components	54
9.1	General	
10	Monitoring system	55
10.1	Load monitoring system	
<b>Section 5</b>	<b>Mooring of Mobile Units</b>	
1	General	56
1.1	Application	
1.2	Applicability and limits	
1.3	In-service surveys	
1.4	General requirements	

# Table of Content

<b>2</b>	<b>Design</b>	<b>56</b>
	2.1 Environment	
	2.2 Design loads	
	2.3 Fatigue	
<b>3</b>	<b>Components of mooring lines</b>	<b>57</b>
	3.1 General requirements	
	3.2 Chains and standard fittings	
	3.3 Deck appliances (winches and windlasses)	
	3.4 Items at the unit-side end	
	3.5 Anchoring devices	
<b>4</b>	<b>Installation and service conditions</b>	<b>57</b>
	4.1 General requirements	
<b>5</b>	<b>Thruster assisted mooring (TAM)</b>	<b>58</b>
	5.1 General	
	5.2 Conditions of analysis	
	5.3 Allowable thrust	
	5.4 Analysis for thruster assisted mooring	
	5.5 System requirements	
	5.6 Sea trials	
<b>6</b>	<b>Mooring equipment tests</b>	<b>60</b>
	6.1 Mooring equipment	
<b>7</b>	<b>Operating manual</b>	<b>60</b>
	7.1 General	

## Section 6 Mooring at a Jetty

<b>1</b>	<b>General</b>	<b>61</b>
	1.1 Application	
	1.2 Applicability and limits	
	1.3 In-service surveys	
	1.4 General requirements	
<b>2</b>	<b>Design</b>	<b>61</b>
	2.1 Environment	
	2.2 Design loads	
	2.3 Fatigue	
	2.4 Side-by-side configuration	
	2.5 Berth area	
	2.6 Dolphins system	
<b>3</b>	<b>Mooring arrangements</b>	<b>62</b>
	3.1 Mooring lines	
	3.2 Release mooring hooks	
	3.3 Winches	
	3.4 Mooring fittings	
	3.5 Fenders	
<b>4</b>	<b>Design requirements for jetty</b>	<b>64</b>
	4.1 General	
<b>5</b>	<b>Operating Manual</b>	<b>64</b>
	5.1 Information to be included	

## Appendix 1 Characterisation of the Line Response

<b>1</b>	<b>General</b>	<b>65</b>
	1.1 Test run	
	1.2 Characterisation	

# Table of Content

<b>Appendix 2</b>	<b>Combination of Metocean Parameters</b>	
1	General	67
	1.1 Scope	
2	Metocean data	67
	2.1 Metocean conditions and design data	
	2.2 Intensity and direction	
	2.3 Sea states	
	2.4 Wind	
	2.5 Current	
3	Metocean design conditions	70
	3.1 Principles	
	3.2 Directions	
	3.3 Intensities	
	3.4 Operating conditions	
4	Extratropical conditions	71
	4.1 Applicability	
	4.2 Typical design conditions	
	4.3 Selection of return periods	
	4.4 Reduction factors	
	4.5 Additional combinations for conditions with swell	
5	Equatorial conditions	73
	5.1 Applicability	
	5.2 Typical design conditions	
	5.3 Waves and wind	
	5.4 Selection of return periods	
	5.5 Directions	
6	Tropical storm conditions	74
	6.1 Applicability	
	6.2 Typical design conditions	
	6.3 Data for the intensity of the elements	
<b>Appendix 3</b>	<b>Structural Strength Criteria</b>	
1	General	76
	1.1 Subject	
2	Design loads	76
	2.1	
3	Elastic design	77
	3.1	
4	Design Based on Elasto-plastic calculations	77
	4.1	
<b>Appendix 4</b>	<b>Permanent Mooring Design in Squall Conditions</b>	
1	General	80
	1.1 Purpose and scope	
	1.2 Application	
	1.3 SquallMoor JIP supporting studies and references	

# Table of Content

<b>2</b>	<b>Squall characterization</b>	<b>81</b>
2.1	General	
2.2	Squall characterization parameters	
2.3	Processing of squall event	
2.4	Application of pure squall	
2.5	Squall peak wind speed statistics	
2.6	Squall wind speed extrapolation	
2.7	Annual frequency	
2.8	Wind speed contours	
<b>3</b>	<b>Background environment conditions and heading</b>	<b>88</b>
3.1	General	
3.2	Background environment	
3.3	Heading distribution	
3.4	Procedure for background environment combinations	
3.5	Background environment intensities	
3.6	Background environment directions	
3.7	Example of background environment combinations for Angola	
<b>4</b>	<b>Design procedure and design criteria</b>	<b>91</b>
4.1	General considerations	
4.2	Inputs data for characteristic response evaluation	
4.3	Characteristic response evaluation procedure	
4.4	Characteristic response calculation	
4.5	Design criteria format for ULS, ALS and SLS	
4.6	Characteristic values for ULS1 and ULS2	
4.7	Characteristic values for ALS	
4.8	Characteristic tension, offset and mooring force in SLS	
4.9	Safety factors	

# Section 1                      General

## 1 General

### 1.1 Application

**1.1.1** The present Rule Note provides requirements for the mooring system (stationkeeping system) within the scope of the classification of:

- floating offshore units with permanent installations (disconnectable or not) (see definitions in [4.1])
- mobile units as defined in Sec 5
- units permanently moored at a jetty (disconnectable, or not), as detailed in Sec 6.

This Rule Note covers, in general terms, the stationkeeping of any free-floating body by means of a principally passive system.

This Rule Note is to be considered during the classification activities based on the applicable Rules for Classification, e.g. NR445 Rules for the classification of offshore units, or NR645 Rules for the classification of floating storage regasification units and floating storage units. See also [1.1.4] for floating offshore wind turbines.

**1.1.2** The present Rule Note gives technical requirements on the design, construction, installation and periodical surveys of the mooring systems, as a complement to the applicable Rules for Classification mentioned in [4.2].

**1.1.3** This Rule Note deals with all the different types of anchoring patterns (such as spread mooring, internal or external turret, etc.), line make up, and the associated materials (such as chain, steel wire ropes, fibre ropes, etc.) in catenary or taut / semi-taut configuration.

Methodology, requirements and recommendations on the anchoring devices, e.g. drag anchor, driven pile, suction caisson, are given in Sec 4 and the Guidance Note NI605 (see [4.2.2]).

#### 1.1.4 Application for Floating Offshore Wind Turbine (FOWT)

For the classification and the certification of the stationkeeping system of a FOWT, application of this Rule Note is defined in NR572 Classification and certification of floating offshore wind turbines.

#### 1.1.5 POSA Notations

Offshore units or FSRUs, classed by the Society and complying with the requirements of this Rule Note may be assigned the additional service features **POSA**, **POSA-HR**, **POSA-MU** or **POSA JETTY**, defined in [2.2]:

These additional service features are also referred as 'POSA notations'.

### 1.2 Exclusion

**1.2.1** The operational procedures for installation, anchoring line deployment, decommissioning, maintenance, etc. are not covered herein.

The integrity of risers, if any, connected to the moored unit is not addressed.

**1.2.2** The POSA notations do not cover the tension leg platforms, which are not deemed free-floating bodies, nor their (tendons) mooring systems.

Note 1: Units of the type tension leg platforms are addressed in NR578, Rules for the Classification of Tension Leg Platforms (TLP).

**1.2.3** The POSA notations cover the thruster assisted mooring (see [2.4.3]). However, the dynamic positioning installations are not covered by the POSA notations, but instead by the additional class notation **DYNAPOS** defined in NR467, Pt F, Ch 11, Sec 5.

## 2 Classification

### 2.1 Scope

**2.1.1** The classification activities span over all the phases of the project (considered as equivalent to the construction of a structure):

- design of the mooring system and of its components (engineering), including the related documentation, reviewed by the Society
- detailed design, manufacturing and testing of all the components of the mooring system (procurement) under survey of the Society,
- installation on unit and deployment at site of the mooring system under survey of the Society
- in-service inspection, for the maintenance of Class.

## 2.2 Class notations

**2.2.1** The POSA notations address the stationkeeping capability of the unit, within the limits of applicability defined in [1.2], for the classification of the following units:

- floating offshore unit as defined in NR445
- floating storage regasification units and floating storage units as defined in NR645. In accordance with [2.6] and the applicable Rules for Classification, the following POSA notations may be assigned:
  - **POSA** or **POSA-HR** for permanent offshore units, see [2.2.2]
  - **POSA MU** for mobile units, see [2.2.3]
  - **POSA JETTY** for units moored at a jetty, see [2.2.4].

In accordance with [2.7], the requirements for the maintenance of these POSA notations are detailed in Sec 2.

### 2.2.2 POSA and POSA-HR

The notation **POSA** covers the stationkeeping system of permanent offshore units.

The notation **POSA-HR** covers stationkeeping systems with higher redundancy for permanent offshore units.

The applicability, limits and scope of the notations **POSA** and **POSA-HR** are defined in [2.4].

In addition to the criteria required for the notation **POSA**, the notation **POSA-HR** addresses the stationkeeping capability of a unit under two lines damaged condition, (see Sec 3, [6.5]).

### 2.2.3 POSA MU

The notation **POSA MU** covers the stationkeeping system of mobile units such as surface and column-stabilized mobile offshore units (list not exhaustive), compliance with the requirements of the IMO MODU Code related to anchoring arrangements.

The applicability, limits and scope of the notation **POSA MU** are defined in Sec 5.

### 2.2.4 POSA JETTY

The notation **POSA JETTY** addresses the stationkeeping capability of the floating offshore units moored at a jetty. This notation typically applies to Floating Storage Regasification units (FSRU) and floating units fitted with equipment for storage of liquefied natural gas.

The applicability, limits and scope of the notation **POSA JETTY** are defined in Sec 6.

## 2.3 Construction mark

**2.3.1** In accordance with the provisions of NR445, Pt A, Ch 1, Sec 2, [6.2], a construction mark is to be assigned to POSA notations defined in [2.2] according to the principles given in NR445, Pt A, Ch 1, Sec 2, [3.1.2].

For units classed through NR645, the construction mark is to be assigned to POSA notations according to the principles given in NR645, Sec 1, [4].

## 2.4 Limits of notations POSA and POSA-HR and interfaces with Class

**2.4.1** The notations **POSA** and **POSA-HR** cover all the outboard elements of a mooring system, namely:

- the anchors, whatever the type (drag anchors, piles, suction piles, etc.)
- all the components of the load bearing lines, including line segments and connecting devices
- all the ancillary components such as buoys, clumpweights, and their attachment to the main lines (excluding installation aids).

**2.4.2** These notations **POSA** and **POSA-HR** also cover:

- fairleads and stoppers on the unit (totally, i.e. including unit-side female support parts)
- any associated load monitoring and control systems.

**2.4.3** The notations **POSA** and **POSA-HR** do not cover windlass, winches and sheaves used only for deployment of the system or for occasional handling of lines during unit operation, nor the associated monitoring and control systems.

Note 1: These elements may be part of the Offshore Handling Systems (OHS), covered by NR595 "Classification of offshore handling systems (OHS)".

Note 2: The notations **POSA MU** and **POSA JETTY** may have different scope and limits, especially regarding winches and windlass. Refer respectively to Sec 5 and Sec 6 for these notations.

However, the foundations of these items into the hull or on the turret are considered as part of the unit hull and, so, are covered by the classification of the unit.

For the assignment of the notations **POSA** and **POSA-HR**, the pieces of equipment and systems related to thruster assistance, if any, are to comply with applicable requirements of NR445.

For other configurations not explicitly addressed here above, the limits of the notations **POSA** and **POSA-HR** are to be specified on a case-by-case basis.

## **2.5 Survey of installation and deployment**

### **2.5.1 Installation on unit**

Installation of the unit-side items (fairleads, stoppers, chain hawses, etc.) and on-board equipment, including the related systems, is to be performed under survey of the Society, in accordance with the applicable provisions of NR445 (these activities are usually to be carried out within the scope of the unit classification surveys).

The survey is to cover the quality of the construction work, particularly welds through non destructive tests (NDT). Load tests are normally not required but, if performed, are to be attended by a Surveyor. NR426 gives specific recommendations for the surveys.

### **2.5.2 Deployment at site (installation)**

The survey of the installation is to be performed on the basis of the general provisions of NR445, particularly those given in NR445, Pt B, Ch 3, Sec 6.

The installation procedures prepared by the relevant Contractor are to be submitted to the Society for information.

The allowed tolerances for the installation are to be specified in the installation procedures, and are to be taken into account in the design calculations through sensitivity studies.

The installation operations are to be surveyed, including, but not limited to:

- installation of the anchors
- deployment of the mooring lines
- traceability of the components
- load tests of the anchors and lines (see Sec 3, [11.5])
- connection to the unit and tensioning
- post-installation inspection of the mooring system: survey by divers and/or remotely operated vehicles (ROV).

Reviews and surveys address the issues only under the scope of the Classification, particularly:

- conformity of all the components to the Classification requirements (as attested by the inspection certificates)
- integrity of the installed parts
- conformity to design of the as-installed system, particularly the setting of the line pretensions.

The operations at site are to be carried out in the presence of a Surveyor of the Society, following an agreed program.

The Surveyor is to review the records and other documentation of the installation operations, prior to the delivery of the certificate.

Note 1: The survey by the Society is, by no way, intended to be a substitute for the installation contractor's duty to fully document the mooring system installation.

## **2.6 Assignment of the class notation**

**2.6.1** Upon satisfactory completion of the mooring system installation, of all the prior activities and of the related surveys performed by the Society, one of the POSA notations defined in [2.2] may be assigned and entered in the Initial Hull Classification Certificates of the unit.

## **2.7 Maintenance of Class**

**2.7.1** Maintenance and renewal of the classification certificate are subject to the completion of in-service surveys to be performed by the Society, as described in Sec 2.

## **3 Documents to be submitted**

### **3.1 Design data**

#### **3.1.1 General**

The party applying for classification is to provide the Society with the classification data and assumptions.

The design of the mooring system is to be performed on the basis of the design data, operational data and environmental data of the unit.

In addition to the requirements of this Article, general requirements for documents to be submitted are provided in NR445 Pt A, Ch 1, NR445 Pt B, Ch 2 and NR645 Sec 2, [6], as applicable.

#### **3.1.2 Site data**

The party applying for classification is to specify:

- for permanent installations: the site at which the unit is to operate
- for mobile units: conditions in which the unit is to operate.

### 3.1.3 Operating conditions and loads

The operational data are to include the following information:

a) environmental conditions:

- extreme (survival conditions)
- fatigue (operational conditions).

Note 1: Operational conditions are to be understood as usual conditions (day-to-day conditions). This notion does not take into consideration any process or production.

Note 2: For site subject to squall events, extreme conditions squall data are to comply with App 4.

b) characteristics and range of loading conditions, with the associated responses, of the unit

c) description of the mooring lines components from anchor to stopper

d) mooring system layout (paid-out length and mooring leg azimuths, anchors locations)

e) the following loads, in all the relevant loading conditions mentioned in item b):

- environmental loads
- anchoring/mooring loads
- hawser line loads
- risers loads
- thruster loads
- loads induced by other pieces of equipment.

## 3.2 Components of mooring system

### 3.2.1 Line components

Design specifications and design documentation are to be submitted to the Society for review.

For units surveyed by the Society during construction, the manufacturing of materials and sub-components, and the construction of components of the stationkeeping system are to be performed under survey of the Society, according to an approved program as described in NR320 and NR266.

The certificates are to be delivered for each set of items, upon satisfactory completion of all the related reviews and surveys.

## 3.3 List of documents to be submitted

**3.3.1** The submitted documents are to include the following information, in addition to the documentation specified in the NR445, Pt A, Ch 1, Sec 4:

a) Design criteria and data, as defined in Article [2]:

- metocean data, soil data, and background information (see NR445, Pt B, Ch 2, Sec 2 and NI605)
- characteristics and range of loading conditions of the unit
- reports of design analysis.

b) General drawings:

- layout description including positions of the anchor points, water depth, surrounding equipment (riser, well head, ...) and layout of the units located in close proximity (see Sec 3, [10.3.5])
- description of the mooring lines (from anchor to stopper)
- general arrangement of the mooring patterns showing location of fairleads and stoppers with lead angles
- turret structure, if any.

c) Structural drawings, specifications and supporting documents:

- mooring systems foundations (fairleads, stoppers, winches, bollards, etc.), as applicable.

d) Drawings and specifications of the mooring fitting:

- connecting systems
- ancillary elements
- anchoring systems.

e) Model tests (when performed):

- specification
- final report.

f) Monitoring and control system:

- monitoring system description
- control system description.

g) Risk analysis reports:

- when relevant, risk analyses performed for the unit are to include the positioning of the mooring system (equipments and line components) and are to evaluate the potential impact of accidental events on this system.

h) Mooring inspections philosophy as specified in Sec 2, [1].

## 4 Definitions and references

### 4.1 Definitions

#### 4.1.1 Permanent mooring

As defined in NR445, Pt A, Ch 1, Sec 1, [4.5], a permanent installation is an installation performing its service for a duration not less than 5 years on a single site.

Note 1: For units classed through NR645, see also NR645, Sec 2, [4.2.8].

The mooring system of a permanent installation is considered as a permanent mooring system.

#### 4.1.2 Disconnectable permanent mooring

As defined in NR445, Pt A, Ch 1, Sec 1, [4.5], a disconnectable permanent installation is a permanent installation able of disengaging from its mooring and riser systems in extreme environmental or emergency conditions.

The mooring system of a disconnectable permanent installation is considered as a disconnectable permanent mooring system.

When the installation is disconnected, the mooring system stays at location.

#### 4.1.3 Mobile mooring

As defined in NR445, Pt A, Ch 1, Sec 1, [4.5], a mobile mooring is related to the mooring system of a mobile unit. The unit is neither a permanent installation nor a disconnectable permanent installation.

The mooring system of a mobile unit is considered as a mobile mooring system and is designed for stationkeeping at a specific location for less than 5 years without interruptions.

Mobile mooring systems can be removed and redeployed through dry-docking inspections (see Sec 2, [1.3]).

#### 4.1.4 Unit moored at a jetty

A unit is considered moored at a jetty when the stationkeeping system maintains the floating structure alongside a floating or bottom-fixed jetty structure (e.g., a pier, or a quay). The anchoring points of the mooring system are located on the jetty structure.

#### 4.1.5 Hawser

A hawser is a mooring line connecting an offloading unit to a buoy or a mooring line between two offshore units.

Note 1: The mooring lines connecting units to a jetty are defined as jetty mooring lines.

#### 4.1.6 Close proximity

Mooring systems are considered to be in close proximity to an installation if any part of the other installation lies within a contour described by the set of offsets coinciding with each line reaching 100% MBS in the intact or redundancy check condition, whichever is larger (see also ISO 19901-7:2013).

#### 4.1.7 Vicinity

Mooring systems in the vicinity of other structures means mooring systems that may be hit by these other structures in case of failure of the mooring system.

Note 1: A nominal distance of 1 mile may be considered.

#### 4.1.8 Uplift

The uplift is a configuration where a drag anchor experiences a load component perpendicular to the seabed.

The uplift value is the perpendicular-to-the-seabed component of the load divided by the wet weight of the anchor projected onto the same direction. The uplift angle is the anchor load component angle with the seafloor corresponding to this uplift value.

#### 4.1.9 Shallow and moderate water depths

Shallow and moderate water depths correspond to water depths less than 150m.

## 4.2 Reference documents

### 4.2.1 Bureau Veritas Rules for Classification, Rule Notes and Guidance Notes

The following documents are used for reference in this Rule Note:

- NR445 Rules for the Classification of Offshore Units
- NR467 Rules for the Classification of Steel Ships
- NR645 Rules for the Classification of Floating Storage Regasification Units and Floating Storage Units.
- NI604 Fatigue of Top Chain of mooring lines due to in-plane and out-of-plane bendings
- NI605 Geotechnical and Foundation Design
- NI638 Guidance for Long-term Hydro-structure Calculations
- NI657 Classification Scheme under Risk Based Inspection
- NI691 Environmental conditions, loads and induced responses of marine units
- NI693 Remote Inspection Techniques
- NR216 Rules on Materials and Welding for the Classification of Marine Units
- NR266 Requirements for Survey of materials and equipment for the Classification of Ships and Offshore Units
- NR320 Certification Scheme of Materials and Equipment for the Classification of Marine Units
- NR426 Construction Survey of Steel Structures of Offshore Units and Installations
- NR432 Fibre Ropes for Offshore Services
- NR494 Rules for the Classification of Offshore Loading and Offloading Buoys
- NR533 Approval of service suppliers
- NR572 Classification and Certification of Floating Offshore Wind Turbines

### 4.2.2 International Maritime Organisation (IMO) instruments

MODU Code means the IMO Code for the Construction and Equipment of Mobile Offshore Drilling Units, as amended.

### 4.2.3 Other industry documents

The following standards from American Petroleum Institut (API), International Organization for Standardization (ISO) or Oil Companies International Marine Forum (OCIMF), are referenced throughout this Rule Note:

- a) API RP 2I:2008 In-service Inspection of Mooring Hardware for Floating Structures
- b) API RP 2SK:2024 Recommended Practice for Design and Analysis of Stationkeeping Systems for Floating Structures
- c) ISO 2408:2017 Steel wire ropes - Requirements
- d) ISO 10425:2023 Steel wire ropes for the petroleum and natural gas industries - Minimum requirements and terms of acceptance
- e) ISO 19901-7:2013 Petroleum and natural gas industries - Specific requirements for offshore structures - Part 7: Stationkeeping systems for floating offshore structures and mobile offshore units
- f) ISO 19901-4:2025 Oil and gas industries including lower carbon energy — Specific requirements for offshore structures — Part 4: Geotechnical design considerations
- g) OCIMF-MEG:2018 Mooring Equipment Guidelines 4.

## Section 2 In-service Surveys

### 1 General

#### 1.1 Application

##### 1.1.1 Mooring inspection philosophy document

A mooring inspection philosophy is to be developed and submitted to the Society. This document is to be integrated to the unit Operating Manual as a general basis for mooring inspection program development.

The inspection philosophy is to be based on a review of degradation modes present on the mooring system depending on the unit characteristics, mooring arrangement, site characteristics and environmental constraints based on return of experience and/or risk evaluation.

For each degradation mode, inspection schemes are to be developed, with justification based on industrial recognised practices. The inspection schemes are to indicate inspection modes, tools, sampling rate for inspections and frequency. Associated means such as mooring line cleaning is to be also addressed.

This inspection philosophy is also to cover the annual, intermediate and Class renewal inspection requirements in the present Section.

Note 1: Guidance for establishing the mooring inspection philosophy may be found in the DeepStar 19403 project outcomes, see e.g.:

Ma, K. T. and al., (2021, August). Improving Mooring Integrity through Standardized Inspection Practices–A DeepStar® 19403 Project. In Offshore Technology Conference (p. D021S024R004).

##### 1.1.2 Alternative inspection schemes

On a case-by-case basis, upon Society's satisfaction, alternative inspection schemes may be considered. In any case, alternative inspections schemes are to be at least equivalent to the provisions of the present Section.

##### 1.1.3 Risk-Based Inspection

Risk-based inspection (RBI) may be considered as an element in application of [1.1.2]

General requirements for implementing RBI are defined in NI657.

##### 1.1.4 Use of remotely operated vehicles (ROVs) and divers

The use of ROVs and divers for carrying out the in-water survey is acceptable. The company providing this service is to be approved as a service supplier for carrying out in-water surveys, as per the requirements of NR533.

ROVs and divers are to be equipped in order to produce general visual inspection (GVI). ROV capacity is to comply with NORSOK U-102:2020 Remotely operated vehicle (ROV) services.

Guidelines about remote inspection techniques including ROVs are defined in NI693.

##### 1.1.5 Inspection program

Prior to each mooring line inspection, a dedicated inspection program is to be submitted to the Society, based on the general mooring inspection philosophy, incidents records and issues identified during the previous mooring line inspections.

Critical areas in the mooring components are to be specified in the inspection program for each project.

#### 1.2 Permanent mooring

**1.2.1** The in-service mooring system surveys of permanent units assigned the notation **POSA**, **POSA-HR** or **POSA JETTY** are carried out on site. No disruption of the unit's operation is required.

#### 1.3 Mobile mooring

**1.3.1** The in-service mooring system surveys of mobile units assigned the notation **POSA MU** may lead to an offshore inspection, as for the permanent offshore units, or dockside inspection. API RP 21:2008 gives recommended in-service inspection procedures and methods for chains, wire ropes, anchor jewellery and anchor handling equipment.

**1.3.2** According to the definition of mobile mooring (see Sec 1, [4.1.3]), all the mooring lines are to be inspected out of the water every five years.

#### 1.4 Units moored at a jetty

**1.4.1** For units assigned with the notation **POSA JETTY**, the mooring lines are to be replaced at regular intervals. The exact replacement interval is to be specified by the manufacturers.

**1.4.2** At constant time intervals, the entire length of the jetty mooring lines is to be inspected. The frequency of these inspections is to be determined on a case-by-case basis, according to the rope manufacturer recommendations.

**1.4.3** Specific guidelines for inspection and removal of wire and fibre ropes are defined in the OCIMF-MEG:2018. Guidance on maintenance of winches are also provided in this standard.

## **2 Annual surveys**

### **2.1 All units**

#### **2.1.1 Records**

The records of operation of the stationkeeping system equipment and the records of the examination carried out by the unit's crew at the time of tensioning changes, if any, are to be presented to the Surveyor at each annual survey, for review.

**2.1.2** The examination of the mooring components (chain wires or fibre ropes) adjacent to winches or windlasses, stoppers and fairleads is to be performed if above waterline.

Where relevant, visual inspection of the winches and quick release hooks is also to be performed.

**2.1.3** In the case of significant damages revealed during these examinations, or if the Surveyor determines that problems have been experienced since the last annual survey, a more extensive survey may be required by the Surveyor.

## **3 Intermediate surveys**

### **3.1 All units**

#### **3.1.1 General**

An intermediate survey is to be performed every two and a half years (2,5), between two renewal surveys. Due to season alternance, a tolerance of  $\pm 9$  months may be accepted.

The intermediate survey scope is to fulfil the annual survey scope requirements defined in Article [2], in addition to the followings:

- visual inspection, as defined in [3.1.2] and [3.1.3]
- cathodic protection verification, as defined in [3.1.4]
- system integrity verification, as defined in [3.1.5].

In the case of significant damages revealed during these examinations, or if the Surveyor determines that problems have been experienced since the last annual survey, a more extensive survey may be required by the Surveyor, including dimensional checks (see Article [6]).

#### **3.1.2 Visual inspection of chain mooring lines**

For all the lines, a visual inspection is to be performed for the chain links at the following locations, as illustrated in Fig 1:

- the closest links to the stopper
- links from the stopper to the water surface
- links from the water surface to 10 meters below water surface.

For all the lines, at the locations described above, the chain links are to be cleaned in order to allow proper inspection.

On a case-by-case basis, this requirement may be partially waived in case of difficulty of access to this part of the chain.

**3.1.3** In addition to the baseline visual inspection defined in [3.1.2], the visual inspection of the entire line of at least one line per bundle, is to be performed if one of the following conditions is fulfilled:

- When specific risks are identified in the mooring inspection philosophy.
- If the results of the last annual survey reveal deteriorated conditions or damages or if the Surveyor determined that problems have been experienced since the last annual survey.

Note 1: In any case, performing this global visual inspection is a good practice that allows the detection of potential degradation mechanisms at an early stage.

These additional visual inspections are to comply with Article [4]. On a case-by-case basis, this requirement may be waived if suitable mitigation measures are implemented, to the satisfaction of the Society.

#### **3.1.4 Cathodic protection system inspection**

When the structural integrity of the upper sections of chains, wire rope sockets and anchoring devices relies on corrosion protection systems, the condition of these systems is to be verified by appropriate means, as applicable.

In particular, the condition of the anodes, where installed, is to be verified by visual inspection, as applicable.

### 3.1.5 Mooring line integrity verification

For each line of the mooring system, the line catenary settings, determined by pretension, line angle, mooring equipment position measurement or other appropriate means, is to be documented.

## 4 Class renewal surveys

### 4.1 Permanent units

#### 4.1.1 General

Every five years, at class renewal survey, the overall integrity of the mooring system of permanent units is to be examined, e.g. by general visual inspection of all the lines, over their full length, by ROVs or divers. The followings are to be considered:

- Examination, by visual inspection or other appropriate methods, of the integrity of the critical components with respect to corrosion, wear, overload and other possible modes of degradation is to be performed.
- Marine growth cleaning is to be performed for the selected elements.
- When the strength of the upper part of chains, the wire rope sockets and the anchoring devices is relying on corrosion protection systems, the condition of these systems is to be verified by proper means, as applicable. The condition of the anodes, where installed, is to be verified by visual inspection, as applicable. The cathodic protection is also to be verified by direct measurements of the cathodic potential along the cathodically protected parts of the mooring lines and the outcropping parts of the anchors.
- Line catenary settings, by pretension, line angle, mooring equipment position measurement or other appropriate mean, is to be documented.

Additional inspections/tests in accordance with the specific inspection programme are also to be performed.

#### 4.1.2 Records

The records of operation on the stationkeeping system equipment and the records of the examination carried out by the unit's crew at the time of tensioning changes or modifications, if any, are to be presented to the Surveyor at each class renewal survey, for review.

#### 4.1.3 Fairleads or stopper above water level

For all the lines, an inspection, a dimensional check and a visual inspection are to be performed, as far as practicable, for the links connected to the stopper.

#### 4.1.4 Underwater fairleads or stoppers

For units having fairleads or stoppers below water level, the following inspections are to be performed, for all the mooring lines:

- visual inspection of the chain portion adjacent to the stopper
- dimensional checks of all the links in this portion
  - 3 links just below the fairlead or stopper
  - 3 links between 5 to 10 meters from the fairlead or stopper
- measurement of chain angle (or chain tension) at top.

Note 1: Due to the accelerated corrosion of a link after its cleaning, it is recommended to alternate links to be cleaned and checked for dimensional control among successive inspection campaigns.

#### 4.1.5 Wire ropes

Visual inspection is to be performed all along the wire rope segment and any excessive corrosion, visible broken wire, bird-caging damages and distortions, bend stiffener damages (where applicable), damages in the sheathing are to be reported. The diameter of the wire rope is to be measured all along the wire rope segment of the line if there are no sheathing of the wire ropes.

Note 1: API RP 2L:2008 gives acceptance criteria for the diameter of the wire ropes

#### 4.1.6 Fibre ropes

Visual inspection is to be performed all along the lines to detect eventual damage (e.g. cutting) or anomalies in the lines, the termination and connecting hardware. See also NR432, Sec 7, [5.3].

#### 4.1.7 Anchors and buried chains

For anchors and buried chains (including touchdown points), the following inspections are to be performed:

- visual inspection of the soil around the anchors, in particular to check the absence of trenching and scouring in the vicinity of the anchors
- the buried part of the chains and the connection with the anchors being generally not inspectable, the operation logs are to be examined to have the confirmation that each leg was recently subjected to a significant loading and that the segment has not failed.

#### 4.1.8 Jewellery

General visual inspection of all the jewellerys (such as sockets, shackles) of all the lines is to be performed.

**4.2 Mobile units**

**4.2.1** The class renewal survey of the mooring system of mobile units assigned with the notation **POSA MU** is to be carried out, as far as practicable, the unit being in sheltered waters.

**4.2.2** Every five years, at class renewal survey, the following inspections of the mooring system of mobile units are to be performed:

- inspection of chain cables, wire ropes and fibre ropes, consisting in:
  - close visual inspection of the whole length of the mooring lines, in dry conditions after cleaning
  - NDT (Non-destructive tests), such as Magnetic Particle Inspection (MPI) of their whole length
  - dimensional checks
- examination of joining shackles and other accessories
- general examination of fairleads, including testing of free rotation capability and NDT (MPI) as necessary, together with visual examination of all the fairlead chain pockets
- general examination of windlasses, including testing of holding ability, together with visual inspection of all the windlass chain pockets
- general examination of winches, including testing of holding ability and of proper laying down of the wire on drum
- examination of the soundness of the load path from the deck appliances to the unit’s structure
- functional test of the mooring system during anchor handling operation
- anchor visual examination.

In addition, IACS Rec. 38 Rev. 2 - Guidelines for the survey of offshore mooring cable chain in use - is to be applied.

**4.3 Units moored at a jetty**

**4.3.1** Where relevant, the provisions of [4.1] are to be applied for Units moored at a jetty.

**4.3.2** Every five years, at class renewal survey, the following inspections of the mooring system of units moored at a jetty are to be performed where relevant:

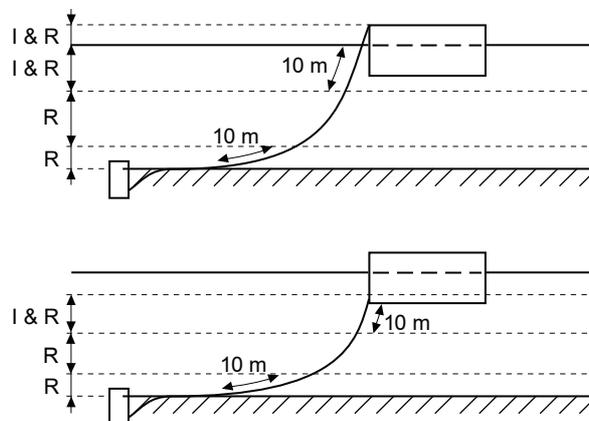
- general examination of quick release hook, including testing of release ability
- general examination of winches, including testing of holding ability and of proper laying down of the wire on drum
- visual examination of fenders
- general examination of mooring fittings.

**5 Survey summary**

**5.1 Intermediate and renewal surveys**

**5.1.1** Fig 1 summarises the intermediate and class renewal surveys to be performed along the anchoring lines of permanent units.

**Figure 1 : Survey summary for permanent and mobile units**



I : Intermediate survey  
 R : Class renewal survey.

## 6 Renewal criteria for chains, steel wire and fibre ropes of permanent installations

### 6.1 General

**6.1.1** For the requirements in this Article, measurements are to be performed after cleaning of the marine growth only at the measurement points.

Note 1: For the purpose of [6.1], it may be referred to API RP 2I:2008.

**6.1.2** Replacement of an element considered as defective is to be based on a plan subject to the Society approval.

The schedule for replacement, including considerations on technical operations, vessel availability and metocean window is to be submitted.

### 6.2 Chains

**6.2.1** As a rule, for studless or studlink chains, a link is to be considered as defective if one of the following criteria is not satisfied:

- the average of the two measured diameters (90 degrees apart) is to be greater than 95% of the nominal diameter
- the diameter, in any direction, is to be greater than 90% of the nominal diameter
- $D_m > 95\% (D - C)$

where:

$D_m$  : Weakest measured diameter

$D$  : Nominal diameter

$C$  : Total design corrosion allowance (annual corrosion rate multiplied by the initial design life).

Note 1: The final criterion to replace chains is linked to the initial computation hypotheses (mainly the hypotheses on wear and corrosion during design of the mooring system).

**6.2.2** The Surveyor is to put an observation for one criteria deficiency.

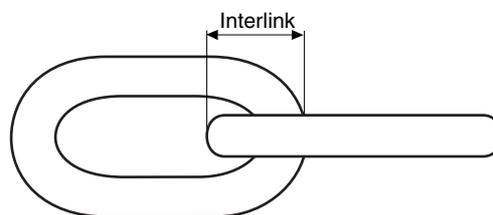
The Surveyor is to put a recommendation for two criteria deficiencies.

**6.2.3** At least one measurement at the interlink (see Fig 2) and one measurement in another location visually judged as the worst are to be performed.

The presence of large pitting corrosion patterns or remarkable corrosion patterns near link flash butt welding is to be identified and measured. An evaluation of the criticality of the damage is to be submitted to the Surveyor.

**6.2.4** For studlink chain, if a stud is missing, the link is considered as defective.

**Figure 2 : Interlink measurement**



### 6.3 Wire ropes

**6.3.1** Damage on the wire ropes or on the sheathing is to be analysed on a case-by-case basis. API RP 2I:2008 gives criteria and recommendations for wire ropes analysis.

### 6.4 Fibre ropes

**6.4.1** Fibre rope renewal criteria is to comply with NR432, Sec 7, [5.3].

# Section 3 Design of Mooring System

## Symbols

$T_p$	: Peak period of the wave spectrum, in s
$T_z$	: Zero-upcrossing period of the wave spectrum, in s
$T_0$	: Largest natural period of the system for motions in the horizontal plane, in s

## 1 General

### 1.1 Scope

**1.1.1** The scope of the present Section is to provide requirements related to the design of a mooring system, with a view to the assignment of one of the POSA notations to a floating offshore unit.

The present Section includes:

- guidance methodology for mooring analysis
- design criteria.

Consideration will be given to alternative methodologies, on a case-by-case basis, provided they are demonstrated to provide a safety level equivalent to the one resulting from the application of the present Rule Note.

Note 1: Unless otherwise specified, the documents listed in Sec 1, [4.2.3] are for general reference and may complement, but not replace, the requirements of the present Rule Note.

**1.1.2** This document covers the analysis of anchored units, including the cases with a second floater connected by a hawser (Single Point Mooring SPM, or tandem mooring).

### 1.2 Review of design

**1.2.1** One of the POSA notations is assigned to the unit upon satisfactory review of the proposed design and supporting documentation, including the documents listed in Sec 1, [3.3.1].

Verification is generally performed by Society's independent analyses, following the methodology of this Rule Note.

Note 1: Independent analysis is, by no way, intended to be a substitute for the designer's duty to fully document his design.

### 1.3 General methodology

**1.3.1** The assessment for the assignment of a POSA notation covers the following items:

- mooring lines
- mooring components
- fairleads / stoppers
- anchors.

The mooring lines are to be assessed for strength (intact, damaged and transient conditions) and for fatigue endurance (Tension-Tension (T-T) and In-Plane Bending/Out-of-Plane Bending (IPB/OPB)).

Regarding the mooring analysis, time domain calculation of mooring line response is to be considered.

Additional considerations for the integrity of the lines are also to be given (for e.g. contact of connectors with soil, uplift at anchor, clashing, fibre rope minimum tension). All these items are covered by this Rule Note.

**1.3.2** A moored unit is subjected to actions from the environments (waves, winds, currents), refer to [3.1].

Loading actions from sea water, wind and current are modelled by wind/current drag loads whereas wave loads are generally computed at wave and low frequencies, refer to [3.2].

## 2 Methods of evaluation

### 2.1 Purpose

**2.1.1** The purpose of the mooring analysis is to obtain information on the unit motions, the resulting excursions and the line tensions, under some specified metocean conditions representative of:

- either the extreme metocean conditions at intended site, or some limit operating conditions, for the evaluation of design (extreme) values, or
- more frequently occurring conditions (operational conditions), for the assessment of components fatigue.

**2.1.2 Available methods**

The available analysis methods vary based on the approach taken to evaluate:

- overall system response and resulting excursions and unit motions, see [3.3]
- line response and resulting tensions, as defined in [5].

Model tests are another possible source of information, according to the provisions of [2.6].

Methodology and criteria in the present Section are defined with reference to the following analysis methods:

- the quasi-static analysis method, defined in [2.2]
- the quasi-dynamic analysis method, defined in [2.3]
- the dynamic analysis method, defined in [2.4]
- the fully coupled analysis method, defined in [2.5].

The recommended methods to be performed for Classification purpose are the fully coupled analysis, the dynamic analysis and the quasi-dynamic analysis.

The different features of the analysis methods are summarized in Tab 1.

**Table 1 : Summary of analysis methods**

Analysis type	Line response	Unit response
quasi-static	static	static
quasi-dynamic	static	dynamic, with different possibilities and couplings, see [2.3].
dynamic	two steps: a) static b) dynamic	
fully coupled	dynamic	dynamic

**2.2 Quasi-static analysis**

**2.2.1 Methodology principles**

In a quasi-static analysis, the line tensions are evaluated as follows:

- line static response, as defined in [5.1]
- loads/displacements applied on the unit as static actions.

**2.2.2 Applicability**

For permanent mooring, this method is often used at an initial conceptual stage, but is not deemed acceptable neither for system design nor for classification assessment.

**2.3 Quasi-dynamic analysis**

**2.3.1 Methodology principles**

In a quasi-dynamic analysis, the floater dynamic response (see [3.3]) is evaluated based on static behavior of the mooring system (see [5.1]).

Note 1: The methodology developed by the Society using the quasi-dynamic analysis is available in the document referenced in:

L. Leblanc, J.L. Isnard, H. Wilczynski, 1995, A complete and Consistent Methodology for the Assessment of Mooring Systems, OTC-7709

**2.3.2 Applicability and limitations**

The quasi-dynamic analysis may generally be used for the strength design assessment of mooring systems in shallow and moderate water depths.

The quasi-dynamic analysis methodology has the following assumptions and limitations:

- a) Resonance and out-of-horizontal-plane low-frequency motions:

The mooring system is assumed not to be subjected to resonance at the wave frequency. In addition, out-of-horizontal-plane low-frequency motions are supposed to be negligible. Hence, this methodology may not be appropriate to spars or certain types of semi-submersibles operating at very deep drafts.

- b) Low frequency and wave frequency interference and coupling:

For uncoupled quasi-dynamic analysis, it is supposed that horizontal low-frequency and wave frequency phenomena do not interfere. Compliance with this assumption is reasonably satisfied if the natural period of the mooring system in surge, sway and yaw is greater than five times the zero-up crossing period of the wave. When this condition is not fulfilled, a quasi-dynamic analysis methodology with motions coupling, referred to as coupled quasi-dynamic analysis, may be considered. It is defined in [3.3.4].

c) Variation of suspended line weight with motion:

The variation of the suspended line weight with the motion of the moored unit is supposed not to significantly modify the average unit draft, trim or list angles.

When one of the condition mentioned above is not fulfilled, a dynamic analysis is to be used unless an evaluation of the line response model (see [5.3]) allows for the use of the quasi-dynamic analysis.

Note 1: Additional background information is provided in the document referenced in M. François, R. Guilivo, F. Legerstee, C.V. Raposo, J.M. Machado, 2001, Statistics of extreme and fatigue loads in deep water moorings, OMAE01-2162.

## 2.4 Dynamic analysis

### 2.4.1 Methodology principles

In a line dynamic response analysis, referred to as dynamic analysis in this Rule Note, the dynamic unit response is computed by the same method as in quasi-dynamic analysis, but the line tensions are evaluated from a dynamic analysis of the line response to the fairlead motion. Therefore, the dynamic analysis is a two-step process, as follows:

- a) Perform a quasi-dynamic analysis to get unit response and fairlead motions.
- b) Perform an analysis with dynamic analysis of the mooring lines, and with imposed fairlead motions from step a)

As for the quasi-dynamic analysis, coupling between low frequency and wave frequency motions may be considered in the step a) (see [3.3.4]).

### 2.4.2 Applicability and limitations

This method is to be used for strength assessment recommended for deep water moorings, or very harsh metocean conditions, where the acceptance criteria for a quasi-dynamic analysis (see [2.3.2]) are not met, depending on the result of the line response evaluation (see [5.3]).

For fatigue analysis, a dynamic analysis is to be used unless sensitivity studies defined in [10.8.3] demonstrate the suitability of the quasi-dynamic analysis.

The dynamic analysis approach has still some limitations, that may be waived by the use of the fully coupled analysis (see [2.5]).

## 2.5 Fully coupled analysis

**2.5.1** This method is based on floater dynamic response to a dynamic behavior of the mooring system. The dynamic anchor leg response affects the first and second order motions of the floaters. The calculations process is performed in a single step.

### 2.5.2 Applicability

Fully coupled analysis is the most accurate and general method. The different limitations of quasi-dynamic analysis approach (see [2.3.2]) are waived.

Fully coupled analysis may be requested by the surveyor when couplings are deemed important or when additional validation is considered necessary.

## 2.6 Model tests

**2.6.1** As a rule, tunnel (or basin) tests are to be performed to obtain load coefficients for wind and current on the unit. Model tests in the basin are to be carried out for validation of the overall behavior of the system and for calibration of the analyses.

Consideration may be given, on a case-by-case basis, to the model tests performed on a very similar system, in equivalent metocean conditions and water depth.

However, the model tests are generally not deemed sufficient to fully document a design, due to the practical limitations in the modelling of the system (e.g. with respect to water depth), and in the number of system configurations and combinations of metocean parameters which can be addressed within a testing program.

**2.6.2** Computational fluid dynamic (CFD) may be accepted if documented, upon the satisfaction of the Surveyor.

Note 1: Guidance on the use of CFD is defined in NI691, Sec 8.

## 3 Environmental conditions, actions and unit response

### 3.1 Environmental conditions

#### 3.1.1 Wave conditions

Waves are defined by the parameters of a wave energy spectrum. In certain areas, it is relevant to split the incoming energy in two (or more) parts (e.g. swell and wind sea), modelled by two (or more) spectra with different directions of approach.

For the modelling of waves by elementary Airy wave components, through the technique of random frequency and random phase, the number  $n_i$  of elementary Airy wave components, in each spectrum, is to be such that:

$$n_f \geq \text{Max} (100 ; 30 \cdot \sqrt{T_0/T_p})$$

provided the range of circular frequency  $\Delta\omega = \omega_M - \omega_m$  does not exceed  $15 / T_p$

with:

$\omega_M$  : Maximum circular frequency for wave spectrum, in Hz

$\omega_m$  : Minimum circular frequency for wave spectrum, in Hz.

Otherwise,  $n_f$  is to be increased accordingly.

**3.1.2 Sustained wind conditions**

A description by an appropriate wind spectrum combined with a wind speed  $V_{1\text{-hour}}$  is to be used.

In the discretisation of spectrum, the minimum frequency  $f_m$ , in Hz, is not to be taken less than the frequency corresponding to a 1-hour period, i.e.:

$$f_m = 2,8 \cdot 10^{-4}$$

The upper frequency  $f_M$  may be taken in the range of 0,03 to 0,05 Hz. However, a higher frequency content is to be taken into account if the smallest natural period of the system (for horizontal motions) is lower than 1 minute.

The number of frequencies is to be selected so that the frequency interval  $\Delta f$  satisfies the following relation:

$$\Delta f < \text{Min} (0,1 / T_0 ; f_m)$$

A description by a constant speed  $V_{10\text{-min}}$  (without wind spectrum) may be used for initial evaluations or when the natural period  $T_0$  is greater than 120 s. Otherwise, and if no other description is available,  $V_{1\text{-min}}$  is to be considered.

**3.1.3 Squall wind conditions**

Strong and sudden winds (squalls) occurring in inter tropical convergence zone (ITCZ) are to be modelled by representative time series of wind speed and direction, as defined in App 4.

**3.1.4 Current conditions**

A description of near-surface current by a constant speed is normally sufficient (see App 2, [2.5]).

Sudden changes (local surface currents, loop currents) occurring in certain areas may induce significant transient effects and are to be modelled by representative time series of current intensity and direction.

**3.2 Actions**

**3.2.1 Wave drift load**

Quadratic Transfer Functions (QTF) are the second order low-frequency wave loads for floating bodies occurring at the frequency equal to the difference ( $\omega_1 - \omega_2$ ) between two wave frequencies ( $\omega_1$  and  $\omega_2$ ) of bichromatic waves.

Note 1: Definitions and details on the different possibilities to take into account second-order wave loads are defined in NI691, Sec 4, [5].

The most general way to reconstruct the second order loads in time domain is to use the full QTF matrix. The low-frequency wave loading is computed by a double summation. This requires the full QTF matrix determination and can induce large amounts of computing time. As a guidance,  $\Delta\omega_{\text{max}} = \text{Max} (\omega_1 - \omega_2)$  may be set to 20% above the mooring resonance frequency for the determination of the full QTF matrix. Setting  $\Delta\omega_{\text{max}}$  above 0,4 rad/s is generally useless since first order loads are largely predominant.

Approximations may be acceptable in specific cases. The most popular one is the Newman’s approximation.

Note 2: Newman’s approximation may be used under the following assumptions:

- General applicability conditions:  
As a guidance, Newman’s approximation may be used in deep water for soft mooring systems, with resonance frequency below 0,05 rad/s. Newman's approximation is typically invalid for shallow water or stiff mooring systems.
- Verification against full QTF approach:  
It is strongly recommended to verify that the Newman’s approximation provide same results than the ones obtained with full QTF approach, at least through a sensitivity study on a selection of critical cases.

**3.2.2 Load coefficients for wind and current loads**

Load coefficients for wind and current loads are to be obtained from tunnel (or basin) tests. Consideration will be given to derivation of data from tests on a very similar model.

In such tests, a model is maintained in a turbulent flow of adequate intensity and profile, in a fixed position, with a given incidence. The loads thus measured are projected on the unit axes as follows:

$$F_x = \frac{1}{2} \rho C_x(\theta) V^2$$

$$F_y = \frac{1}{2} \rho C_y(\theta) V^2$$

$$M_\psi = \frac{1}{2} \rho L_{pp} C_\psi(\theta) V^2$$

where:

- $F_x$  : Force, in N, along the unit longitudinal axis  
 $F_y$  : Force, in N, along the unit transverse horizontal axis  
 $M_\psi$  : Yaw moment, in N·m  
 $C_x, C_y, C_\psi$  : Force coefficients corresponding, respectively, to  $F_x, F_y$  and  $M_\psi$   
 $V, \theta$  : Flow (reference) velocity and incidence  
 $\rho$  : Fluid density  
 $L_{pp}$  : Length between perpendiculars of the unit.

Note 1: Concerning yaw moment, a particular attention is to be paid to the reference point where the moments are calculated (origin O of the axis system, centre of gravity G, midship section, etc., of the unit).

When applicable, the data in OCIMF-MEG may be used.

Note 2: These data are relevant for tankers or gas carriers but not applicable to other hull shapes or other arrangement of superstructure.

At initial design stage, the load coefficients may be obtained from analytical expressions or other heuristic expression, provided all three components of the force are taken into account (no particular reduction of wind fore coefficient is allowed).

Guidance for current drag loads coefficients are defined in NI691, Sec 3. For wind drag loads coefficients, values considered for stability calculations, defined in NR445, Pt B, Ch 1, Sec 2, Table 2, may be used as a guidance for initial design stage.

### 3.2.3 Wind Loads

Wind loads are evaluated by the formulae given in [3.2.2], taking into account the wind speed at a reference elevation (typically 10 m above sea level - the same as in tests), and the incidence of wind with respect to the unit.

Note 1: Wind vertical profile effect is considered through the wind load coefficient.

### 3.2.4 Current Loads

As the unit is moving in water, the instantaneous loads (combining current load and drag induced by motions) are evaluated by the formulae given in item a), taking account of the equivalent current velocity  $U_c$ , in m/s, and the current relative incidence  $\alpha_c$ , in degree, defined as follows:

$$\vec{U}_c = \vec{V}_c + \vec{V}$$

$$\alpha_c = \beta_c + \psi$$

where:

- $V_c$  : Current velocity, in m/s  
 $V$  : Unit instant velocity, in m/s  
 $\beta_c$  : Current angle from the north, in degree  
 $\psi$  : Unit heading, in degree.

When the unit is fixed during current model tests, the force coefficient  $C_\psi$  does not include any effect due to the rotation of the unit in the fluid. In such a case, the Molin's yaw moment (only valid for barge or ship-shaped units) is therefore to be added to the yaw moment derived from model tests.

Note 1: Additional information are defined in NI691, in particular NI691, Sec 4, [2] about manoeuvring loads

### 3.2.5 Riser loads

Risers and other fluid carrying lines (e.g. export lines) are generally kept under tension (possibly resulting in permanent pull on the unit), and are subjected to the action of current over the water column. The resulting forces may represent a significant part of the total load on the unit.

The reactions on the unit may be obtained from a static analysis of the lines.

Attention is to be given to the effect of varying direction and intensity of current along the water column.

The mean static load, depending upon the instantaneous low-frequency position of the unit, may be modelled by:

- either a static load, corresponding to a mean offset condition, and dummy lines to represent variations of load around this position, or
- tabulated loads, for a range of positions around the expected mean position.

### 3.2.6 Damping of low frequency motions

The sources of low frequency motions damping on a moored unit are multiple and of various nature, as defined in NI691, Sec 6, [3.3.5]. Different theories exist to explain and model these effects. However, all of them are based on either fully empirical or semi-analytical formulations, the range of validity of which is necessarily limited.

Three main sources of damping can be listed:

- viscous damping on the hull
- wave drift damping
- damping due to the mooring lines (including bottom friction).

- a) A direct assessment of damping terms requires that these main contributing terms are separately evaluated:
- viscous damping on the hull is modelled together with current loads since these loads are calculated on the basis of the relative fluid velocity (see [3.2.2])
  - wave drift damping may be obtained from the drift forces and its derivatives. Guidance is defined in NI691, Sec 4, [5].
  - damping due to the lines (risers and mooring lines, including bottom friction effect) may be estimated from line dynamic calculations.
- b) Any damping model requires to be calibrated and its field of applicability clearly identified. Limitations of the present approach are specified in [2.3.2].

Some sources of damping may be modelled by a linear damping, i.e. forces proportional to the absolute speed of the unit, according to the following formulae:

$$F_{B_x} = - B_{xx} u$$

$$F_{B_y} = - B_{yy} v$$

$$M_{B_{\Psi/0}} = -B_{\Psi\Psi} \frac{d\Psi}{dt}$$

where:

- F : Force induced by damping, in N
- M : Moment induced by damping, in N·m
- B<sub>xx</sub> : Linear damping coefficient in surge, in kg·s<sup>-1</sup>
- B<sub>yy</sub> : Linear damping coefficient in sway, in kg·s<sup>-1</sup>
- B<sub>ΨΨ</sub> : Linear damping coefficient in yaw, in kg·m·s<sup>-1</sup>
- u : Absolute velocity in surge of the origin O of the unit axis system, in m·s<sup>-1</sup>
- v : Absolute velocity in sway of the origin O of the unit axis system, in m·s<sup>-1</sup>
- Ψ : Function versus time of the unit heading.

- c) The result of the simulation is quite sensitive to the linear damping coefficients. Great care is therefore to be paid to their evaluation.
- d) If no data is available from direct calculations or model tests, the formulae in Tab 2 may be used as a preliminary approach. These formulae tentatively account for the damping due to the mooring lines and the wave drift damping. They apply only to usual mooring systems.

Great care is to be paid to the use of these formulae, since they are only based on experience and empirical calibrations.

For units moored by surface lines only, as units moored on a single point mooring or shuttle tankers moored to a FPSO, the values obtained from Tab 2 for tanker on a SPM are to be multiplied by the factor 0,37.

**Table 2 : Low-frequency linear damping coefficients for different types of usual mooring systems**

Mooring system	B <sub>xx</sub>	B <sub>yy</sub>	B <sub>ΨΨ</sub>
Barge or tanker in spread mooring (1)	$0,06 \sqrt{K_{Oxx}(m + Ma_{xx})}$	$0,06 \sqrt{K_{Oyy}(m + Ma_{yy})}$	$0,10 \sqrt{K_{O\Psi\Psi} [I_{\Psi\Psi} + Ma_{\Psi\Psi} + (m + Ma_{yy})x_G^2]}$
Barge or tanker on a SPM (2) (3)	$0,01 m \sqrt{\frac{g}{L}}$	$0,02 m \sqrt{\frac{g}{B}}$	$0,083 L^2 B_{yy}$
Semi-submersible unit at operating draft	$0,20 \sqrt{K_{Oxx}(m + Ma_{xx})}$	$0,20 \sqrt{K_{Oyy}(m + Ma_{yy})}$	$0,10 \sqrt{K_{O\Psi\Psi} [I_{\Psi\Psi} + Ma_{\Psi\Psi} + (m + Ma_{yy})x_G^2]}$

(1) For spread mooring, B<sub>xx</sub> and B<sub>yy</sub> correspond to 3% of the critical damping and B<sub>ΨΨ</sub> corresponds to 5% of the critical damping.  
 (2) The values of B<sub>xx</sub>, B<sub>yy</sub> and B<sub>ΨΨ</sub> are given assuming that the origin O of the unit axis system is in the midship section.  
 (3) For units moored by surface lines only, the values are to be multiplied by the factor 0,37.

**Note 1:**  
 K<sub>Oxx</sub>, K<sub>Oyy</sub>, K<sub>OΨΨ</sub> : Diagonal terms of the mooring stiffness matrix [K<sub>O</sub>], evaluated at the average position of the unit during the storm, in N·m<sup>-1</sup> for K<sub>Oxx</sub> and K<sub>Oyy</sub>, and in N·m·rad<sup>-1</sup> for K<sub>OΨΨ</sub>  
 Ma<sub>xx</sub>, Ma<sub>yy</sub>, Ma<sub>ΨΨ</sub> : Diagonal terms of the asymptotic added mass matrix of the unit, in kg for Ma<sub>xx</sub> and Ma<sub>yy</sub>, and in kg·m<sup>2</sup> for Ma<sub>ΨΨ</sub>  
 I<sub>ΨΨ</sub> : Moment of inertia in yaw, in kg·m<sup>2</sup>, calculated at the centre of gravity G of the unit  
 m : Mass of the unit, in kg  
 L : Length of the unit, in m  
 B : Breadth of the unit, in m.

### 3.2.7 Other loads

Thrusters are sometimes used to assist a passive mooring system.

The driving system of the thruster loads may be either very simple (e.g. constant load in a constant direction relative to the unit heading) or more complex.

Note 1: Additional definitions and principles about thrusters assisted moorings are defined in ISO 19901-7:2013 or API RP 2SK:2024.

In any case, the loads that the thrusters actually induce on the moored unit are to be computed at each time step as a function of the applicable parameters.

Loads induced by thrusters are to be implemented using appropriate models, on a case-by-case basis. Models using equivalent forces and/or equivalent stiffness and dampers may be accepted provided that the choice of parameters is duly documented and justified, at the satisfaction of the Surveyor

## 3.3 Unit response

### 3.3.1 Main principles for the quasi-dynamic analysis

In a quasi-dynamic analysis, the dynamic unit response is computed through an analysis mixing time and frequency domains and taking into account the static line response.

The calculation procedure consists in the determination of the low-frequency response of the moored unit under the effect of waves, wind and current, by time domain simulations (see [3.3.2]), followed by the superimposition of the wave frequency motions (see [3.3.3]). It is assumed that low and wave frequency components do not significantly interfere with each other because of very different time scales (see [2.3.2]). As a consequence, they are assessed separately in the framework of this approximation and added together at the end of each time step of the simulation.

Note 1: This calculation procedure is referred to as LF+WF in NI691, Sec 6.

At the end of each time step, the line tensions are evaluated from the quasi-static line response to the fairlead motion.

Coupled quasi-dynamic analysis unit response is defined in [3.3.4].

### 3.3.2 Low-frequency response

The mean- and low-frequency responses (three degrees of freedom) of the unit in the horizontal plane are calculated by resolving, in a time domain simulation, the equations of the dynamic equilibrium of the unit (equation of manoeuvrability, expressed typically in a system of axes linked to the unit), for predefined time series of wave elevation and other parameters.

The different actions as detailed in [3.2] (waves, wind, ...) are taken into account, all evaluated considering the instant of low-frequency position and the relative heading of the unit with respect to each action, as well as:

- the restoring mooring force (see [4.2])
- the mass matrix and the added mass of the unit (added mass calculated for  $\omega$  converging toward 0)
- a linear damping as per [3.2.6].

Additional definitions and background are defined in NI691, Sec 6, [3.3].

### 3.3.3 Wave frequency motions

#### a) Unit motions (Response Amplitude Operators, RAO's)

As a pre-requisite to mooring analysis, the six motions of the unit in the frequency domain (RAO's motions) are to be determined.

The RAO's motions may be obtained by model tests or by a recognized first order diffraction-radiation analysis program, with due account for the actual site water depth.

RAO's calculation is further defined in NI691, Sec 5, [2].

It is assumed that the wave frequency motions of the unit are not significantly disturbed by the variation of the mooring stiffness with the low-frequency offset. An average mooring stiffness may therefore be used for pre-determining the RAO's motions of the unit.

In motion analysis, account may be taken of hydrodynamic damping on the floating body (e.g. roll damping), by appropriate formulation. Modelling of damping for RAO calculation is defined in NI691, Sec 5, [2.7.4]

The effects of suspended load of the mooring lines and of risers (vertical and horizontal components) around the mean unit position is to be accounted for, not as mass but as terms in the stiffness matrix, together with the stiffness of these systems.

Additional wave frequency dynamic effects of lines (primarily damping) might be significant in some cases, and may be estimated from line dynamic calculations or inferred from a fully coupled analysis.

#### b) Wave frequency motions

The wave frequency motions are obtained by linear summation of those due to each component of the waves, taking into account the instant low-frequency position and the relative heading of the unit with respect to waves.

At each time step of the simulation, the six wave frequency motions are superposed to the low-frequency motions in order to get the instant position of the unit and hence the position of each fairlead from which the line response (see Article [5]) can be evaluated.

### 3.3.4 Coupling between low-frequency and wave frequency components

For some cases, interferences between horizontal low and wave frequencies can occur. If compliance with the assumption of non-interference (see [2.3.2]) is not satisfied, a specific quasi-dynamic analysis with coupling between low and wave frequencies is to be carried out.

This method is still considered as quasi-dynamic since it is based on floater dynamic response to a static behavior of the mooring system. However a coupling between low and wave frequencies is added to the analysis described in [3.3.1].

For this type of analysis, the low-frequency and wave frequency responses of the structure are solved simultaneously in the six degrees of freedom. In this case, the radiation and first order loads are to be taken into account in the time domain calculations.

This approach is further defined in NI691, Sec 6, [3.4] and referred to as unified formulation.

The coupled motions are calculated taking account of the:

- mass matrix and infinite frequency added mass of the unit
- vessel hydrostatic stiffness
- radiation loads
- mooring restoring forces
- linear damping
- low-frequency external loads
- high-frequency external loads.

## 4 Mooring system

### 4.1 Mooring pattern and initial tensions

**4.1.1** The mooring pattern is the theoretical description of the mooring system as installed on site. It includes the general layout of the mooring system and the elevation of each line in its initial vertical plane. To achieve the description, the following information is needed:

- site bathymetry
- unit position and heading
- unit draft and vertical centre of gravity
- fairlead position
- anchor position
- mooring line composition
- paid-out line lengths
- reference points for anchors (for calculations).

**4.1.2** The knowledge of all the information listed in [4.1.1] automatically settles the initial tensions, since a relation of the following form exists for each line as soon as its vertical plane is known:

$$f(L, D, T) = 0$$

where:

- L : Paid-out length of the line, in m
- D : Horizontal distance between the anchor and the fairlead, in m
- T : Tension at fairlead, in N.

In practice, an iterative process is needed to set the initial tensions to their prescribed values and to ensure that the three parameters are compatible together.

### 4.2 Mooring response

**4.2.1** Following the assumptions in [5.1.1], the load induced by any mooring line on the moored unit depends only on the anchor-to-fairlead relative position.

The azimuth of a mooring line is defined by the relative position of fairlead and anchor.

In the time domain simulation of low-frequency motion, the mooring restoring force (horizontal force and yaw moment) at each time step is obtained by summation of the horizontal components of line tensions at each fairlead, as resulting from fairlead position under the low-frequency motion.

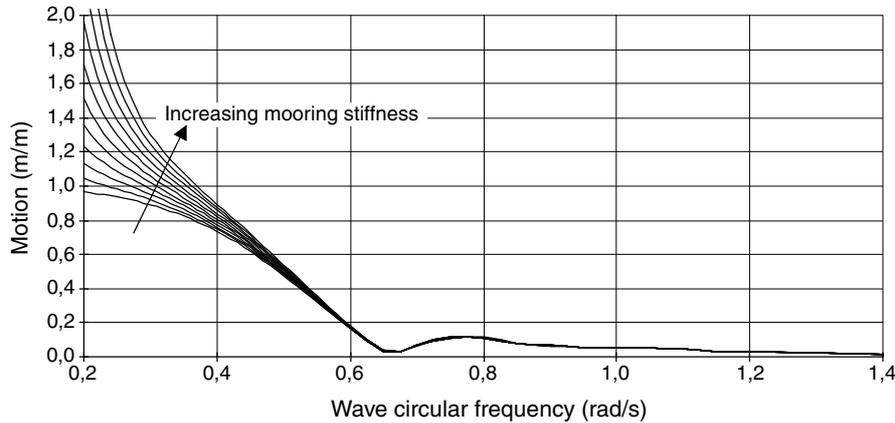
### 4.3 Mooring stiffness

**4.3.1** The mooring stiffness is the 6x6 matrix which links the elementary external loads applied to the unit with its resulting elementary displacements around a given position.

The mooring stiffness is to be considered for the calculation of the unit motions RAO's. In most cases, the stiffness induced by the mooring system for out-of horizontal plane motions is negligible in comparison with the hydrostatic stiffness. However, special care may be taken for non-linear mooring system where the matrix can be significantly different from one offset position to another.

The sensitivity to input is illustrated in Fig 1 (example of unit surge motion).

**Figure 1 : Effect of mooring stiffness on surge RAO's**



**4.3.2** The stiffness matrix is obtained by the summation of the contributions of all the mooring lines under six elementary displacements of the unit.

Note 1: The stiffness matrix can be also obtained by multi-linear regression, versus the time series of unit motions, of a time series of the mooring force, computed after an analysis taking into account both low-frequency and wave frequency motions.

## 5 Line response

### 5.1 Static line response

#### 5.1.1 Assumptions

The lower end of the mooring line is anchored to a fixed point. The upper end is connected to a fairlead of the moored unit which may be either emerging or immersed. The mooring line cannot penetrate the seabed.

The mooring line is made up of a series of homogeneous segments attached end-to-end, the bending stiffness of which is negligible. An homogeneous segment is characterized by constant mechanical properties over its whole length. A buoy or a sinker may be connected at the upper end of any segment.

At any time, the mooring line is assumed to be in the vertical plane passing by its anchoring point and its fairlead. This implies that:

- wave, current, wind and dynamic loads on any of the mooring line components are neglected
- friction effects, transverse to those parts of the line laying on the seabed, are not taken into account.

In-line friction effects are to be considered.

These assumptions correspond to the static string model defined in NI691, Sec 6, [2.3].

#### 5.1.2 Line elements

The static line response is based on the equations of the elastic catenary.

For chains and wire ropes, the elastic response is linear:

$$\frac{d\ell}{\ell} = \alpha T$$

where:

$d\ell$  : Elongation of an elementary length  $\ell$  of the line at rest, when submitted to a tension T at both ends

$$\alpha = \frac{4}{\pi E \phi^2}$$

with:

$\phi$  : Nominal diameter of the chain or wire rope, in mm

E : Equivalent Young modulus, in N/mm<sup>2</sup>.

For some other materials (e.g. some synthetic materials, see [5.1.5]), the relation  $d\ell/\ell = f(T)$  is not linear. In this case, it may be approximated, e.g. by a polynomial function of the tension.

The elasticity properties of different materials are given from [5.1.3] to [5.1.5].

### 5.1.3 Wire ropes

Specific data are to be obtained from the manufacturer since the stiffness properties depend upon the wire rope design.

### 5.1.4 Fibre rope mooring lines

A model for the load-elongation characteristics of fibre rope mooring lines is given in NR432, App 2.

The equivalent linear elastic properties are here expressed as a non-dimensional stiffness:

$$K_r = \frac{\Delta T / MBS}{d\ell/\ell}$$

where:

MBS : Minimum breaking strength of the line, in N.

$\Delta T$  : tension difference during successive cycles, in N. Guidances are given in NR432.

Thus  $\alpha$  (see [5.1.2]) is given by:

$$\alpha = \frac{1}{K_r \cdot MBS}$$

Note 1: A polynomial fit of the break load test load-elongation curve is not appropriate in this case.

For polyester and polyamide (nylon) ropes, the values and application range of the stiffnesses are given in NR432, App 2.

### 5.1.5 Hawsers

Hawsers are generally substantially more compliant to the quasi-static line response assumption than deep water mooring ropes. In the absence of better data, the load-elongation curve corresponding to a worked rope of the same material and construction may be used, but may still over-predict mean offset and under-predict maximum load. Data taken from a new rope (first extension) are not acceptable.

Manufacturer's data (usually presented as a curve giving the tension in percent of the breaking load BL versus the relative elongation of the material) may be converted into a relation as given in [5.1.2].

### 5.1.6 Buoys and sinkers

A buoy or a sinker induces, respectively, an upward or a downward load to the point of the line to which it is attached.

Note 1: Buoys and sinker are to be carefully modelled so that the net action that they exert to the mooring line remains correct whatever the tension in the line and the resulting position of the element with respect to sea level or seabed.

## 5.2 Dynamic line analysis and response

**5.2.1** The dynamic line response is obtained from a finite element model of the line or equivalent numerical model, see NI691, Sec 6, [2.2].

a) The hydrodynamic drag coefficient CD and inertia coefficient CA may be taken as shown in Tab 3.

CD and CA are given considering, respectively, the reference diameter and the volume per unit length of a rod, with the effective diameter  $D_{\text{eff}}$  based on:

- for chains: the nominal chain diameter d
- for wire and fibre ropes: the rope outside diameter D.

Note 1: The force coefficient  $CM_N = 1 + CA_N$  is also used to specify the normal inertia coefficient.

b) It is recommended that the length  $\ell_i$  of each line segment i in the finite element model remains below:

$$\ell_i = T_p \sqrt{\frac{F_{\text{mean}}}{m_{Ni}}}$$

where:

$F_{\text{mean}}$  : Mean line tension, in kN

$m_{Ni}$  : Total normal (transverse) mass, including the added mass, per unit length, in kg/m, of the line segment i.  
 $m_{Ni}$  may be obtained from Tab 3 based on the mass in air per unit length  $m_i$  of the line segment i.

Note 2: A smaller length of the line segments is generally necessary:

- in the touchdown area
- for the top chain, and
- close to the fairlead.

**Table 3 : Hydrodynamic coefficients**

	$D_{eff}$	$CD_N$ (1) (2)	$CA_N$ (1)	$CA_L$ (1)	$m_{Ni}$ (3)
Chain	1,8 d	0,8	1,0	0,50	1,13 $m_i$
Wire rope	D	0,7	1,0	0	1,20 $m_i$
Fibre rope (4)			1,1	0,15	2,00 $m_i$

(1) Suffix N is for normal (transverse) direction.  
Suffix L is for longitudinal (tangential) direction  
(2)  $CD_N$  are specified as lower bound, to avoid unconservative over-estimate of damping effects  
(3)  $m_i$  is the mass per unit length of the line segment i  
(4) For fibre rope,  $CA_N$  and  $CA_L$  are inclusive of entrapped water

**5.2.2** The mean position is set to get the mean tension  $F_{mean}$  from the unit response analysis, and the 3D fairlead motion is applied as an imposed displacement at the top of the line.

Current and time dependent water particle kinematics are also applied, but this latter term gives a marginal contribution and may be neglected.

**5.2.3** As the time domain analysis involves iterations at each time step, the iteration parameters (particularly the maximum number of iterations) are to be set so as to get an unspoiled solution.

**5.3 Evaluation of the line response model**

**5.3.1** When the quasi-dynamic line response has been obtained (i.e., with a static line response model, see Article [2]), a test-run of dynamic line response is to be performed in order to characterize the dynamic response and evaluate, or confirm, whether the quasi-dynamic line response may be used for the evaluation of the extreme loads.

The methodology and criteria for this evaluation are defined in App 1.

Such an evaluation may be omitted for chain moorings in shallow and moderate water depths when all the other conditions specified in [2.3.2] are met, and the safety factors for quasi-dynamic analysis are used accordingly (see Article [11]).

**5.4 Selection of windows for dynamic line maximum tension**

**5.4.1** For the application of the design tension calculation (see Article [6]) a given simulation, the maximum tension over the duration of this simulation is to be obtained.

This can be achieved by performing dynamic analyses over a limited number of windows, each of them with a duration not less than the natural period  $T_0$  of the unit low-frequency motion.

From three to five windows are to be selected, based on the maxima of  $dT_{qd}/dt$ , or of  $T_{qd}$ , if relevant, with:

$T_{qd}$  : Time series of the quasi-dynamic tension, in N, as defined in App 1, [1.1].

Alternatively, when the correlation between  $T_{dyn}$  (time series of the dynamic tension, in N, as defined in App 1, [1.1]) and  $dT_{qd}/dt$  is clearly established, an option is to limit the analysis to the window corresponding to the expected maximum. This impacts the short term extrema estimation defined in [6.2.3].

**5.4.2** The maximum tension for the simulation is then taken as the maximum among the several windows, or the maximum in the selected one-window, as relevant (see App 1).

**6 Design tension**

**6.1 Application**

**6.1.1 General**

This Article defines the requirements for the calculation of the design tension in the mooring lines for the different design conditions defined in Article [10].

This design tension is to be used for checking the following criteria:

- mooring lines strength criteria, as defined in [11.1]
- anchors criteria, as defined in [11.2]
- testing criteria, as defined in [11.5].

Note 1: Characteristic tension for fatigue analysis is defined in Article [8].

**6.1.2 Design tension due to squall events**

The design tension  $T_D$  due to squall events is found by application of the Serviceability Limit State (SLS) defined in App 4, [4].

Applicable criteria using the SLS squall design quantities are defined in App 4, [4.1.2].

## 6.2 Design tension in intact condition

### 6.2.1 Number of simulations and durations

For any sea-state to be considered, n simulations of at least three hours each are to be performed, using different sets of elementary waves representative of the whole spectrum. If a wind gust spectrum is used, the same provision applies.

Note 1: For squalls analysis, the number of simulations and the duration of the simulations depend on the squall time series record and are defined in App 4.

### 6.2.2 Time step

The response signals are to be built up with a time step equal to, or less than, one tenth of the peak or zero-up crossing period of the wave spectrum, whichever is the most appropriate.

### 6.2.3 Short-term extrema estimation

The design tension  $T_D$  of a line in intact condition, for a specified set of design conditions, i.e. unit state condition and metocean conditions (see Article [10]), is defined from the mean and the standard deviation of the n maximum values of  $T_k$ , each obtained from n simulations, using different random “seeds”, i.e. different sets of elementary waves and wind components, with:

$T_k$  : The maximum tension obtained during the k-th simulation

n : number of simulations

The maxima are either the maximum values of the quasi-dynamic tension or those of the dynamic tension, obtained as defined in [5.4].

The design tension  $T_D$  for the condition analysed is given by:

$$T_D = T_M + a T_S$$

where:

$T_M$  : Mean of the n maximum values of  $T_k$ :

$$T_M = \frac{1}{n} \sum T_k$$

$T_S$  : (n – 1) standard deviation, given by:

$$T_S^2 = \frac{1}{n-1} \sum (T_k - T_M)^2$$

a : Factor given in Tab 4 depending on the type of analysis method (see [2]), the number of simulations, and the number of windows considered in case of a dynamic analysis method (see [5.4]).

Note 1: A high number of simulations with different random seeds gives a more converged value of  $T_D$ .

Note 2: Guidance on extrema calculations can be found in NI638.

**Table 4 : Factor a**

Method of analysis	Number of simulations			
	n = 5	n = 10	n = 20	n ≥ 30
Dynamic	0,60	0,30	0,10	0
Dynamic – 1 window	1,20	0,80	0,55	0,45
Quasi-dynamic	1,80	0,90	0,50	0,40

**Note 1:** For intermediate values of n, a is obtained by interpolation.

## 6.3 Design tension in one-line damaged condition

**6.3.1** The design tension  $T_D$  of a line in one-line damaged condition is obtained by the same method as for a line in intact condition, considering the different mooring system configurations for the damaged mooring system state conditions defined in [10.3].

## 6.4 Design tension in one-line failure (transient) and thruster failure condition

**6.4.1** The design tension  $T_D$  of a line in one-line failure (transient) condition is defined as the average, for a set of possible failure instants, of the maximum transient tensions.

The procedure described in the following items a) and b) is to be repeated for each line:

- a) For the sea-state to be considered and for each mooring line, the simulation to be selected for the study of the one-line failure case is to satisfy the following criteria:
  - the maximum fairlead tension is the closest to its design tension in intact condition as defined in [6.2], and
  - this maximum value occurs while the low-frequency component of the tension is increasing.

If the second criterion is not met, the selection procedure is to be resumed with the second highest maximum tension in the same simulation or in the second closest simulation.

The two instants around the maximum tension where the low-frequency component of the tension is respectively minimum and maximum are to be identified. See Fig 2.

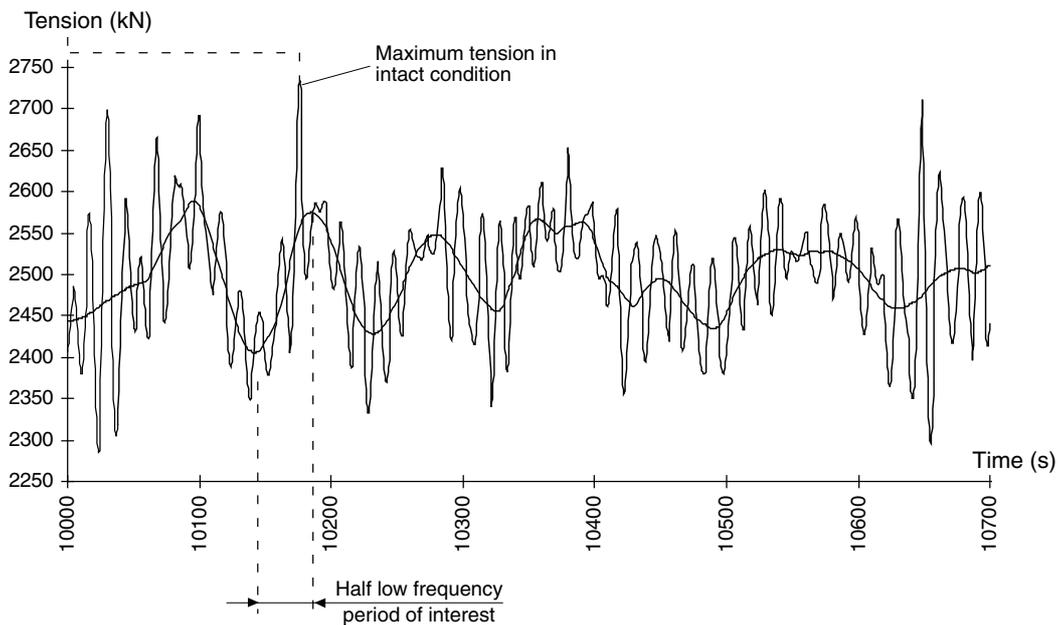
- b) Using always the same sets of Airy waves and wind components as those used in the simulation identified in item a), five simulations are repeated. During these simulations, the line is to be broken at different times equally distributed between the two instants identified in item a), with the objective of catching maximum.

The five simulations are to be run from the beginning, in order to ensure the same initial numerical transient. They may be terminated after two low-frequency cycles following the line failure.

The maximum tension obtained at the fairlead of each remaining line after the line failure is to be identified for the five simulations. For this particular one-line-failure case, the design tension in damaged condition of each remaining line is the average of the five maximum values identified for this line.

- c) For a given line, the design tension in one-line failure condition is the maximum tension of all the possible one-line failure cases.

**Figure 2 : Range of time to be selected for the one-line failure condition**



**6.4.2 Thruster failure**

The design tensions  $T_D$  in the mooring lines following a thruster system failure are to be determined by a method similar to the one described in [6.4.1]. The instants of failure, however, may be randomly selected during the simulation, in a sufficient number to ensure that the statistics derived from the response samples are reasonably representative.

Note 1: Thruster failure conditions are defined in [10.3.3]

**6.5 Design tension in two-line damaged condition**

**6.5.1** The residual strength based on a system with two lines removed is to be estimated.

The design tension  $T_D$  of a line in two-line damaged condition is obtained by the same method as for a line in intact condition, considering a system with two adjacent lines removed.

This criterion is requested for the notation **POSA-HR** only and does not concern the other **POSA** notations.

**6.6 Design tension in line components**

**6.6.1** The tensions at different locations along the lines, as required for sizing of the line components, are to be obtained by the same methods as those defined from [6.2] to [6.5].

When a quasi-dynamic analysis is performed, the design tension  $T_D$  and other parameters (e.g. uplift angle at anchor point) may be obtained from the catenary with a fairlead position corresponding to the situation leading to the design tension at fairlead.

Note 1: There may be several positions, with different combinations of offsets and vertical positions, that are governing for different locations along the line.

**6.7 Minimum design tension**

**6.7.1** For fibre rope moorings only, and when required (see NR432, Sec 7, [4.2]), the minimum design tension  $T_{Dm}$ , in N, is to be obtained from dynamic line analysis, by the same method as for the maximum tension (see [6.2]), i.e.:

$$T_{Dm} = T_m - a T_{ms}$$

where:

$T_m$  : Mean of the n minimum values of  $T_{mk}$ :

$$T_m = \frac{1}{n} \sum T_{mk}$$

with:

$T_{mk}$  : The minimum tension obtained during the k-th simulation

n : number of simulations

$T_{ms}$  : (n – 1) standard deviation, given by:

$$T_{ms}^2 = \frac{1}{n-1} \sum (T_{mk} - T_m)^2$$

a : Factor as defined in [6.2.3].

**7 Offset calculations**

**7.1 Intact conditions**

**7.1.1** For offset calculations in non squall events, the methodology used for the short-term extrema estimation of the design tensions may be applied (see [6.2]).

In particular, the design offset  $O_D$  for the condition analysed is given by:

$$O_D = O_M + b O_S$$

where:

$O_M$  : Mean of  $O_k$ :

$$O_M = \frac{1}{n} \sum O_k$$

with:

$O_k$  : The maximum offset obtained during the k-th simulation

n : number of simulations

$O_S$  : (n – 1) standard deviation, given by:

$$O_S^2 = \frac{1}{n-1} \sum (O_k - O_M)^2$$

b : Factor depending on the number of simulations, as given in Tab 5.

**Table 5 : Factor b**

Number of simulation n	5	10	20	n ≥ 30
b	0,60	0,30	0,10	0
<b>Note 1:</b> For intermediate values of n, b is obtained by interpolation.				

The same methodology may be applied to calculate the azimuth  $\Phi_D$ :

$$\Phi_D = \Phi_M \pm b \Phi_S$$

where:

$\Phi_M$  : Circular average of the associated to the maximum offsets  $\Phi_k$

$\Phi_S$  : (n – 1) circular standard deviation of the azimuth associated to the maximum offsets  $\Phi_k$

b : Factor depending on the number of simulations, as given in Tab 5.

Note 1: For squalls, durations are defined in App 4.

## 8 Fatigue analysis

### 8.1 General

**8.1.1** Fatigue analysis is to be conducted all along the lines, at each critical point where specific issues could occur, such as touch down point, all connections, singularities particular features of the mooring line.

**8.1.2** Fatigue induced by dynamic line responses is to be assessed for at least a group of sea states as defined in [10.8.3].

### 8.2 Tension range

**8.2.1** For each environmental condition selected as specified in [10.7], the distribution of tension ranges is to be obtained from dynamic line analyses (see App 1), with a minimum duration of 30 min each and a minimum of 10  $T_0$ . Both windward and leeward lines are to be analysed.

An appropriate cycle counting method accounting for both low and wave frequency cycles, such as rainflow, is to be used.

#### 8.2.2 Miner summation

The fatigue damage  $D_j$  accumulated over one year by any component of the mooring line, for the environmental condition  $j$ , is obtained by means of the Miner's ratio (yearly average over 4 years: 31 557 600 seconds):

$$D_j = p_j \frac{3,15576 \cdot 10^7}{d_j} \sum_k \frac{n_{jk}}{N_k}$$

where:

$p_j$  : Probability of occurrence for the environmental condition  $j$  (the sum of the probabilities of all the selected environmental conditions is to be equal to 1)

$d_j$  : Duration of the simulation for the environmental condition  $j$

$n_{jk}$  : Number of cycles, within interval  $k$  of the tension range, encountered by the component for the environmental condition  $j$

$N_k$  : Number of cycles to failure within interval  $k$  of the tension range, as given by the appropriate T-N curve.

The total fatigue damage  $D$  accumulated over one year by any component of the mooring line is then given by the following formula:

$$D = \sum_j D_j = \sum_j \sum_k p_j \frac{3,15576 \cdot 10^7}{d_j} \cdot \frac{n_{jk}}{N_k}$$

The maximum width of each tension range interval to be considered is to be less than, or equal to, one thousandth of the mooring line component breaking load, or 10 kN, whichever is the lesser.

### 8.3 In-Plane Bending/Out-of-Plane Bendings (IPB/OPB)

**8.3.1** Fatigue damage due to OPB or IPB is to be assessed for chain mooring line with pretension greater than 10% of the minimum breaking strength of the top part of the mooring line.

Note 1: For minimum breaking strength and API-ORQ equivalence, see [9.4.3].

For pretension less than 10% of the minimum breaking strength (MBS), special consideration may be required by the Society, on a case-by-case basis.

**8.3.2** A complete methodology to evaluate top chain combined fatigue, including fatigue damage due to OPB and IPB, is defined in the Guidance Note NI604.

## 9 Strength of line

### 9.1 General

**9.1.1** The line arrangement is to take duly into account the position limitations with respect to surface/sea bottom, for certain line segment materials, as specified in Sec 4.

**9.1.2** Line segments and connecting devices are to ensure an homogeneous strength along the line. As a general rule, no component is to work as weak link for the mooring line design.

### 9.2 Breaking strength of line components

**9.2.1** The reference load for the evaluation of the safety factor is the MBS of the mooring line component (see Sec 4), taking into account the reduction resulting from corrosion and wear, where applicable (see [9.3] and Sec 4), except if justified by design constraints or other particular configuration.

**9.3 Corrosion and wear**

**9.3.1 Wear and corrosion allowances for chains**

At the design stage, the practice for a chain with a specified diameter D (see Fig 3) depends on the mode of failure considered:

- For mooring line strength verification (see Article [11]), the minimum breaking strength to be considered is the one of a chain of the same grade, having a diameter  $D_c$ , obtained by reducing D by the specified corrosion (or wear) allowance for the duration of the design life L, i.e.:

$$D_c = D - c \cdot L$$

With:

c. : annual nominal diameter reduction for corrosion and wear (corrosion rate), defined in [9.3.2]

- For fatigue assessment, a minimum of half the corrosion (or wear) allowance for the duration of the design life is to be taken into account.

In both cases, the weight of the non-corroded link is to be used for mooring line tension computation.

**9.3.2 Chains corrosion rates**

For chains, the corrosion and wear annual rates, referred to as corrosion rates for simplicity, to be used for minimum breaking strength calculation and fatigue capacity (see [9.3.1]), are to be at least as follows:

- The corrosion rate on nominal chain diameter is a 0,4 mm/year in the splash zone area and at the bottom area.

Note 1: The splash zone area is between ± 5 metres around the free surface. Change of unit draft, if any, is to be accounted for in the definition of the splash zone area.

Note 2: The bottom area is the length of the line in contact or potentially in contact with seabed, plus 10 metres, see Sec 2, [5].

- This corrosion rate (0,4 mm/year) is also to be applied for the 5-metre length of line in the vicinity of the stopper.
- The corrosion rate may be reduced to 0,3 mm/year in the remaining length.

Note 3: These corrosion rates seem relevant for cold seas but may be insufficient in tropical seas.

Higher corrosion rates may be defined, based on local regulations or on-site data.

These minimum nominal diameter reductions are summarized Tab 6.

**Table 6 : Summary of minimum chain nominal diameter reduction for corrosion and wear**

Zone	Nominal diameter reduction (corrosion rate)
splash zone	0,4 mm/year
vicinity of the stopper	0,4 mm/year
bottom area	0,4 mm/year
rest of the line	0,3 mm/year

**9.3.3 Other line components**

For other line components subjected to corrosion and wear, the thickness to be considered for their capacity evaluation is obtained as follows:

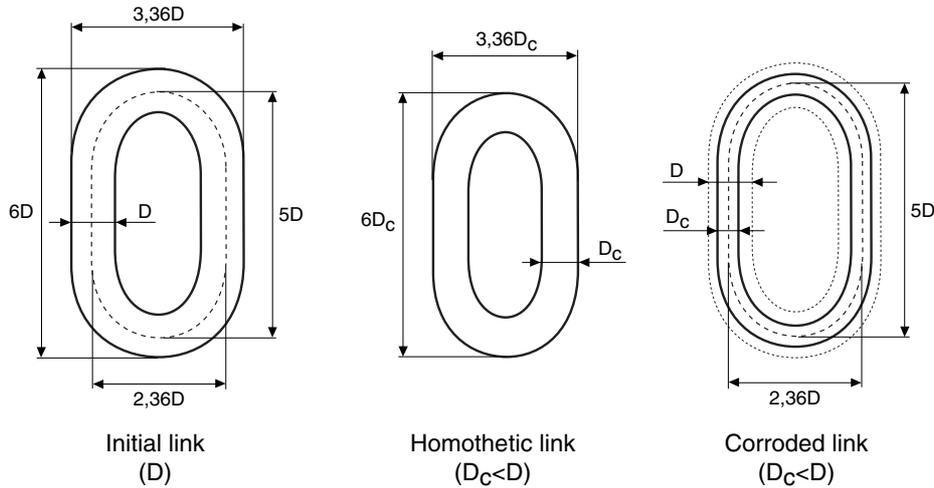
- For strength verification, the nominal thickness may be reduced by the specified corrosion rate for the duration of the design life.
- For fatigue, half this reduction may be considered.

The following corrosion and wear rates may be considered for these components:

- 0,2 mm/year per face in the splash zone, the bottom area, and the vicinity of the touchdown point
- 0,15 mm/year per face in the other zones.

Higher corrosion and wear rates may be defined, based on local regulations or on-site data.

Figure 3 : Modelisation of corrosion for studless links



**9.3.4 In-service system**

The common design practice mentioned in [9.3.1] to [9.3.3] is implicitly assuming an homothetic reduction of all the dimensions in the ratio  $D_c/D$ .

For the evaluation of an in-service system, the minimum breaking strength of a link is to be evaluated by strength analysis, taking into account the reduced diameter (see Sec 2, [6.2]) but based on non corroded distance between neutral fibre.

**9.4 Tension-tension fatigue endurance**

**9.4.1 General**

A fatigue analysis is to be performed for installations intended to stay moored on site for a period longer than two years. Change of unit draft, if any during the period of exposure, is to be accounted for.

**9.4.2 Fatigue endurance curve**

The fatigue endurance under tension-tension cyclic loading is given here for typical line components. Reference is also to be made to the relevant requirements of Sec 4.

The fatigue endurance (T-N curve) of a line component is written as:

$$N R^m = K$$

where:

- R : Ratio of tension range (double amplitude) T to a reference load equal to the line minimum breaking strength, unless otherwise specified
- N : Allowable number of cycles under tension range T
- m : Inverse slope parameter of T-N fatigue curve
- K : Constant (for a given component).

The T-N curve used is to be appropriate to the mooring line component and to the type of excitation encountered. Without further information, the T-N curves specified from [9.4.3] to [9.4.5] may be used for mooring line components under pure tension cycles.

The fatigue resistance of the other components is to be evaluated from appropriate sources or by analysis (see Sec 4).

**9.4.3 Chains**

For chains, the reference load is to be taken as the minimum breaking strength of an element of the same diameter but in API-ORQ quality (Oil Rig Quality), whatever is the grade of the element.

Note 1: API-ORQ has lesser mechanical properties than the QR3 grade. For chain grades, reference is made to NR216.

For studlink chain common links, the following parameters of T-N curve may be considered:

$$m = 3$$

$$K = 1000$$

Note 2: See also [12.2.2].

This T-N curve may be assumed to be also applicable to standard end links and to D-shackles (see API RP 2SK:2024).

The fatigue strength of studless chains is lower than for studlink chain. The K parameter is modified as follows:

$$K = 316$$

#### 9.4.4 Wire ropes

The following parameters of T-N curve may be considered:

- for six/multi-strand wire ropes:  
 $m = 4,09$   
 $K = 231$
- for spiral strand wire ropes:  
 $m = 5,05$   
 $K = 166$

Note 1: These data are for a mean load equal to 30% of the rope minimum breaking strength. Fatigue endurance at a higher mean load is lower (see documents referenced in Sec 1, [4.2.3]). This may be given into consideration, where applicable.

Note 2: The above T-N curves do not cover termination sockets. Fatigue of these structures is to be separately evaluated.

#### 9.4.5 Fibre ropes

- a) The fatigue endurance of polyester and high modulus polyethylene (HMPE) fibre ropes may be conservatively assumed to be at least five times the one of a spiral strand wire rope of the same minimum breaking strength, i.e.:

$$m = 5,05$$
$$K = 1000$$

Note 1: Other published curves, with a large slope parameter  $m$ , would lead to unconservative evaluations and are not to be used.

- b) Other types of materials may be used for fibre rope manufacturing, such as nylon.

Further guidance for fibre ropes analysis may be found in NR432.

Attention is drawn to the fact that, in a fibre rope mooring, the adjacent steel components will generally have a fatigue strength significantly lower than the one of the rope itself.

### 9.5 In-plane/out-of-plane bending endurance

9.5.1 The Guidance Note NI604 (see Sec 1, [4.2.2]) gives methodologies, requirements and recommendations to be considered regarding in-plane and out-of-plane bending loadings

9.5.2 T-T cycling, OPB cycling and IPB cycling are to be considered as acting together, unless otherwise documented.

## 10 Selection of design conditions

### 10.1 General

#### 10.1.1 Application

This Article is applicable to design against non-squall events. For design against squall events, see App 4.

10.1.2 For a given design condition, a set of time domain simulations provides a design tension  $T_D$  (see Article [6]) which is a short-term extreme value over the duration of the simulations (3 hours), and for the design condition analysed.

The design tension for each line (or its components) is then to be taken as the maximum value of  $T_D$  obtained from all the relevant design conditions, i.e. all the possible combinations of:

- Unit configurations, see [10.2]
- Metocean parameters, defined from [10.4] to [10.6].

The intact, damaged, and transient mooring system state conditions (see [10.3]) are separately analysed.

### 10.2 Unit state configuration

10.2.1 A unit state condition, i.e. a set of representative configurations of the system is to be selected for analysis so as to cover all the intended situations of operations of the unit and to ensure that the conditions the most onerous for the mooring system have been examined.

This may include:

- variations of the unit draft in relation with operations (e.g. draft of a storage unit) or weather considerations (operating/survival draft)
- connected/disconnected situations between, e.g., a floating offshore unit and an export tanker or between adjacent units (multi-unit systems)
- other relevant conditions.

Note 1: For the analysis of a unit in the offloading conditions, further guidance can be found in the published paper: C. Morandini, F. Legerstee, J. Mombaerts, 2002, Criteria for Analysis of Offloading Operation, OTC-14311-MS.

### 10.3 Mooring system state conditions

#### 10.3.1 General

The mooring system state conditions are as follows:

- Intact condition. It is a condition with all mooring lines and their components, and, where applicable, all thrusters, are intact.
- Damaged conditions, see [10.3.2] to [10.3.4].
- Transient conditions between intact and damaged, see [10.3.5].

#### 10.3.2 Damaged mooring system configurations

The damaged conditions include all the configurations of a mooring system with a single mooring line considered broken (i.e. entirely removed) or where a single thruster system failure has occurred.

Each mooring line is to be removed one at a time to evaluate the line failure leading to the largest characteristic quantity (e.g., tension in an adjacent line, largest offset of the unit).

Selection of the lines to be broken and the load cases to be considered may be based on intact conditions results, to the satisfaction of the Society. As a guidance, for mooring systems made of bundles, the following approach may be considered for each bundle:

- a) Perform a selection of load cases based on critical load cases in intact conditions.
- b) For each selected load case, identify both the most loaded line and the second most loaded line in intact conditions.
- c) The following damaged configurations are to be evaluated:
  - One configuration with the second most loaded line to be considered broken.

Note 1: This configuration typically produces the largest tension in the adjacent line that carried the highest tension in intact condition.

- One configuration with the most loaded line to be considered broken.

Note 2: This configuration typically results in the maximum offset of the unit.

For the **POSA-HR** notation only, as defined in [6.5], the damaged configurations to be considered also include all the configurations with two adjacent mooring lines broken.

Additional requirements are defined in [10.3.3] for thruster system failures and in [10.3.4] for ancillary components failures.

#### 10.3.3 Damaged configurations for thruster system failure

The thruster failure is assumed not to be concomitant with a mooring line failure.

Two cases corresponding to a single failure of the thruster system are to be investigated:

- a) the total loss of one thruster, the other thrusters having two thirds of their maximum thrust capacity available
- b) the loss of half the total thrust capacity.

Note 1: It is possible that a single failure of the thruster system can result in the failure of more than one thruster.

Note 2: For a unit equipped with four identical thrusters, these two cases a) and b) lead to the same remaining thrust capacity.

#### 10.3.4 Damaged configurations for ancillary components

The failure of an ancillary line component (buoy, sinker, clump weights, etc.) is also a damaged condition.

In most cases, such a condition is already covered by the one-line broken damaged condition defined in [10.3.2].

In addition, for the loss of clump weights, sensitivity studies are to be conducted, see [10.8.5].

#### 10.3.5 Transient mooring conditions

A transient analysis for mooring line failure or thruster failure (see [6.4]) is to be performed in the following cases:

- a) when the unit is moored in close proximity to a fixed installation or another floating structure  
In this case, the analysis may, however, be limited to the critical lines (line TYPE I, see [11.1.1]).
- b) for operating conditions with specified metocean limiting conditions as defined in [10.6.1] (e.g. tandem offloading)  
The analysis may, however, be omitted in case of a system with large redundancy, as demonstrated to the satisfaction of the Society (e.g. when an analysis in damaged condition for the same operating situation was far from critical).

In the other cases, the transient analysis may generally be omitted.

When required, the transient analysis is to be performed for the most critical design conditions of the intact mooring system.

### 10.4 Metocean conditions

#### 10.4.1 Metocean data

The metocean data (see NR445, Pt B, Ch 2, Sec 2) are described by the intensity distributions of each element as a function of the return period (marginal distribution of the independent all-direction extremes), and by associated parameters (e.g. spectral shape and peak period, for waves).

Directional data may be used under the conditions specified in NR445, Pt B, Ch 2, Sec 2 and in App 2.

### 10.4.2 Design conditions

The metocean design conditions for a N-year return period (see [10.5] and [10.6]) are to be defined as combinations of intensity and direction of the waves, wind, current and associated parameters.

Depending on the climate, several sets are to be defined, in which one of the elements is generally governing, such as:

- wave (wind sea or swell) governed conditions
- current governed conditions
- concomitant swell and wind sea
- etc.

More detailed information is given in App 2.

### 10.4.3 Combinations of intensity and direction

For each set, the intensity of the elements is to be selected with values depending on the degree of correlation of the extremes, both in intensity and in direction, and on the relative directions between the elements.

For both governing and other elements, scanning on the incoming directions is to be performed, over a large enough range for each, so as to provide the evidence that the maximum response has been caught.

The criteria in App 2 may be considered for guidance, unless more accurate data are available for the site under consideration.

Note 1: In a set of conditions where one element is governing, this element is generally to be taken with an intensity corresponding to the N-year return period. Other parameters are to be taken as “associated values”, with an intensity corresponding generally to a lower return period.

### 10.4.4 Associated parameters

Associated parameters are usually given to obtain a best estimate (or most likely) value.

For the spectral peak (or zero-crossing) period  $T_p$  (or  $T_z$ ) of a sea-state, a range is to be considered around the specified value, as a minimum. For a significant wave height  $H_s$ , response contour ratio  $H_s/T_p$  (or  $H_s/T_z$ ) may be used when available (inverse FORM approach detailed in App 2, [2.3]).

A similar approach may be applied to other parameters, when relevant.

**10.4.5** The same sets of design conditions are typically applicable to both intact and damaged mooring system state conditions. However, the governing conditions may be different.

For transient conditions, see [10.3.5].

## 10.5 Extreme metocean conditions

**10.5.1** For a permanent installation, the extreme metocean conditions to be considered are those corresponding to a design return period N of 100 years, in-line with NR445, Pt B, Ch 2, Sec 2, [4.2.2].

**10.5.2** For mooring systems of installations other than permanent installations (e.g. mobile drilling units, installation units, ...) far away from any other offshore structure, N may be reduced to five times the duration of the operation, without being, nevertheless, taken less than 5 years.

**10.5.3** For mooring systems of installations, other than permanent installations, which are in the vicinity of other structures, N is not to be taken less than 10 years. Special considerations as regards the risk of collision may however require a larger value of N.

**10.5.4** If a unit working alongside another platform can move away and reach a pre-defined stand-off position within a time reasonably compatible with the local metocean forecast, the provisions of [10.5.2] may be applied to the stand-off position. The environmental conditions beyond which the unit is to move away are to be specified in the Operating Manual and taken into account as an operating condition for the mooring system in working position.

**10.5.5** Return periods N defined from [10.5.1] to [10.5.4] apply to manned installations and to offloading buoys. For unmanned installations, criteria are to be defined on a case-by-case basis.

## 10.6 Operating conditions

**10.6.1** The operating conditions, i.e. the limiting metocean conditions for particular operations (e.g. offloading, maintenance, working alongside, etc.), are to be specified either as an envelope of possible combinations of elements, or as a discrete set of conditions. In such a case, the acceptable envelope is to be determined at a later stage, for incorporation in the unit operation criteria, part of the Operating Manual of the unit.

**10.6.2** When the limiting metocean conditions are infrequent, such as 1-year return period conditions or above, the combinations of metocean parameters are to be considered as per [10.4], taking into account the specified return period N.

**10.6.3** For more frequently occurring conditions, the limiting conditions are to be defined by a set of ascertainable limiting values on some metocean parameters. The design operating conditions are then to be established by application of these limiting values to the sets of N-year (extreme) return period conditions.

**10.6.4** For short-duration infrequent operations not requiring particular conditions, the operating metocean conditions, when they need to be considered, may be taken as the metocean conditions with 1-year return period conditions.

## 10.7 Fatigue analysis

**10.7.1** For fatigue analysis, a series of metocean conditions representative of the long-term conditions at the intended site or of the intended operations are to be considered. This series may be time series obtained by adequate hindcasting or may be derived from available statistical data (typically directional scatter diagrams of sea-states or wave systems in multimodal sea-states), combined with wind and current in an appropriate way taking into account joint occurrences.

For each condition selected, the fatigue damage  $D$ , in each segment or component of the lines, is calculated by the Miner sum, taking into account the fatigue capacity (see [9.4]) and the duration of the sea-state.

The fatigue life  $FL$ , corresponding to the duration of exposure for which the cumulative damage (Miner sum) would be equal to 1, is obtained as follows:

$$FL = \frac{L_{ref}}{D}$$

where:

$D$  : Fatigue damage calculated by summation over all the conditions considered, for a reference duration of exposure  $L_{ref}$

## 10.8 Sensitivity studies

**10.8.1** Sensitivity studies are to be performed on all the parameters able to affect the results of the mooring analysis, such as:

- metocean parameters ( $T_p$ , spectra parameters,...)
- line pre-tension
- theoretical anchor point
- dynamic line response (see [5.3] and [10.8.3])
- loss of clump weights (see [10.8.5])

in order to assess the influence of these parameters.

Safety factors for intact case are to be applied for these sensitivity studies.

### 10.8.2 Extreme metocean conditions cases to consider

For extreme metocean conditions, it is recommended that sensitivity studies are carried out at least for the sea states giving a tension higher than 95% of the maximum tension.

### 10.8.3 Dynamic line response for fatigue analysis

As defined in [2.4.2], for fatigue analysis, a dynamic analysis is to be used. In order to use a quasi-dynamic analysis, sensitivity studies are to be performed to assess the influence of the dynamic line response. The following sea states are at least to be considered:

- the top 5% of the sea states sorted by damaging effect
- the sea states contributing to 50% of the total damage.

The line where the maximum damage occurs is to be considered.

The criteria for acceptance of the quasi-dynamic analysis for fatigue is to be agreed with the Society.

**10.8.4** For fatigue analysis, a sensitivity study on the influence of the seeds is to be performed in order to assess the influence of the short-term variability.

It is recommended to consider the sea states defined in [10.8.3] for this sensitivity study.

### 10.8.5 Loss of clump weights

For a mooring system design including clump weights, an additional sensitivity study on clump weight loss around the touchdown point is to be considered.

## 11 Criteria

### 11.1 Mooring lines strength

#### 11.1.1 Type of lines

Two types of mooring lines are defined:

- a) lines of TYPE I are those lines the failure of which leads to a transient response that moves the moored unit towards an installation in close proximity (see Sec 1, [4.1.6]), if any
- b) lines of TYPE II are the lines which are not of TYPE I.

#### 11.1.2 Safety factor

The safety factor SF of mooring line components for mooring line strength verification is defined as follows:

$$SF = \frac{BL}{T_{max}}$$

where:

- BL : Minimum breaking load of the mooring line component, in kN, as defined in Article [9]. By application of [9.3] the corroded breaking load of the mooring line component is to be considered.
- T<sub>max</sub> : Maximum tension, in kN, occurring over the mooring line component length when the design tension T<sub>Dr</sub>, as determined in Article [6], is applied to the fairlead.

#### 11.1.3 Minimum values of safety factors

The safety factors SF calculated in [11.1.2] are not to be less than the values given in Tab 7 for different mooring system conditions and analysis methods defined in Article [2].

Note 1: Tab 7 is not applicable to hawsers. The minimum values for hawsers may be obtained from NR494. The requirements of NR494 are not applicable for the assignment of the notation **POSA JETTY**.

**Table 7 : Minimum values of safety factors for mooring line components**

Mooring system state condition	Method of analysis (1)	
	Quasi-dynamic	Dynamic
Intact (2)	1,75	1,67
Damaged (2)	1,25	1,25
Transient (3) (4)	1,25	1,20
Damaged (two adjacent lines removed) (2) (5)	1,00	1,00

**Note 1:** Base factors are for line type II (see [11.1.1]) i.e. they do not apply to structures in close proximity. See (2) and (4).  
**Note 2:** For fibre ropes, the minimum values of safety factors are to be increased in the rope itself (i.e. not including other parts of the line) as defined in NR432, Sec 7, [4.1.2]. However, on case-by case basis, where materials are certified, their constitutive law behavior identified, additional increase for synthetic ropes may be waived.

- (1) The minimum values given for dynamic analysis may also be used with the results of a quasi-dynamic analysis, after agreement of the Society, when the characterization of the line response has provided a firm evidence of a dynamic amplification factor DAF lower than 1,0 in all the relevant conditions (see App 1).
- (2) Minimum values to be increased by 25% for line type I.
- (3) Applying the methodology in [6.4], and when required.
- (4) Minimum values to be increased by 40% for the most loaded line, following the breakage of a line type I.
- (5) Only for notation **POSA-HR**.

#### 11.1.4 Minimum tension in mooring lines

For fibre rope mooring lines, minimum tensions are to be considered, as defined in NR432, Sec 7, [4.2]. The design tension to be considered in the criteria is defined in [6.7].

#### 11.1.5 Connectors

Connectors are to maintain a positive stability under a low tension and are to be fitted with a locking system.

Note 1: Where applicable, a minimum tension is to be specified, and the device is not to be allowed for use in the touchdown area.

## 11.2 Anchors

#### 11.2.1 Safety factor

The safety factor SF of anchors is defined as follows:

$$SF = \frac{MHP}{T_{a_{seabed}}}$$

where:

- for drag anchors:

MHP : Minimum expected holding power applicable to the mooring site, in kN

T<sub>a seabed</sub> : Tangent-to-the-seabed component of the tension in the line at the anchoring point when the design tension is applied to the fairlead, in kN.

- for driven pile anchors:

MHP : Minimum expected load, in kN, that the pile can withstand, in compliance with the requirements of applicable codes and standards for structural and soil mechanics

T<sub>a seabed</sub> : Tension in the line at the anchoring point when the design tension is applied to the fairlead, in kN.

**11.2.2 Minimum values of safety factors for drag anchors**

For drag anchors, the safety factors SF calculated in [11.2.1] are not to be lower than the values specified in Tab 8.

When the line is submitted to its maximum tension (including damaged condition tensions) at fairlead, if uplift occurs (see definition in Sec 1, [4.1.8]), the following apply:

- For uplift above 0% but below 20%, a reduction of holding capacity is to be considered.

Guidance for holding capacity decrease for an uplift may be found in API-RP-2SK:2024 7.1.2.2 and in ISO 19901-4:2025 Annex A.11.4.6.

- Uplift above 20% may be accepted by the Society on a case-by-case basis. The anchor manufacturer is to justify the holding capacity associated to uplift.

**Table 8 : Minimum values of safety factors for drag anchors**

Condition of system	Method of analysis (1)	
	Quasi-dynamic	Dynamic
Intact (2)	1,60	1,50
Damaged (2)	1,15	1,05
Transient (3) (4)	1,15	1,05

**Note 1:** Base factors are for line type II (see [11.1.1]) i.e. they do not apply to structures in close proximity. See (2) and (4).  
 (1) The minimum values given for dynamic analysis may also be used with the results of a quasi-dynamic analysis, after agreement of the Society, when the characterization of the line response has provided a firm evidence of a dynamic amplification factor DAF lower than 1,0 in all the relevant conditions (see App 1).  
 (2) Minimum values to be increased by 25% for line type I.  
 (3) Applying the methodology in [6.4], and when required.  
 (4) Minimum values to be increased by 40% for the most loaded line, following the breakage of a line type I.

**11.2.3 Minimum values of safety factors for pile anchors**

For long (soft) pile anchors, the minimum values of safety factors SF are defined in NI605, Sec 3.

**11.2.4 Suction anchors and vertical load anchors**

A partial factor verification format is given in NI605, Sec 3.

**11.3 Minimum clearance**

**11.3.1** In any condition, the distance between any part of the moored unit and any external object normally not in contact with the unit is to remain, at a minimum, equal to ten (10) metres.

In any condition, the distance between any point of the mooring line and any external object, either suspended or laying on the seabed, the contact with which could be damageable for either the mooring line or the aforesaid object, is to remain, at a minimum, equal to ten (10) metres.

More stringent requirements may be specified by operators.

**11.3.2** As a guidance, the minimum values for seabed clearances may be obtained as requested or recommended in Tab 9.

**Table 9 : Minimum Clearances between the bottom of the suspended wire of fibre rope and the seabed**

Clearance, rope with seabed		Permanent mooring		Mobile mooring	
		Status	Minimum distance	Status	Minimum distance
Steel wire rope	Intact (mooring, thrusters)	Recommended	> 1 m	Permitted	Owner defined value
	Single failure (mooring, thrusters)	Permitted	Owner defined value	Permitted	Owner defined value
Fibre rope	Intact (mooring, thrusters)	Required (1)	> 1 m	Recommended	> 1 m
	Single failure (mooring, thrusters)	Recommended (1)	> 1 m	Permitted	Owner defined value

(1) See also NR432, Sec 7, [2.3.1]

**11.4 Fatigue life**

**11.4.1** The safety factor in fatigue is specified as a factor on fatigue life.

This safety factor is defined as the ratio between the calculated fatigue life and the design service life of the installation (as defined in NR445, Pt B, Ch 3, Sec 3, [1.2.2]).

The design service life, for a moored unit, is the duration, in years, that this unit is intended to stay on site.

The fatigue life of the mooring lines is to be determined and compared to the design service life of the installation if this latter is greater than 2 years.

**11.4.2** The minimum value of fatigue safety factors for each line component is:

- 10 for anchors and buried parts of the line.
- 3 for all line segments and other components of the line

Note 1: Depending on the consequence of failure of the component and the accessibility for inspection, maintenance and repair, fatigue safety factor larger than 3 may be requested by the Society on a case-by-case basis.

For mooring systems subjected to OPB/IPB fatigue (see [8.3]), the following additional requirements are to be considered:

- when the effect of in-plane/out-of-plane bending or of other local actions is taken into account, the verification criteria specified in NI604 are to be considered, in addition to tension-tension fatigue loading
- a safety factor equal to 10 for tension-tension fatigue is to be applied otherwise in the 5 first chain links after fairlead.

**11.5 Load testing of anchors and mooring lines**

**11.5.1** The load (at fairlead) for the load testing of anchors is to be taken not less than the following values, depending on the anchor type:

a) Drag anchors:

In general, 80% of the design tension  $T_D$  at fairlead, in intact conditions, during at least 15 min.

Higher values of design tension  $T_D$  may be required, up to 100%  $T_D$ , if the mooring line pretension is sensitive to anchor drag, or if the risk of partial embedment or lack of embedment in successive soil layers is high.

b) Vertical load anchors (VLA):

as required to achieve target penetration and related holding capacity

c) Pile anchors and suction anchors:

as for the mooring lines, as specified in [11.5.2].

As per [12.5]evidence is to be provided to demonstrate that target penetration and holding capacity have been achieved.

**11.5.2** The load for the load testing of mooring lines is to be taken not less than the following values, depending on the line type:

a) Steel lines (chains or wire ropes):

the specified pretension, slightly increased (10% minimum is recommended) in order to ensure correct setting of the assembly

b) Fibre ropes:

at least the same specific tension as for steel lines, or alternatively an appropriate cycling. This tension is also to be limited to a percentage of rope minimum breaking strength, as defined in NR432, Sec 7, [5.1.4].

## **12 Installation and service conditions**

### **12.1 General**

**12.1.1** Installation, repairs, maintenance and inspection operations may be considered during mooring system design. This may imply additional connectors or other equipment that was not used/described in the global analysis model.

### **12.2 Chains and standard fittings**

**12.2.1** Deployment of the lines is to be performed in such a way as to avoid jamming on the bottom and accumulation of twists that may result in damage to the chain itself or to other components when the line is tensioned.

**12.2.2** Attention is drawn to the fact that fatigue performance of a stud link chain might be significantly decreased in the case of lost studs. The T-N curve given in [9.4.3] applies to links with tight studs.

**12.2.3** Attention is also to be given to the risks of bending fatigue for chains over stoppers, bending shoes of fairleads (see also Sec 4, [8.2.6]). Where possible, regular and frequent adjustments of the mooring lines are to be carried out in order to mitigate accumulation of fatigue damage in the lines at these locations.

### **12.3 Steel wire ropes**

**12.3.1** Unless periodical renewal is planned, the use of wire ropes is also to be avoided in the splash zone of long-term moorings. Attention is also to be given to the risks of bending fatigue of wire ropes over fairleads. Where possible, regular and frequent adjustments of mooring lines are to be carried out in order to mitigate the accumulation of fatigue damage in the lines at these locations.

**12.3.2** Deployment of the lines is to be performed in such a way as to avoid:

- damage caused by over-bending or chaffing over obstacles
- over-bending in free span, by permanent suitable minimum tension
- excessive bending at terminations, if necessary by provision of bending restrictors
- accumulation of twists, particularly in case of a non-torque compliant structure
- any damage to sheathing (when provided).

### **12.4 Fibre ropes**

**12.4.1** Deployment of the fibre rope lines is to be performed as per NR432, Sec 7, [5.1].

**12.4.2** The service conditions of the fibre ropes are to be as specified in NR432, Sec 7, [5.2] to [5.4].

### **12.5 Anchoring devices**

**12.5.1** Installation on site of the anchoring devices is to be performed under survey of the Society (see Sec 1, [2.5]).

The installation procedures for anchor setting and pre-loading are to be submitted in advance, for review by the Society.

Load testing of anchors and mooring lines is to be performed as required in [11.5].

The installation records, with the related analyses, as needed, are to provide evidence that target penetration and holding capacity have been achieved.

### **12.6 Ancillary components**

**12.6.1** Failure in the functioning of any of these components is to be considered in the design of the mooring system as a damaged case.

**12.6.2** Arrangements are to be made to ensure the integrity of the mooring system at any time. These arrangements are to be submitted to the Society for review.

### **12.7 Transit**

#### **12.7.1 General**

During navigation, the designer is to ensure that all the detachable parts are adequately locked in position by passive means.

# Section 4 Components of Mooring System

## 1 General

### 1.1 Scope

1.1.1 The components under consideration in this Section include:

- main line components, such as:
  - chain cables and standard fittings
  - steel wire ropes and terminations
  - fibre ropes
- non-standard fittings and connectors
- anchors
- items fitted on units at ends, such as fairleads and stoppers
- ancillary components, such as buoys, sinkers, clump weights
- monitoring system.

1.1.2 Compliance with the requirements of this Section is mandatory for the assignment of POSA notations.

1.1.3 Deck appliances (winches and windlasses) are excluded from the scope of notations **POSA** and **POSA-HR**. For units assigned one of these notations, winches or windlasses used as stoppers are to be given special consideration.

1.1.4 For mobile units assigned the notation **POSA MU**, components such as winches and windlasses may be under consideration. The complete scope of this notation is detailed in Sec 5.

1.1.5 For units assigned the notation **POSA JETTY**, components such as release hooks may be under consideration. The complete scope of this notation is detailed in Sec 6.

### 1.2 Application

1.2.1 The purpose of this Section is to provide Class requirements related to the components of a mooring system.

## 2 General requirements

### 2.1

2.1.1 This sub-article [2.1] gives general requirements for all the mooring components. The particular requirements for each type of mooring components are given in Articles [3] to [9], in terms of:

- design
- fabrication and testing (at works or on board)
- installation and service conditions.

#### 2.1.2 Rules and related documents

Reference is made to the Rules and related documents specified in Tab 1, as applicable to particular items, depending on their type of construction (such as forged, or cast).

#### 2.1.3 Designation

The components of a mooring line are to be defined by the minimum breaking strength for which the item is designed and tested, and by other relevant parameters as specified in Articles from [3] to [9].

Note 1: a mooring line component minimum breaking strength can be defined as the design breaking strength of the component or the minimum breaking strength of a component directly connected to it, when lower.

#### 2.1.4 Manufacturing, testing and certification

Manufacturing and testing of the components of a mooring system are to be performed according to the applicable provisions of the Rules, and under survey of the Society.

Parts of mooring line components where minimum breaking strength is relying on material plastic capacity and hardening are to be proof-loaded and minimum breaking load tested. The actual design breaking strength is to be justified before any tests by proper strength computation.

Forgings and castings are to comply with the provisions of NR216 Ch 10 Sec 4.

Load tests performed on the mooring line component, either as part of the Rules requirements or following manufacturer's inspection and testing procedures, are to be witnessed by a Surveyor of the Society.

**2.1.5 Type approval**

Except when specified in Articles from [3] to [9], mooring lines components can be either type approved or designed for a specific project. Type approval of mooring components is recommended by the Society, in particular for serial products.

Type approval is to be performed according to requirement of this Section and to NR320.

For type approval, the documentation of design is to be submitted for review, and manufacturing and testing of the prototype items are to be performed under survey of the Society, as required for the items under consideration.

Note 1: The range of sizes, or other parameters for which approval is granted, is/are to be specified at the time of approval.

For a particular project, once an item is type-approved:

- the documentation of design may be limited to the project specific information and to the adequacy of the item for the intended project
- the provisions of [2.1.4] are applicable to manufacturing and testing of the item for the intended project.

**Table 1 : Rules and related documents or standards**

Item	Defined in	Rules and related documents (1)
General requirements	[2.1]	NR216, NR445, NR426 and NR266, item L20. Other Rules and publications of the Society, as applicable
Chains and standard fittings	Article [3]	NR216, Ch 10, Sec 4
Steel wire ropes	Article [4]	API RP 2SK:2024 ISO 10425:2023 and ISO 2408:2018
Fibre ropes	Article [5]	NR432, NR494, OCIMF-MEG
Non standard fittings	Article [6]	NR216, Ch 10, Sec 4
Anchoring devices	Article [7]	NR216, NI605 and NR426 NR445, Pt B, Ch 3
Items at unit-side end	Article [8]	Ch 3, Ch 4 and Ch 5 of NR216 NR445, Pt B, Ch 3 NR426 and NR467
Ancillary components	Article [9]	NR216 and NR445
(1) See references in Sec 1, [4.2].		

**3 Chains and standard fittings**

**3.1 General**

**3.1.1** The items covered by Article [3] are chain common links, connecting common links, enlarged links and end links.

Note 1: Standard D-shackles are not allowed as not being designed for long term mooring (LTM) application . LTM shackles are considered as non standard fittings, see Article [6].

**3.1.2 Kenter and Baldt links**

The use of Kenter and Baldt links is not allowed for permanent mooring lines, for fatigue strength and durability reasons.

**3.1.3 Rules and related documents or standards**

Reference is made to the Rules and related documents specified in Tab 1.

**3.2 Designation**

**3.2.1** Chain and accessories are to be defined by:

- their type (related to a recognized standard)
- their grade
- their nominal diameter
- their minimum breaking load.

Note 1: For accessories, the nominal diameter is the nominal (bar) diameter of the corresponding chain.

### 3.3 Design

#### 3.3.1 Design documentation to be submitted

Drawings detailing the design of chain and accessories are to be submitted for review at the time of approval.

Fatigue documentation is to be submitted for review, see also [6.2.4].

#### 3.3.2 Dimensions

The dimensions of stud link chains, studless chains and standard fittings are to be as per NR216 for typical designs.

#### 3.3.3 Materials

NR216, Ch 10, Sec 4 gives specification for Chains and standard fittings materials.

The use of ORQ grade is not permitted within the framework of notations **POSA**, **POSA-HR** and **POSA JETTY**. However, this grade may be allowed for non-permanent mooring systems such as mobile units within the framework of the notation **POSA MU**.

Grades higher than QR5 are to be given special consideration.

### 3.4 Manufacturing and testing

#### 3.4.1 General

NR216, Ch 10, Sec 4 gives the requirements and specifications to be applied for manufacturing, testing and examination of Chains and standard fitting.

#### 3.4.2 Manufacturing

Chains and standard fittings are to be manufactured only by manufacturers approved by the Society for the intended product.

#### 3.4.3 Load tests

Each chain link or standard fitting is to be tested at a proof load PL depending on the minimum breaking strength MBS and the specified material grade. NR216 give the ratio PL/MBS to be considered.

Break load tests are to be carried out.

Note 1: Items that have been subject to a break load test are generally to be scrapped.

## 4 Steel wire ropes

### 4.1 General

#### 4.1.1 Scope

Article [4] deals with the steel wire ropes intended for use as mooring lines and their associated termination fittings.

#### 4.1.2 Standards

Reference may be made to the standards specified in Tab 1.

### 4.2 Designation

4.2.1 Steel wire ropes are to be defined by:

- nominal diameter
- sheathed diameter when relevant
- construction type
- wire class (minimum ultimate tensile strength)
- minimum breaking strength

### 4.3 Design of steel wire ropes

#### 4.3.1 Design documentation to be submitted

As a minimum, the following documents or information are to be submitted for review:

- reference standards
- rope construction drawing and specification
- wire specification
- specification of the other materials (galvanic coating, blocking compound, sheathing)
- calculation of wire rope static strength
- documentation on torque properties (tension induced torque and torque compliance)
- cathodic protection calculations
- fatigue analysis for the intended application.

### 4.3.2 Construction

Rope constructions considered in this Rule Note include:

- six-strand construction (with steel core)
- multi-strand construction
- spiral-strand construction (including half-locked and full locked coils).

### 4.3.3 Protection

Protection against corrosion and resistance to wear is to be provided, including at least:

- wire galvanisation or equivalent
- blocking compound.

Complementary protection by one or several adequate means is to be provided as necessary, considering the service conditions and the intended life time. This may include means such as:

- selection of the type of construction and wire profile
- improved galvanic coating
- sacrificial anode wires
- sheathing

Note 1: T-N data in Sec 3, [9.4.4] are valid only when a suitable corrosion protection is provided.

Durability of wire rope is considered as per its construction type and provisions of API RP 2SK:2024

### 4.3.4 Strength

The calculated breaking strength is to be not less than the specified minimum breaking strength (see also [4.5.2]).

## 4.4 Design of terminations

### 4.4.1 Design documentation to be submitted

As a minimum, the following documents or information are to be submitted for review:

- drawings of termination fittings
- specification of materials
- strength and fatigue evaluations
- corrosion protection drawings and calculations
- details of electrical insulation and data sheets of relevant materials
- drawings of connection to ropes
- specification of socketing material
- socketing procedures.

### 4.4.2 Design requirements

Terminations are to be designed in accordance with the requirements given in Article [6].

The termination strength is to be not less than the specified minimum breaking strength of the wire rope (see also [4.5.2]).

Terminations are to provide an effective electrical isolation between the wire rope and the other parts of the mooring line.

Termination fittings are to be provided with cathodic protection, at a level consistent with the protection level of the wire rope.

## 4.5 Manufacturing and testing

### 4.5.1 Manufacturing

The following documents or information are to be provided prior to manufacturing for review and approval of the manufacturing process:

- reference standards
- manufacturing procedures
- process monitoring system and traceability
- procedure for connection of terminations to rope
- sheathing procedure
- repair procedures
- rope sampling procedure
- sample test procedures and acceptance criteria.

Inspection and test plan is to be provided prior to production start for review and marking by Surveyor.

After production and prior to rope final certification, the following documents is to be provided for review:

- process monitoring record
- steel rod raw material certificates
- individual wires records
- manufacturing documentation of termination as per Article 5
- certificate of conformity of termination after inspection during manufacturing
- records of connection of terminations to rope
- rope sample load test reports.

### 4.5.2 Break load test

A break load test is to be carried out on a sample of the wire rope and its terminations, taken from the production under survey.

The sample is to withstand the specified minimum breaking strength.

In case the sample fails to withstand the specified minimum breaking strength, additional documentation and inspection on failed sample and detailed retesting procedure and criteria will have to be provided to the Society for review prior to retesting. Additional testing may be requested by the Society.

## 5 Fibre ropes

### 5.1 General

#### 5.1.1 Scope

Article [5] is applicable to fibre ropes intended for use as anchoring lines and covers both fibre rope and termination thimbles.

Note 1: For mooring hawsers, see NR494, Sec 4, [5].

#### 5.1.2 Rules and related documents

Fibre ropes are to comply with NR432.

#### 5.1.3 Designation

Fibre ropes are to be defined by their minimum breaking strength, the material type and their diameter or rope size.

#### 5.1.4 Approval

Fibre ropes are to be type-approved by the Society, according to NR432, Sec 2.

Note 1: Type approval is based on full size testing of a prototype rope having the specified minimum breaking strength.

Termination thimbles other than steel roller thimbles (spools) are to be in accordance with Article [6].

### 5.2 Design

#### 5.2.1 The fibre rope is to be identical to the approved rope.

Termination thimbles are to be made of the same type of material (steel), the same groove profile and the same inside diameter (within  $-0/+10\%$ ) of those used for prototype testing.

#### 5.2.2 Fibre ropes are not to be used in lines including six-strand wire ropes or other non-torque-balanced components, unless a torque-matched construction is provided.

### 5.3 Manufacturing and testing

#### 5.3.1 Manufacturing and testing of fibre ropes are to be performed in accordance with Rule Note NR432, under survey of the Society.

#### 5.3.2 Thimbles are to be manufactured and tested in accordance with the provisions of Article [6].

However, load tests may be omitted for steel roller thimbles (spools), when a thimble of the same material, and with the same or proportional dimensions, has been tested together with the rope, at the time of rope approval, for a similar or greater minimum bending strength.

## 6 Non standard fittings

### 6.1 General

#### 6.1.1 Scope

Article [6] addresses fittings for connection between line elements, having general dimensions or use deviating from those given in the Rules or recognised standards, such as:

- special links
- Shackles with LTM design
- H-links (straight and twisted)
- tri-plates
- connectors (for underwater connection)
- termination fittings for wire ropes
- termination thimbles (special type) for fibre ropes (see Article [5])
- in-line tensioner.

#### 6.1.2 Rules and related documents

Article [6] primarily addresses fittings made of cast steel or forged steel, or machined from steel plates, for which reference documents are specified in Tab 1.

#### 6.1.3 Designation

Fittings are to be defined by their minimum breaking strength and, as relevant, the nature and nominal dimensions of the items they are intended to connect.

For items connecting ancillary line elements, the minimum breaking strength of the attached elements is also to be specified.

#### 6.1.4 Type approval

Fittings that are not purpose-designed for a specific system are to be type-approved by the Society according to the requirements of this Section.

Fittings that are purpose-designed for a specific system are to be approved in accordance with this Article [6].

## 6.2 Design

### 6.2.1 Design documentation to be submitted

As a minimum, the following documents or information are to be submitted for review:

- drawings with the detailed design of the fittings and all the parts made by, or supplied through, the manufacturer
- specification of materials
- strength and fatigue evaluations
- corrosion protection drawings and calculations, where relevant.

### 6.2.2 Material

Material is to be specified with reference to a recognized standard, with details of chemical composition and heat treatment.

Materials of shackles and other chain-like accessories are to be in accordance with the provisions of NR216, Ch 10 Sec 4.

Materials of other components are to be in accordance with the applicable requirements of NR216, depending on their manufacturing process. In such case, the material specification is to be submitted to the Society for approval. Additional documentation may be required to justify that the material properties and the strength of the component are equivalent to those of the mooring chain it is attached to.

Hardness properties and toughness properties obtained by conventional tests such as Charpy V-notch and crack tip opening displacement tests are to fulfill the properties of the mooring line component they are connected to. Design temperature, unless otherwise specified, is to be considered equal to 4°C.

For components assembled by welding, material weldability is to be justified by proper testing and welding procedures are to be qualified.

The component is considered as a special category component as defined in NR445. Moreover, this component is to fulfill the NDT and Charpy-V Notch requirements.

Toughness requirements based on Charpy-V notch impact testing are given in the applicable requirements of NR216 depending on type of metallic product. In addition, for structural part and part welded to offshore unit toughness requirements given in NR445, Pt B, Ch 3, Sec 2, [3] applied. See also the items at the unit-site end in [8.2.3].

NDT requirements of metallic products are given in relevant section of NR216, Ch 10, Sec 4, for offshore mooring accessory.

For components assembled by welding, the NDT requirements for welds are given in NR426, Sec 5, [2].

Material selection is to be compatible with other materials present in the equipment and adequate for underwater marine chloride environment. When using stainless steel components, appropriate material selection is to be considered.

### 6.2.3 Strength

Strength is to be documented by appropriate calculations, in accordance with the provisions of App 3.

In case strength evaluation is based on elastic computations, plastification is to remain limited to small local zones and stress redistribution in the rest of the structure is able to sustain mooring loads.

The compressive stresses resulting from contacts are to be less than  $1.9\alpha R_f$  (see App 3, [1.3] for the definitions of  $\alpha$  and  $R_f$ ).

If the elastic design criteria are not complied with, elasto-plastic evaluation of the structure is to be performed according to App 3, [1.4].

As a rule, the design of the fittings is to be assessed considering a corrosion margin. See also Sec 3, [9.3].

For components assembled by welding, no plastic strain is allowed in welds under all design conditions.

### 6.2.4 Fatigue

Resistance to fatigue is to be documented for installations intended to stay moored on site for a period longer than two years.

Fatigue resistance is to be determined with reference to the data for the line components (see Sec 3, [9.4]) and, as a rule, is not to be lower than the fatigue resistance of the main line components of the mooring line.

### 6.2.5 Protection

Fittings are to be protected against corrosion by adequate means, such as cathodic protection, coating and/or corrosion thickness margins. Fitness-for-purpose and protection performances are to be documented.

For high yield strength materials, attention is however to be given to the risk of hydrogen-induced stress cracking.

Any welding operation is to be carried out according to a qualified procedure with a limitation of hardness value according to a recognised standard accepted by the Society.

Electrical insulation of connectors is to be provided, as applicable.

## 6.3 Manufacturing and testing

### 6.3.1 Manufacturing

The following documents or information are to be submitted in due course:

- reference standards
- quality and test plans with proposed witness points for the Surveyor
- fabrication and testing procedures and records.

### 6.3.2 Qualification

For forged or casted items, the manufacturer is to be recognized and approved by Society for the forging/casting of mooring components with intended material specifications and size range.

For steelworks items, the manufacturer welding procedures are to be qualified

### 6.3.3 Load tests

When mooring line component is relying on component plasticisation and hardening for its breaking strength, load tests are to be performed on actual component production to ensure its strength, as per NR216, Ch 10, Sec 4.

- all components are to be tested until a proof load corresponding to the proof load of the chain component is to be connected to, or to the equivalent chain proof load (in term of material and MBL)
- one component per production batch is to be load tested until component minimum breaking load. This item is generally scrapped.

For small production batches (less than 5 items), consideration can be made to perform mechanical testing on break load tested item, provided presence on the component of representative material areas that have sustained only limited plasticisation. These areas are to be confirmed during design review of strength computations.

Otherwise, component strength is to be tested by proof-loading only or alternative solutions.

For type approval, tests are to be performed on a prototype item as per NR216, Ch 10, Sec 4. Consideration is to be given on tests made for certification of a range of size of an item, provided proportionality of dimensions.

For components assembled by welding such as in-line tensioners, and when the components remain in elastic domain at breaking strength except compression strain limited to contact zone, break load tests may be waived. Proof load tests may also be waived except if proofloading is required for justifying extreme or fatigue strength of the component it connected to.

## 7 Anchoring devices

### 7.1 General

#### 7.1.1 Scope

Article [7] covers all anchoring devices for permanent and mobile offshore mooring. Temporary mooring solutions are excluded from this scope.

### 7.1.2 Designation

The anchoring devices are to be defined, as a minimum, by the required ultimate holding capacity and the related uplift angle at anchor lug.

When required to verify the design (see [7.2]), the details of the loads in each design condition are also to be specified.

### 7.1.3 Approval

The drag anchors and the VLA's are to be type-approved by the Society on the basis of this Rule Note.

Note 1: The type approval is generally delivered for a specified range of sea bottom conditions.

Note 2: The other types of anchoring devices are generally approved for the particular application for which they are specifically designed.

## 7.2 Design

### 7.2.1 Design documentation to be submitted

As a minimum, the following documents or information are to be submitted for review, as applicable to the type of anchoring device:

- specification of design soil conditions (for type approval), and documentation on the conditions at the testing site (see [7.2.7])
- documentation on the site conditions (see NR445, Pt B, Ch 2), including the study of possible geo-hazards
- design loads at anchor lug, with the details of derivation from the loads in line at sea bottom
- loads/design conditions at the time of installation
- drawings with the detailed design of all the parts made by, or supplied through, the manufacturer
- geotechnical strength evaluations, and supporting test reports
- specification of materials
- strength and fatigue evaluations
- corrosion protection drawings and calculations.

### 7.2.2 Geotechnical design

The geotechnical ultimate capacity of an anchoring device is to be documented, as per [7.2.7] to [7.2.9] and as per NI605 Geotechnical and Foundation Design.

For type approved anchors, an evaluation of the feasibility of recognized anchoring device is to be performed for the intended location and soil properties.

Cyclic loading and soil set-up time are to be considered in anchor selection and dimensioning.

### 7.2.3 Materials

Materials are to conform with the applicable requirements of NR445, Pt B, Ch 3, Sec 2 and of NR216 (for offshore grades), taking into account the design temperature and the structural categories, as defined in [7.3.2].

### 7.2.4 Strength

Strength is to be documented by appropriate calculations, in accordance with the provisions of App 3.

Anchor pad-eye, shank, and adjacent structure are to be designed to withstand the minimum breaking strength of the line.

The anchor body is to be able to withstand the ultimate holding capacity of the anchoring device (see Sec 3, [11.2] and NI605), with deformations within such limits that they do not impair anchor geotechnical capacity. See also [7.2.7] to [7.2.9].

### 7.2.5 Fatigue

Resistance to fatigue is to be documented for installations intended to stay moored on site for a period longer than two years.

The data referenced in [6.2.4] may be used as a guidance for the purpose of type approval.

For a given project, the achieved fatigue life is to be documented.

Sec 3 gives the requirements for fatigue analysis.

### 7.2.6 Protection

Anchoring devices are to be protected against corrosion by adequate means.

When the geotechnical capacity of the anchor is relying on skin friction between soil and steel, the condition of the steel surface is to be consistent with the assumptions made at the time of design.

Note 1: Where appropriate, protective coating is to be avoided in the relevant area of the anchor.

If the steel structure under the mudline is not protected against corrosion, a minimum corrosion margin of 0,1 mm/year per metal face exposed to the soil is to be considered (see NI605, Sec 3, [1.4.2]).

### 7.2.7 Particular provisions for drag anchors and Vertical Load Anchor (VLA)

Geotechnical behaviour of drag anchors and VLA's is to be documented through testing of prototype anchors in representative soil conditions.

Complementary analysis, where applicable, may be used.

For VLA's, the relations between achieved penetration (and related load), soil parameters, and ultimate capacity of the anchors are to be established and documented through these tests.

The anchor body is to be able to withstand the minimum expected holding power (ultimate holding capacity) computed as per Sec 3, [11.2]. This case is to be considered as a load case 3 (accidental), with respect to the strength criteria of NR445, Pt B, Ch 3.

### 7.2.8 Particular provisions - Suction piles

Geotechnical capacity of suction piles may be established by analysis, with due consideration for the potential modes of failure under the combination of the vertical load, horizontal load, overturning moment and torsional moment.

In strength evaluation, due attention is to be given to the followings:

- the buckling resistance of the anchor body with respect to the under-pressures generated by suction effects, at installation, in service, or for retrieval
- the loads generated during installation and retrieval.

Additional requirements and detailed methodology are given in NI605.

### 7.2.9 Particular provisions - Anchor piles

The design of long (soft) anchor piles may be documented in accordance with recognised procedures, such as those specified in NI605, where:

- the pull-out capacity (axial load) and the strength under lateral load can be evaluated separately
- the strength of the pile under lateral load is assessed considering factored loads (e.g. as per NI605), with load factors taken as per Sec 3, Tab 8.

Additional requirements and detailed methodology are given in NI605.

## 7.3 Manufacturing

### 7.3.1 Manufacturing

Manufacturing of anchoring devices is to be performed under Survey of the Society, in accordance with the relevant requirements of:

- NR445, Pt B, Ch 3
- NR216, Chapter 5 and NR216, Chapter 6
- NR426.

### 7.3.2 Structural categories and design temperature

For the selection of materials, and the definition of fabrication and NDT requirements, the following elements are to be considered as belonging to the following structural categories (as defined in the NR445, Pt B, Ch 3, Sec 2):

- pad-eye, shank, and adjacent structure are to be considered as 'special category' elements
- the other parts of the anchor body are to be considered as 'first category' elements.

A design service temperature of 4°C is generally to be considered for anchoring devices in deep waters. In the other cases, the design temperature is to be specified.

## 8 Items at the unit-side end

### 8.1 General

#### 8.1.1 Scope

Article [8] covers the items intended to guide and secure the anchoring lines at their end on board units, such as:

- fairleads or bending shoes
- stoppers
- supporting structures for connection of the above items to the unit hull.

Note 1: The foundations of these items into the hull (or turret, as applicable) are covered by the main Class of the unit (see also [8.2.5]).

Note 2: For winches, windlasses and other deck appliances, see [1.1.3].

#### 8.1.2 Designation

The items are to be defined by the nature and nominal dimensions of the line segment they are intended to support, and the related minimum breaking strength.

#### 8.1.3 Approval

The items are generally approved for the particular application for which they are specifically designed.

The standard items may be type-approved by the Society on the basis of the requirements of Article [8] and the relevant Sections of the Rules and related documents.

## 8.2 Design

### 8.2.1 Design documentation to be submitted

As a minimum, the following documents or information are to be submitted for review, as applicable to the type of item:

- drawings of arrangement, construction, and mechanical components, with the detailed design of all the parts made by, or supplied through, the manufacturer
- design loads and other relevant design conditions
- detailed structural drawings
- specification of materials
- strength and fatigue evaluations
- documentation on mechanical components
- documentation on interface loads
- interface drawings
- corrosion protection drawings and calculations.

### 8.2.2 Design conditions

The items are to be designed to withstand the mooring line they are intended to support under the two following conditions:

- the design tension  $T_D$ , as defined in Sec 3, [6], for each mooring system condition, considering intact and damaged conditions as design cases and, when relevant, transient condition as accidental case
- the design breaking strength of the weakest mooring line element plus the weight of the mooring line suspended between the upper end of this element and the fairlead considered as an accidental case.

Note 1: For type approval,  $T_D$  is to be taken as the design breaking strength divided by the minimum value of safety factor for mooring line strength integrity as specified in Sec 3, [11.1].

For items supporting the suspended part of the line, due attention is to be given to the range of orientation of the line load resulting from tolerances in system geometry, unit offset and unit motions, in addition to those resulting from possible configurations or predicted by mooring analysis.

### 8.2.3 Materials

Materials used at the unit-side end are to conform to NR216 and to NR445, taking into account their structural categories and design temperature, as defined in [8.3.2].

Note 1: for materials used in deck equipment of units with **POSA JETTY** notation, their grades are to conform to NR467 and to NR216.

### 8.2.4 Strength

Strength is to be documented by appropriate calculations, in accordance with the provisions of App 3.

The items are to be designed to withstand the loads specified in [8.2.2].

Strength criteria are provided in App 3.

The parts supporting mechanical components are to have, under the highest design tension  $T_D$ , deformations within such limits that they do not impair the integrity of mechanical components.

For items assembled by welding, no plastic strain is allowed in welds under all design conditions.

### 8.2.5 Interface with unit structure

Loads and load distribution at the interface with the unit structure are to be documented.

Interface arrangement and weld details are to be specified, in a manner consistent with the arrangement of unit underdeck structure, in order to ensure suitable structural continuity. Attention is to be given to thickness transitions between materials of different strengths.

### 8.2.6 Fatigue

Resistance to fatigue of the items and of the interface connections is to be documented.

The data referenced in [6.2.4] may be used as a guidance for the purpose of type approval.

For a particular project, the achieved fatigue life is to be documented and in accordance with the relevant requirements of Sec 3.

Possible detrimental interaction with the mooring line is to be assessed and taken into account for the design of the upper segment of the line, as well as for the design of the item itself.

In this respect, attention is to be given to:

- minimise out-of-plane bending in chain
- locked-in modes that may arise due to friction between the suspended part of the line and the unit body.

**8.2.7 Mechanical components**

The mechanical components are to be of a suitable type with respect to the functional requirements (e.g. low friction properties) and durability in marine environment/seawater.

The mechanical components are to be able to withstand the internal loads induced by the design breaking strength in the line, and to operate under the highest design tension  $T_D$  in the line.

The parts requiring replacement are to be identified, and the criteria specified.

**8.2.8 Protection**

Protection against corrosion and wear is to be provided by adequate means.

For the submerged items, consideration may be given to a complementary cathodic protection (when electrical bonding is provided to benefit from hull cathodic protection system), or an independent protection.

**8.3 Manufacturing and testing****8.3.1 Manufacturing**

Manufacturing of the items is to be performed in accordance with the relevant requirements of:

- NR445, Pt B, Ch 3
- NR216
- NR426.

**8.3.2 Structural categories and design temperature**

For the selection of materials, and the definition of fabrication and NDT requirements:

- principal load bearing items and adjacent structure are to be considered as 'special category' elements
- the other parts of the item body may be considered as 'first category' elements
- the design temperature is to be specified, and taken not higher than the design air temperature for the unit. The seawater minimum temperature at depth of the equipment is however to be considered for the permanently submerged parts.

**8.3.3 Testing and installation on board**

The installation on board of items is to be performed under survey of the Society.

Interface welds are to be considered as 'special category' elements (100% NDT).

NR426 gives specific recommendations for surveys of such steel structures.

Functional testing is to be performed in workshop, as far as practicable, and, after installation on board, following an agreed program.

**8.3.4 Testing of chain stoppers**

Chain stoppers are to be proof load tested to evaluate their proper functioning under load from chain, and to ensure the absence of any defect by inspection after proof load test.

Proof load test may be dispensed, providing that:

- no main load bearing structure is working in tension (exception is to be made for parts of the structure close to contact area)
- non-linear analysis is performed as per App 3 to demonstrate that failure in way of local high stress is not foreseeable.
- the chain stoppers working in tension remain in elastic domain at breaking strength, with a tolerance on compression strain to be limited to contact zone.

Break load testing is not required for chain stoppers.

**9 Ancillary components****9.1 General**

**9.1.1** Article [8] is addressing ancillary components such as buoys, sinkers and their connections, that are permanent parts of the mooring system (see Sec 1, [2.4.1]).

Attention is to be paid to the following potential issues:

- wear
- degradations, such as corrosion and loss of pretension in bolting
- local fatigue
- impact loads.

**9.1.2** Design methodology and criteria are to be submitted for review during design assessment. These are to be in line with recognized standards and integrate failure modes identified through risk assessment and return of experience on similar components. As a rule, the ancillary components design criteria are to comply at least with App 3.

Drawings, design calculation notes and material specifications are to be submitted to the Society.

Based on this documentation, additional calculations and tests may be required.

**9.1.3** Surveys during manufacturing and testing, as agreed during design assessment, are to be carried out to the satisfaction of the Society.

As a rule, these are to fulfill the requirements of NR216 and of NR445.

## 10 Monitoring system

### 10.1 Load monitoring system

**10.1.1** For permanent mooring, such as fibre rope moorings (usually in deep-water), and other cases where checking of the line pretensions cannot be achieved by conventional methods, a permanent load monitoring device is to be fitted on each line, for verification of the line pretensions at the time of the periodical surveys.

The control system may include the transmission of line failure detection system, or the capability for continuous recording over some time, e.g. for re-tensioning operations.

Alternative solutions may be considered on a case-by-case basis by the Society and are to be integrated in the mooring inspection philosophy (see Sec 2).

**10.1.2** The tension data in each mooring line are to be continuously monitored and available on board the unit by appropriate means. The load monitoring system is to be approved by the Society.

**10.1.3** For jetty mooring lines, monitoring for each line may not be requested.

# Section 5 Mooring of Mobile Units

## 1 General

### 1.1 Application

**1.1.1** The purpose of this Section is to provide Class requirements with a view to the assignment of the notation **POSA MU** to a mobile offshore unit.

**1.1.2** The notation **POSA MU** covers the stationkeeping system of mobile units, such as surface and column-stabilized MODUs, in compliance with the IMO MODU Code requirements related to anchoring arrangements. The mooring systems are to be capable of being retrieved for regular inspections out of the water.

### 1.2 Applicability and limits

**1.2.1** The notation **POSA MU** covers the stationkeeping systems of spread mooring type, which are principally passive systems. This notation covers also:

- all the possible types of anchoring patterns, line make-up, and materials
- the thruster-assisted mooring, if any.

**1.2.2** The notation **POSA MU** covers all the outboard elements of the mooring system (see Sec 1, [2.4.1]).

**1.2.3** The notation **POSA MU** covers also:

- the fairlead stoppers on the unit (in whole, i.e. including unit-side female support parts)
- any associated monitoring and control systems
- the deck appliances (winches and windlasses).

### 1.3 In-service surveys

**1.3.1** The surveys of the mooring system of units assigned with the notation **POSA MU** are to comply with the provisions of Sec 2.

**1.3.2** Mooring components are to be inspected on board as per Sec 2. Registrations of component usage are to be kept on board and made available to the Surveyor for review at each annual survey.

### 1.4 General requirements

**1.4.1** The design of the mooring system is to be in accordance with the provisions of the notation **POSA**. Deviations from these provisions and additional requirements due to the mobile unit specificities are detailed in the present Section.

## 2 Design

### 2.1 Environment

**2.1.1** Mobile units may have different areas of operations. The design metocean data are to be provided by the party applying for the classification. These assumptions are to be listed in the Design Criteria Statement (see NR445, Part A).

The site assessment is to be conducted by the party applying for the classification in order to ascertain that the actual conditions met at the contemplated operating site remain on the side of safety when compared to the design data and assumptions, particularly those listed in the Design Criteria Statement.

ISO 19905 series 'Petroleum and natural gas industries — Site-specific assessment of mobile offshore units' gives specific requirements regarding site-specific assessment of mobile offshore units.

**2.1.2** As specified in Sec 3, [10.5.2], the extreme metocean conditions may be considered as corresponding to a return period  $N$  equal to five times the duration of the operation, provided  $N$  is never taken less than 5 years.

For the mooring systems in the vicinity of other structures,  $N$  is not to be taken less than 10 years.

### 2.2 Design loads

**2.2.1** As specified in Chapter 2 of the IMO MODU Code, the environmental loading to be considered is depending on the intended areas of operation and is to include, as applicable: wind, waves, current, ice, seabed conditions, temperature, fouling and earthquake.

**2.2.2** In the loading calculation, consideration is to be given to the interaction of waves and current. The resultant velocity to be used is to be calculated from the superimposition of current velocity and wave particle velocity.

### 2.3 Fatigue

**2.3.1** For mooring systems installed on the same location for a duration greater than two years, Fatigue assessments are to be included in the site assessment in accordance with the criteria of Sec 3, [11.4]. The results are to be made available for the Surveyor.

## 3 Components of mooring lines

### 3.1 General requirements

**3.1.1** The components of a mobile mooring which cannot be inspected or retrieved are to be considered as permanent mooring components.

### 3.2 Chains and standard fittings

**3.2.1** Grade of materials for chains and standard fittings is specified in NR216, Ch 10, Sec 4. For temporary mooring systems, the use of ORQ grade may also be considered.

### 3.3 Deck appliances (winches and windlasses)

**3.3.1** According to the IMO MODU Code, two independent power-operated brakes are to be provided for each windlass. Each of these brakes are to be able to withstand a static load in the mooring line at least equal to 50% of its minimum breaking load.

**3.3.2** In case of loss of windlass power, these two power-operated brakes are both to be automatically activated. Together, they are to be capable of withstanding at least 50% of the total static braking capacity of the windlass.

**3.3.3** Each windlass is to be designed to comply with the following requirements:

- to provide adequate dynamic braking capacity in order to control normal combinations of loads from the anchor, the mooring line and the anchor handling vessel during the deployment of the anchors at the maximum design unwinding speed of the windlass
- to be controlled from a position allowing for a good visibility of the operation
- to provide means, at the windlass control position, to monitor mooring line tension, power load and mooring line unwinding length.

### 3.4 Items at the unit-side end

**3.4.1** Items at the unit-side end, such as fairlead and sheaves, are to be designed to withstand the line when loaded to the minimum breaking load of the mooring line.

**3.4.2** The strength criteria of the items are to be documented by appropriate calculations, in accordance with the provisions of App 3.

**3.4.3** Loads and load distribution at the interface with the unit structure are to be documented.

Interface arrangement is to be designed in a manner consistent with arrangement of the underneath unit structure, in order to ensure a suitable continuity. Welding details are to be specified. Attention is to be given to the thickness transitions between the materials of different strengths.

### 3.5 Anchoring devices

**3.5.1** Suitable anchor stowage arrangements are to be provided to prevent a move of the anchors into a seaway during the transit phase.

**3.5.2** For the mobile units, ordinary anchors and high holding power anchors may be considered. Refer to the NR467, Pt B, Ch 12, Sec 4, for more details.

## 4 Installation and service conditions

### 4.1 General requirements

**4.1.1** Means are to be provided for display and automatic recording of cable tensions, wind speed and wind direction.

## **5 Thruster assisted mooring (TAM)**

### **5.1 General**

**5.1.1** Thrusters may be part of the stationkeeping system providing that a thruster assist system has been properly defined and designed.

Dynamic positioning systems used as a sole means of position keeping are not addressed in the present article. These systems are covered by the additional class notation **DYNAPOS**, as described in NR467, Pt F, Ch 11, Sec 5.

ISO 19901-7:2013 gives specific recommendations for the design of thruster assisted moorings (TAM).

**5.1.2** The thruster system may be used to assist the mooring system, for the purpose of:

- reducing the environmental loads
- controlling the unit’s heading
- adding damping to the low frequency motions.

**5.1.3** TAM systems may be controlled by an automatic or a manual system. This specificity is to be taken into account in the design process.

### **5.2 Conditions of analysis**

**5.2.1** Conditions of intact and damaged TAM systems to be considered for the analysis are given in Tab 1.

**Table 1 : Conditions of analysis**

Conditions of analysis	Mooring system conditions	Thruster assist system conditions
Intact	Intact	Intact
Damaged	Damaged	Intact
Damaged	Intact	Damaged

**5.2.2** The thruster allocation used in the analysis is to reflect the on-board allocation algorithm.

**5.2.3** The simulations are to be consistent with the operating conditions.

### **5.3 Allowable thrust**

#### **5.3.1 Available thrust**

When a thruster assist system is used, it is necessary to evaluate the allowable thrust that may be used for the mooring analysis.

The first step is to determine the available thrust taking into consideration:

- efficiency of the thrusters
- losses due to the unit motions, current, thruster/hull and thruster/thruster interference effects, and
- any directional restrictions.

A guidance for evaluation of the available thrust is given in the document ISO 19901-7.

#### **5.3.2 Worst thruster system failure**

The available thrust calculated as per [5.3.1] is to account for the worst thruster system failure.

This worst failure is to be determined by a failure mode and effects analysis (FMEA) and is to include failure of any mooring line, failure of any single thruster, or stop of thrusters occurring in the event of the most serious failure in the power system.

#### **5.3.3 Allowable thrust for automatic thruster control systems**

For automatic thruster control systems, the allowable thrust may be determined as follows:

- for the intact thruster condition, the allowable thrust is equal to the available thrust (see [5.3.1]) or the effective bollard pull when the thruster system is operating normally
- for the damaged thruster condition, the allowable thrust is equal to the available thrust after accounting for the worst thruster system failure as determined by a FMEA (see [5.3.2]).

#### **5.3.4 Allowable thrust for manual thruster control systems**

For manual thruster control systems, the allowable thrust is equal to the value determined as per [5.3.3], multiplied by a reduction factor taken equal to 0,7.

**5.3.5** The allowable thrust used in the mooring analysis is to be verified during thruster system sea trials.

## **5.4 Analysis for thruster assisted mooring**

**5.4.1** The analysis for thruster assisted mooring systems is to be properly conducted by a time-domain system dynamic analysis.

As defined in Sec 3, [3.3], the quasi-dynamic or coupled quasi-dynamic methods may be used, providing compliance with the different assumptions. The thruster responses are to be added to the different loads of the system and calculated at each time step of the simulation.

More information about the time-domain system dynamic method is given in document ISO 19901-7.

**5.4.2** A simple mean load reduction method may also be used as a simplified approach. Reference is made to ISO 19901-7:2013 for guidelines on this method.

## **5.5 System requirements**

### **5.5.1 Functional requirements**

The thruster system, and thruster control and monitoring are to comply with NR467, Pt F, Ch 11, Sec 5, [4.4] to NR467, Pt F, Ch 11, Sec 5, [4.6].

The power system and monitoring of the power production and propulsion are to comply with NR467, Pt F, Ch 11, Sec 5, [4.2] and NR467, Pt F, Ch 11, Sec 5, [4.3].

### **5.5.2 Position reference system and sensors**

The position reference system is to comply with the recommendations of NR467, Pt F, Ch 11, Sec 5, [5], with the following deviations:

- for manual TAM systems, only one reference system is required
- for automatic TAM systems, at least two independent reference systems are required.

The sensors and monitoring are to comply with the requirements of NR467, Pt F, Ch 11, Sec 5, [5.5].

## **5.6 Sea trials**

**5.6.1** For TAM systems, sea trials are to be performed in order to test the propulsion system.

**5.6.2** Prior to the mooring trials, a comprehensive list of the tests intended to be carried out by the builder, including procedures and planning of the tests, is to be submitted to the Society and the Surveyor.

**5.6.3** The mooring trials are to be carried out during the construction, in the presence of, and to the satisfaction of, the attending Surveyor.

### **5.6.4 Mooring system**

The mooring system is to be tested during the mooring trials under working conditions, to demonstrate satisfactory operation.

### **5.6.5 Thruster assisted mooring**

For thruster assisted mooring, the trials are to be conducted according to the requirements of NR467, Pt C, Ch 1, Sec 15.

### **5.6.6 Control systems**

Tests of control and monitoring systems are to be performed during the mooring trials.

Where relevant, the following control systems are to be tested by measurements:

- line tensions
- wind speed and direction
- wave elevation
- unit position
- line unwinding length.

Means of communication between locations which are critical for the mooring operations are to be tested.

It is also to be checked that all the control stations provide a good visibility of the mooring operations.

## **6 Mooring equipment tests**

### **6.1 Mooring equipment**

**6.1.1** The mooring equipment is to be tested on board under working conditions.

The test program is to include:

- test for braking
- test for clutch functioning
- test for lowering and hoisting of chain/cable and anchor
- test for the proper riding of the chain/cable through the other mooring components
- verification of proper storage of the chain/cable and anchor
- verification of proper alignments and arrangements of mooring components (for e.g. winches, fairleads).
- test for mooring handling equipments.

## **7 Operating manual**

### **7.1 General**

**7.1.1** The Operating Manual defines the operational characteristics and capabilities of the mooring system in accordance with NR445 and the IMO MODU Code.

**7.1.2** The reference site assessment is to be included in the Operating Manual.

**7.1.3** NR445, Pt A, Ch 1, Sec 4 gives the requirements to be included in the Operating Manual.

# Section 6 Mooring at a Jetty

## 1 General

### 1.1 Application

**1.1.1** The purpose of this Section is to provide Class requirements with a view to the assignment of the notation **POSA JETTY** to an offshore unit moored at a jetty.

### 1.2 Applicability and limits

**1.2.1** The notation **POSA JETTY** covers the station keeping capability of a unit moored at a jetty or a quay within the limits of applicability defined in this Section.

**1.2.2** As a minimum, the notation **POSA JETTY** covers the following items:

- all the components of the load bearing lines, including the connecting devices
- the fairleads, rollers, bitts and winches, and their foundations, used for connecting the mooring lines on board the unit
- the quick release hook for disconnectable systems
- any associated monitoring and control systems.

**1.2.3** The scope of the notation **POSA JETTY** may also cover the jetty, including the devices connecting the mooring lines, and its foundations. In case the jetty is covered by this notation, it is to be explicitly written in the Design Criteria Statement.

### 1.3 In-service surveys

**1.3.1** The surveys of the mooring system for units granted with the notation **POSA JETTY** are to comply with the provisions of Sec 2.

### 1.4 General requirements

**1.4.1** Unless otherwise specified in this Section, the design of the mooring system is to be in accordance with the provisions of the notation **POSA**, as specified in Sec 3 and Sec 4.

#### 1.4.2 Line tending strategy

Accounting for the tensioning measurement is to be considered in the design review of the mooring system and to be in accordance with provisions of the Operating Manual.

## 2 Design

### 2.1 Environment

**2.1.1** The metocean data to be considered are the conditions at the unit location.

For permanent mooring systems (no disconnection expected during the service life), the extreme metocean conditions to be considered at the unit location are those corresponding to a return period N of 100 years, as described in Sec 3, [10].

For disconnectable mooring systems, the design metocean data are to be provided by the party applying for the classification. In addition, the disconnection procedures are to be submitted to the Society for review. Such procedures are to include:

- description of the load monitoring system
- alarm levels for disconnection decision and alarm types (visual, audible)
- locations of the load monitoring devices.
- procedure for reconnection and pretension

The disconnection procedures are to be included in the operation manual.

**2.1.2** Attention is to be paid to the water level variations due to the tides.

## **2.2 Design loads**

**2.2.1** Description of the environmental loads is given in Sec 3, [3].

**2.2.2** For calculation of the wave drift load, the influence of the jetty or of any other structure is to be considered in the calculation of the Quadratic Transfer Functions (QTF).

In case of interaction with another unit or floating structure, as in side-by-side configuration, the potential influence is to be considered in the calculation of QTF.

**2.2.3** Where applicable, the loads due to the waves from passing ships are to be taken into account.

## **2.3 Fatigue**

**2.3.1** Generally, jetty mooring lines and accessories are periodically renewed, given the conditions of use, ambient temperatures, daily UV exposures, etc

The service life of jetty mooring lines is to be specified in the Operating Manual.

For the mooring lines and mooring components having a service life greater than 2 years, a fatigue analysis is to be performed.

The foundations of mooring fittings subjected to cycling loads are to be verified in fatigue.

## **2.4 Side-by-side configuration**

**2.4.1** When transfer operations may be done between the unit and another one in side-by-side position, such configurations are to be analyzed.

## **2.5 Berth area**

**2.5.1** The berth area is to be such that it allows a sufficient depth for the unit under-keel clearance at any states of the tide.

**2.5.2** The case of emergency departure is to be taken into account for determination of the sufficient depth at any states of the tide.

## **2.6 Dolphins system**

**2.6.1** For this type of system, the unit is moored at a set of piles with the help of brackets and fenders.

**2.6.2** Stiffness of soil, piles and fenders is to be taken into account in the mooring calculations.

**2.6.3** For such systems, the gap between the unit and the fenders is to be taken into account in the calculations as it usually induces non-linear stiffness of the piles and fenders system, and may induce damping.

**2.6.4** Attention is to be paid to the type of analysis to be used for the mooring calculations. A quasi-dynamic analysis with no coupling between low and wave frequencies may not be sufficient, given the non-linear stiffness of the piles (see Sec 3, [2.3.2]).

When selecting the type of analysis to be used, the compliance with the different assumptions is to be clearly demonstrated.

# **3 Mooring arrangements**

## **3.1 Mooring lines**

**3.1.1** The mooring lines design is to be in accordance with the requirements of Sec 3 and Sec 4.

**3.1.2** Fibre ropes intended for use as permanent jetty mooring lines are to be type approved according to the requirements of Appendix B of OCIMF-MEG:2018.

**3.1.3** Regarding the methods of evaluation to be used for the design, a great care is to be paid to the compliance with the required assumptions. In particular, the uncoupled quasi-dynamic analysis may not be sufficient when the mooring system natural period is less than five times the zero-up crossing period of the wave (see Sec 3, [2.3.2]).

The different methods, and their corresponding scope of validity, are fully described in Sec 3, [2].

## **3.2 Release mooring hooks**

**3.2.1** When quick release mooring hooks are provided, gravity-based release mechanisms are not acceptable.

**3.2.2** In case a remote release system is provided, the failure of a single component or of electrical power is not to result in the release of the mooring hooks.

**3.2.3** Release mooring hooks are to be designed to be able to move in both vertical and horizontal planes.

**3.2.4** Release mooring hooks are to be designed to release independently of each other.

**3.2.5** The safe working load (SWL) of a quick release hook is defined as being equal to 60% of the minimum breaking load (MBL) of the mooring line.

**3.2.6** The quick release hooks are to be capable of releasing the mooring lines, whether slack or under full SWL.

**3.2.7** Release mooring hooks are to be tested to the following loads:

- proof load test: at 1,25 times the SWL
- release test: at the SWL.

**3.2.8** Release mooring hooks are to be designed to withstand the mooring lines when loaded to the SWL and to the proof load.

**3.2.9** The hook strength is to be documented by appropriate calculations, in accordance with the provisions of App 3.

Release mooring hooks are to be designed to withstand the loads specified in [3.2.7], and the allowable stress factor  $\alpha$  to be considered for the strength criteria is as follows:

- for the safe working load (“static”):  
 $\alpha = 0,6$
- for the proof load (“testing”):  
 $\alpha = 0,9$

**3.2.10** The SWL of the quick release hooks, expressed in tonnes, is to be clearly marked on each hook by weld bead outline, in such a location that it is always easily readable by the unit operators during any operation of the hook.

**3.3 Winches**

**3.3.1** On-board winches may be of different drive type (hydraulic, electric, or steam) and of different control type (automatic or manual tensioning).

In the scope of the notation **POSA JETTY**, the winches are supposed to operate in brake mode. Drive components are not covered by the notation **POSA JETTY**.

This sub-article gives specific strength requirements.

Note 1: Additional guidance regarding the winch design is provided in the OCIMF-MEG:2018.

**3.3.2 Rated pull**

The rated pull is the pull that the mooring winch is able to develop at the rated speed on the outer layer.

The rated speed is the speed able to be maintained with the rated pull applied to the mooring line. The rated speed in combination with the rated pull determines the power requirement for the winch drive.

**3.3.3 Brake holding load**

The brake holding load is to be taken equal to 80% of the line MBL.

**3.3.4 Winch components**

Winch frames, foundations, drums, shafts, bearings and brakes are to be designed to withstand the line when loaded at the design loads defined in Tab 1.

Strength of the winch components is to be documented by appropriate calculations, in accordance with the provisions of App 3.

The basic allowable stress factors to be considered (see NR445, Pt B, Ch 3, Sec 3) are defined in Tab 1.

**Table 1 : Design loads and strength criteria**

Mooring winch components	Design loads	Allowable stress factor $\alpha$
Frames and foundations	MBL	0,8
Drums, shafts and bearings	MBL	0,8
Brakes	80% of MBL	0,8

**3.3.5 Marking of winch**

The MBL of the mooring line, expressed in tonnes, is to be clearly marked on each winch by weld bead outline, in such a location that it is always easily readable by the unit operators during any operation of the winch.

**3.4 Mooring fittings**

**3.4.1** Fittings, such as fairleads, bits or bollards (list not exhaustive), may also be part of the mooring system.

Design specifications and documentation of these fittings, if any, are to be submitted to the Society for review.

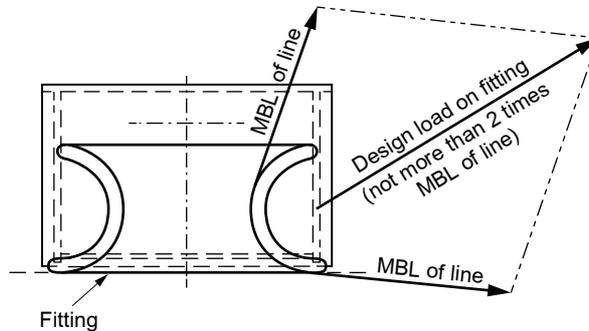
**3.4.2** The fittings are to be designed to withstand a load corresponding to the mooring line MBL, taking account of the mooring line entry and exit directions, as defined in Fig 1.

In case several mooring line arrangements are possible for a fitting, the one leading to the maximum resultant load on the fitting is to be considered.

Fitting strength is to be documented by appropriate calculations, in accordance with the provisions of App 3.

Note 1: Additional guidance regarding strength of the mooring fittings is provided in the OCIMF-MEG.

**Figure 1 : Example of mooring component arrangement**



**3.4.3** Each mooring fitting is to be marked with the MBL of the mooring line.

### **3.5 Fenders**

**3.5.1** The fenders are to offer a sufficient surface area to avoid damaging both the jetty and the moored unit.

## **4 Design requirements for jetty**

### **4.1 General**

**4.1.1** The jetty may be part of the scope of the notation **POSA JETTY**.

**4.1.2** The design of the jetty structure is to comply with the NR445, Part B.

The design of the jetty foundations is to comply with the requirements of NI605.

## **5 Operating Manual**

### **5.1 Information to be included**

#### **5.1.1 Disconnection procedures**

Disconnection procedures, if any, are to be included in the Operating Manual.

#### **5.1.2 Environmental conditions**

The limiting environmental conditions, in terms of operating conditions, and scenarios where disconnection decision is to be made are to be included in the operating manual.

The following environmental conditions are to be included, where relevant:

- wave data
- wind data
- current data
- water levels taken into account tide data and storm surge
- minimum air and sea temperatures.

#### **5.1.3 Mooring lines**

The design life of mooring lines is to be documented in the Operating Manual.

Where relevant, the periodicity of the jetty mooring lines inspections is to be documented in the operating manual.

Tending strategy and its monitoring system is to be included in Operating Manual.

In case of periodic replacement of the mooring lines, a replacement procedure is to be submitted for review.

#### **5.1.4 Side-by-side operations**

Where relevant, side-by-side procedures are to be fully documented in the Operating Manual.

The limit conditions for such operations are also to be included in the Operating Manual.

# Appendix 1 Characterisation of the Line Response

## 1 General

### 1.1 Test run

**1.1.1** A characterisation of the line response is to be performed to obtain information on the respective contribution of the mean load, slow drift, and wave frequency motions to the line tension, the level of dynamic tensions, and to evaluate whether the quasi-dynamic analysis is sufficient. A relatively short run (from 10 to 15 min in real time) is generally sufficient.

The run conditions are to be taken as close as possible to those of the “wave governed” case leading to maximum quasi-dynamic tensions at fairlead, or at any other point of interest, in the governing (intact or damaged) situation.

**1.1.2** The time series of the quasi-dynamic tension  $T_{qd}$  and the dynamic tension  $T_{dyn}$ , in N, is to be taken equal to:

$$T_{qd} = T_{mean} + T_{lf} + T_{wfqd}$$

$$T_{dyn} = T_{mean} + T_{lf} + T_{wfdyn}$$

where:

$T_{mean}$  : Mean tension, in N

$T_{lf}$  : Low frequency tension variation, in N

$T_{wfqd}$ ,  $T_{wfdyn}$  : Quasi-dynamic and dynamic wave frequency variations, respectively, corresponding to the difference between the total signal and the previous terms, in N.

$T_{lf}$ ,  $T_{wfqd}$  and  $T_{wfdyn}$  may be characterised by their standard deviation, respectively  $\sigma_{lf}$ ,  $\sigma_{wfqd}$  and  $\sigma_{wfdyn}$ .

### 1.2 Characterisation

**1.2.1**  $T_{mean}$  and  $T_{lf}$  are to be checked for consistency between dynamic and static response analyses.

**1.2.2** Significance of the dynamic tension may be assessed from the following dynamic amplification factor DAF:

$$DAF = \sigma_{wfdyn} / \sigma_{wfqd}$$

Note 1: Ratio between the total (maximum) tensions  $T_{maxdyn}/T_{maxqd}$  from time domain simulation is not a proper indication, and cannot be considered as a DAF.

**1.2.3** The quasi-dynamic analysis is sufficient, if one the following conditions is satisfied:

$$a) \sigma_{lf} > \frac{1,9 \text{ DAF } \sigma_{wfqd}}{3,2 - \log T_0}$$

where:

DAF : Coefficient defined in [1.2.2]. DAF is to be taken not less than 1

$T_0$  : Largest natural period defined in Sec 3, Symbols.

In that case, the low frequency part of the tension is governing over the wave frequency part.

$$b) 1,75 (M + 1,8 S) > 1,67 (M' + 0,7 S')$$

and, if the analysed case is a damaged condition:

$$M + 1,8 S > M' + 0,7 S'$$

where:

M, S : Mean and  $(n - 1)$  standard deviations of the maximum tension over 5 simulations, in the same conditions

M', S' : Estimators of the same quantities in case of a dynamic simulation, taken equal to:

$$S' = \text{DAF} \cdot S$$

$$M' = M + B (\text{DAF} - 1)$$

with:

$$B = M - (T_{mean} + 2 \sigma_{lf})$$

**1.2.4** In case a) of [1.2.3], and on condition that DAF is undoubtedly below 1, the safety factors for the dynamic analysis may be used with the results of the quasi-dynamic analysis.

**1.2.5** When the line dynamic is prevailing, plots of  $T_{dyn}$  versus  $T_{qd}$  and  $T_{dyn}$  versus  $dT_{qd}/dt$  are to indicate with which of these  $T_{dyn}$  is correlated, as needed for the selection of windows in the dynamic analysis.

**1.2.6** For scanning through the combination of the unit conditions and metocean parameters, the following tension criteria (based on API RP 2SK:2024, and the above data) may be used, with the results of a single quasi-dynamic simulation for each combination:

a) when low frequency is prevailing over wave frequency for the tension variations:

$$T_{AL} = T_{mean} + (4,9 - 0,9 \log T_0) \sigma_{liqd} + 2 \sigma_{wliqd}$$

b) otherwise:

$$T_{AW} = T_{mean} + 2 \sigma_{liqd} + 3,7 \text{ DAF} \sigma_{wliqd}$$

# Appendix 2      Combination of Metocean Parameters

## Symbols

H	: Waves
S	: Swell
W	: Wind sea
V	: Wind
C	: Current
H-V, C-V	: Relative directions between waves and wind, and between (near) surface current and wind, respectively. Relative headings are between incoming directions and are taken positive, viewed from above, when clockwise in the northern hemisphere, and when anti-clockwise in the southern hemisphere
RP	: Return period of each individual (or marginal) environmental action
N, n	: N denotes the specified return period $n = \log(N)$
RP <sub>0</sub>	: Reference return period $r_0 = \log(RP_0)$ (see [3.3])
nXd	: Number of exceedance per year $nXd = 1/RP$
r	: Reduction factor (see [3.3])
pe(X)	: Probability of exceedance of X $pe(X) = p(x > X)$
p <sub>asi</sub>	: Probability of exceedance for associated independent parameters.

## 1 General

### 1.1 Scope

**1.1.1** This Appendix defines the combinations of metocean parameters to be considered as design metocean conditions for a mooring system (such as stationkeeping, offshore tandem or side-by-side mooring).

The criteria herein may be considered as minimum requirements, for guidance, and may be adjusted when more accurate data are available for the site under consideration.

**1.1.2** These criteria are also applicable to heading analysis and sea-keeping analysis in extreme conditions (short term approach). In such cases, it is most often necessary to consider intermediate combinations between those defined herein.

Note 1: The approach is that the possible metocean design conditions for a N-year return period form a response contour, in the sense of the Inverse First Order Reliability Method (I-FORM), so that the N-year response is the maximum response over all the possible design points.

The N-year contour is notionally an hyper-surface in a multi-variate space. It is limited here to a set of discrete combinations, with generally one governing element, the others being 'associated values'.

The true contour (or a subset of it) is to be considered when supported by adequate data, and where needed.

Note 2: Reference is also made to the published paper by M. François, C. Camps, J.Alvarez, V.Quiniou, 2007: Multi-variate I-FORM contours for the design of offshore structures (practical methodology and application to a West Africa FPSO), ISOPE-2007-JSC-434.

## 2 Metocean data

### 2.1 Metocean conditions and design data

**2.1.1** The metocean conditions at a given site are generally based on site measurements, or may be derived from satellite data or by hindcasting, duly validated by site measurements.

Processing of such a database is to provide metocean design data (extremes). The statistical techniques used to choose these values are to be documented, to the satisfaction of the Society.

The database processing is also to provide adequate joint statistics regarding the parameters.

**2.2 Intensity and direction**

**2.2.1** The metocean data are normally available as the intensity of each element (wind speed, current speed, wave -or wave system- significant height), in function of the return period (independent extremes in all directions).

**2.2.2** When available, directional data (i.e. different values per sectors of incoming -geographical- direction) may be used, provided they are consistent with all-direction data, as detailed hereafter.

Directional data are derived from joint (or conditional) distributions of intensity and incoming sector. Inconsistent variations between adjacent (small) sectors are to be removed by appropriate means, and values are to be properly «rescaled» as defined in [2.2.3].

**2.2.3 BV reference directional contour methodology**

The following methodology is referred to as BV reference directional contour methodology, and is further developed in the document in Note 2 of [1.1.2])

Given:

$X^*$  : The all-direction extreme value of an intensity variable X at a given return period

$pe(X, \Delta\Theta_k)$ : The joint probability of exceedance of X in sector  $\Delta\Theta_k$

$\Delta\Theta^*$  : The most probable sector for exceedance of  $X^*$ ,

thus:

$$pe(X^*, \Delta\Theta^*) \geq pe(X^*, \Delta\Theta_k)$$

$\Delta\Theta^*$  is also the incoming sector of the maximum of the directional values  $X_k$  (at the same return period).

Then the values  $X_k$  at the same return period in each sector  $\Delta\Theta_k$  are to be such that:

- in sector  $\Delta\Theta^*$ :  
 $X_k = X^*$ , i.e. the maximum (over all sectors  $\Delta\Theta_k$ ) of  $X_k$  is taken equal to the all-direction extreme value  $X^*$  at the same return period
- in other sectors:  
 $X_k$  is to be taken such that  $pe(X_k, \Delta\Theta_k) = pe(X^*, \Delta\Theta^*)$ , or lower.

Besides,  $X_k = 0$  when  $p(\Delta\Theta_k)$ , the probability of incoming direction being in sector  $\Delta\Theta_k$  is such that:

$$p(\Delta\Theta_k) \leq pe(X^*, \Delta\Theta^*)$$

Note 1:  $p(\Delta\Theta_k) = pe(0, \Delta\Theta_k)$

**2.2.4 Alternative directional contour methodology**

On a case-by-case basis, alternative directional contour may be considered, such as the NORSOK directional contour, defined in NORSOK N-003:2017 Actions and action effects.

Additional guidance and possible methodologies for environmental contours in general including directional contours are defined in NI638.

**2.2.5** For frequent values of intensities (see [3.3.4]), when needed, the all-direction value can be obtained from the observed (marginal) distribution of the considered parameter. Directional values can be then derived following the same method as above.

Note 1: The intensity for intermediate return periods between those quoted in the specification may be obtained by linear interpolation of intensity as a function of the (decimal) log of return period (i.e. of the factor r defined in [3.3]), or by fitting the data to an adequate extremal distribution.

Note 2: When RP is less than one year, it is more representative to use one of the following:

- the number of exceedance, per year  
 $nXd = 1 / RP$
- the probability of exceedance, in % of time (based on 3-hour sea states)  
 $pe = 100 nXd / 2922$

The intensity for a specified pe may be then obtained by linear interpolation of intensity as a function of the (decimal) log of pe, on the observed distribution.

Note 3: When the intensity is defined for a discrete set of incoming directions, the same value applies to any other direction within the sector around each specified direction.

**2.3 Sea states**

**2.3.1** A sea state may be described by:

- a wave spectrum (unimodal sea state), or
- the sum of several wave spectra (for multi-modal -and generally multi-directional- sea states).

Each spectrum is defined by its significant wave height  $H_s$ , in m, the period  $T_p$  (or  $T_z$ ), in s, and additional parameters as relevant for the specified spectral shape (e.g. the peakedness factor  $\gamma$  for a JONSWAP spectrum).

Additional guidance for sea state description and properties are defined in NI691, Sec 2, [3].

The significant wave height  $H_s$  is to be selected as per [3.3].

**2.3.2** Associated parameters are generally available as a best estimate/most likely value.

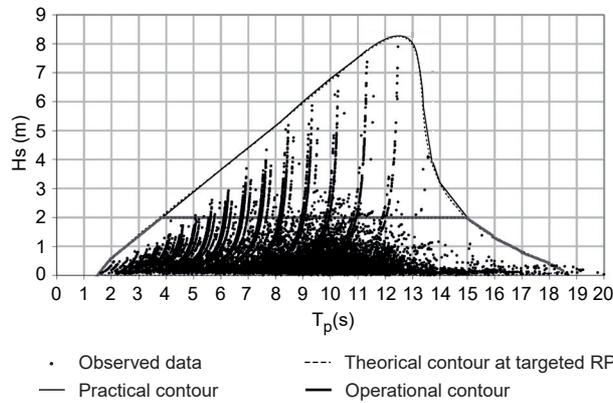
For the spectral peak (or zero-crossing) period  $T_p$  (or  $T_z$ ), when waves (or the sea state component under consideration) are quoted as the governing parameter, a range is to be considered around the specified value, as a minimum. A range of  $\pm 15\%$  (around the specified value) is to be considered. However, the minimum period may be adjusted, based on considerations of minimum steepness at considered site.

**2.3.3**  $H_s/T_p$  (or  $H_s/T_z$ ) response contours (inverse FORM approach (e.g. see references in [1.1.2], Note 2) or NI638 (see Sec 1, [4.2.2]) may be used when available, and are to be preferred when the response is found very sensitive to wave period.

Contours are to be defined, covering a range of return periods. Where relevant and possible, directional contours (i.e. different  $H_s/T_p$  contours for different sectors) are to be defined.

The contour having its maximum at the specified  $H_s$  is to be selected, and scanned as being the most onerous  $H_s/T_p$  combination (i.e. the combination leading to the maximum response). However, it is recommended to take a plateau (i.e. no reduction of  $H_s$ ) over not less than  $\pm 10\%$  around the specified period. See Fig 1.

**Figure 1 :  $H_s/T_p$  contour (for illustration)**



**2.3.4** For spectral peakedness parameter, when waves (or sea state component) are quoted as the governing parameter, a range of values is to be considered, unless (depending on the available data), a relation with e.g. steepness (or other relevant parameter) can be documented. In the other cases, the specified (mean) value may be used.

**2.4 Wind**

**2.4.1 Sustained winds**

The design wind speed for sustained wind conditions  $V$  is to be selected as per [3.3].

Sustained winds are specified by the 10-minute or 1-hour average speed (see Sec 3, [3.1] and Sec 3, [3.2]), typically at 10 m above the sea level.

Additional definitions and features of sustained wind conditions are defined in NI691, Sec 2, [3.2].

**2.4.2 Squall winds**

Squall winds are defined in App 4.

**2.5 Current**

**2.5.1** The design current speed  $C$  is to be selected as per [3.3].

**2.5.2 Actions on floaters**

When a current profile is specified, an average speed may be considered for the actions on floaters.

Note 1: Pending more accurate evaluations, the average current speed may be taken as the average over a depth of:

- 1,3 times the unit draft for ship- and barge-shaped units
- 1,1 times the unit draft for semi-submersible units.

**2.5.3 Actions on risers and mooring lines**

In shallow and medium water depths, the relevant current profile is to be considered. Guidance for current modelling including current profile is defined in NI691, Sec 2, [4].

In deep waters, surface currents and currents over the water column are generally uncorrelated and are to be considered in separate sets of design conditions.

**3 Metocean design conditions**

**3.1 Principles**

**3.1.1** The design metocean conditions for a specified N-year return period are defined as combinations of direction and intensity of waves, wind and current, and of associated parameters.

Depending on the climatic conditions at site, several sets are defined. In each set, one of the elements is generally governing.

For each set, the intensity of the elements is to be selected with values depending on:

- the degree of correlation of the extremes, both in intensity and in direction, that are also depending on the climatic conditions at site
- the relative directions between the elements.

Note 1: This is intended to take into account that extreme values of element intensities may not all result from the same meteorological conditions, nor from the same storm event, nor at the same time within the same event, so are not to happen simultaneously, nor necessarily with the same incoming direction.

The criteria to select intensities are defined in Articles [4], [5] and [6], for different types of climatic conditions.

These criteria are given for guidance and may need adjustments when more accurate data are available for the site under consideration.

Note 2: For a given site, several climatic conditions may be applicable, depending on the season.

**3.2 Directions**

**3.2.1** All the relevant combinations of direction of the governing element (or an element taken as reference) and the relative directions between the elements are to be investigated by appropriate scanning.

In principle, scanning is to be performed over 360° for the governing (or a reference) element.

For each of the other elements, scanning is to be performed over an interval large enough to provide the evidence that a maximum response has been caught. Generally, the relative direction between any two elements need not exceed 120°.

A scanning step of 15° is generally sufficient to catch a maximum response, taking into account the directional variations of intensities.

Note 1: The scanning interval may be reduced, depending on the symmetry(ies) of the mooring system (same lines over a flat bottom) and of the unit (including load coefficients, e.g. for wind), and taking into account the required accuracy (envelope or results in individual lines). Such a reduction, however, is to preclude the use of directional data.

Note 2: Depending on the type of mooring (e.g. spread or turret), considerations of, e.g., the relative contribution of the elements to the total mooring force or to the line tension (as evidenced by test runs, see also App 1) may be used to optimise the scanning effort and organise it in appropriate steps, but are not to replace such scanning.

**3.2.2** Directional sectors are defined for the following conditions: extratropical, equatorial and tropical storm.

Due to physical phenomena (such as Coriolis effect), some sectors could be unsymmetrical. These sectors, defined for Northern hemisphere in this Rule Note, are to be inverted in case of study in Southern hemisphere areas.

**3.3 Intensities**

**3.3.1** The intensity of the elements is specified from [3.3.2] to [3.3.5], except otherwise noted, by the return period RP of the value to be used.

**3.3.2 Combination of metocean parameters for extratropical and equatorial conditions**

For a design return period N of the combination of the extreme metocean parameters as defined in Sec 3, [10.5], the return period RP of the metocean parameters to be used in the combination is to be calculated as follows:

$$RP = N10^{r_n}$$

where:

$$r_n = \frac{(n + 3) \cdot (r + r_0 - 2)}{5}$$

r : Reduction factor, function of the relative directions between the elements:

- for extratropical conditions, r is defined in Tab 1, Tab 2 and [4.4]
- for equatorial conditions, r = 0

$$r_0 = \log(RP_0)$$

with:

$RP_0$  : Reference return period to be taken into account in the combination for the considered metocean zone (extratropical, equatorial) and the governing conditions, and defined in Tab 1, Tab 2 and Tab 3.

When the design return period  $N$  is equal to 100 years, the formula of  $RP$  may be simplified as follows:

$$RP = RP_0 10^r$$

### 3.3.3 Combination of metocean parameters for tropical storm conditions

For tropical storm conditions, the provisions of [6.3] and Tab 4 are to be applied.

Reduction factor on the  $N$ -year value is specified in the Article [6].

**3.3.4** Frequent values of intensities are specified by the following probability of exceedance:

$$pe(X) = p_{asi}$$

$p_{asi} = 11\%$  may be considered in the combinations (corresponding to  $RP = 10^{-2.5}$  in [3.3.2]).

Then,  $r = 0$  in any combinations.

Note 1: Other value is to be used if defined in the specifications of the party applying for classification (e.g.  $p_{asi} = 5\%$  for West Africa).

**3.3.5** When directional data are used, intensity for each element is taken as the intensity in the geographical sector where that element is lying.

## 3.4 Operating conditions

**3.4.1** The limiting operating conditions may be specified in different ways (see Sec 3, [10.6]).

**3.4.2** When the limiting conditions for specific operations are infrequent, they can be defined by a return period (not less than one year). Then the combinations of metocean parameters are defined in the same way as (extreme) design conditions, taking into account the specified return period.

**3.4.3** More frequently occurring conditions are specified by limiting values on some measurable parameters.

Then the combinations of metocean parameters are to be established, based on:

- a set of combinations, as applicable to the specific climatic conditions, with however, except those between wind and wind sea, no restriction on the relative direction between elements
- intensities taken, for each element in a combination, as the lowest of the explicitly specified limiting value, and the value in the  $N$ -year design (extreme) combination (with no restriction for relative direction, see [3.3.2] except factor  $r_v$  for wind and wind sea, where applicable).
- a range of wave period, selected based on a  $N$ -year contour, unless otherwise specified in criteria.

Note 1: The same acceptance criteria as for extreme conditions are applicable to operating conditions. Thus, notionally, the contour for operating conditions is defined by applying to the  $N$ -year design (extreme) contour the limiting criteria that are explicitly specified (e.g. the combined  $H_s$  of the sea state). See Fig 1.

## 4 Extratropical conditions

### 4.1 Applicability

**4.1.1** The combinations in [4.2] to [4.5] are applicable to areas where metocean conditions are driven by extratropical storms during the whole year (e.g. North sea, Mediterranean sea, ...) or at some seasons (e.g. winter storms in tropical areas), in which:

- wind driven seas and wind driven current are governing over other components
- sea states are described by an unimodal spectrum and, most often, the strongest sea states are unimodal wind seas.

Some swell is however often present and, in some areas (e.g. North West Europe, South West Atlantic), a bimodal description is more appropriate, see [4.5].

### 4.2 Typical design conditions

**4.2.1** Three typical conditions may be defined, as follows:

- wave governed, with the following relative headings:  
H-V between  $-45^\circ$  and  $+60^\circ$ , and  
C-V between  $-60^\circ$  and  $+60^\circ$
- wind governed, with the following relative headings:  
H-V between  $-45^\circ$  and  $+60^\circ$ , and  
C-V between  $-60^\circ$  and  $+60^\circ$

- current governed, with the following relative headings:  
 H-V between  $-30^\circ$  and  $+45^\circ$ , and  
 C-V between  $-60^\circ$  and  $+90^\circ$ .

Note 1: In a mooring analysis, the wind governed condition may be omitted in most cases, subject to documentation, to the satisfaction of the Society.

**4.2.2** For swell conditions, the additional requirements of [4.5] are to be considered.

**4.3 Selection of return periods**

**4.3.1** Data for the selections of return periods as per [3.3] are given in Tab 1, for N = 100 years.

However, when directional wave data are used, and unless swell is modelled as per [4.5], a minimum value of  $H_s$  is to be considered to account for occurrence of swell, see [4.4.1].

**Table 1 : Extratropical conditions - Reduction factor r and return period  $RP_0$  for N = 100 years**

Type of combination	Waves H		Wind V		Current C	
	$RP_0$ , in years	r	$RP_0$ , in years	r	$RP_0$ , in years	r
H governed	100	$r_v + r_c$	50	$r_v + r_c$	10	$0,8 r_c$
V governed	50	$r_v + r_c$	100	$r_v + r_c$	10	$0,8 r_c$
C governed	10	$0,8 (r_v + r_c)$	10	$0,8 (r_v + r_c)$	100	$r_c$

**4.4 Reduction factors**

**4.4.1 General**

- Contours of reduction factor  $r_v$  (as defined in [4.4.2]) and of reduction factor  $r_c$  (as defined in [4.4.3]) may be adjusted when adequate data of joint occurrence are available.
- When a value of current quoted as “simultaneous” (with wind or waves) is defined in the Site specification, the values of C in a combination (wind and wave governed conditions) may be taken as the lowest between the specified value (without reduction for relative direction) and the value obtained by the above criteria for that specific combination.
- When directional data are used, and to account for the possible occurrence of some swell that is uncorrelated with wind,  $H_s$  in any direction are to be taken not less than the smallest directional values of  $H_s$  at the return period  $RP_0$  (i.e. without reduction for relative direction) specified in Tab 1 for the subject combination (or another appropriate value).

**4.4.2 Reduction factor  $r_v$**

The reduction factor  $r_v$  is given by (see Fig 2):

$$r_v = 1 + \frac{H-V}{15} \text{ when } -45^\circ \leq H-V < -15^\circ$$

$$r_v = 0 \text{ when } -15^\circ \leq H-V \leq +30^\circ$$

$$r_v = 2 - \frac{H-V}{15} \text{ when } +30^\circ < H-V \leq +60^\circ$$

**4.4.3 Reduction factor  $r_c$**

The reduction factor  $r_c$  is given by (see Fig 2):

$$r_c = 0 \text{ when } |C-V| \leq 45^\circ$$

$$r_c = 1 - \frac{|C-V|}{45} \text{ when } 45^\circ < |C-V| \leq 90^\circ$$

**4.5 Additional combinations for conditions with swell**

**4.5.1** Following combinations are to be added to those given in [4.2]:

- Swell governed, with the following relative headings between wind-sea W, wind and current:  
 W-V between  $-30^\circ$  and  $+45^\circ$ , and  
 C-V between  $-60^\circ$  and  $+60^\circ$
- Swell with wind and wind sea, with the following relative headings:  
 W-V between  $-45^\circ$  and  $+60^\circ$ , and  
 C-V between  $-60^\circ$  and  $+60^\circ$

- Swell and current, with the following relative headings:  
W-V between  $-30^\circ$  and  $+45^\circ$ , and  
C-V between  $-60^\circ$  and  $+90^\circ$ .

Note 1: Swell is assumed here to be independent of the other parameters, both in intensity and in direction, so any direction is to be considered over  $360^\circ$ , and no reduction is applicable (i.e.  $r = 0$ ) for the relative direction between swell and other elements. However same direction as in [4.4] above are applicable to W, V and C combinations.

Note 2: In a mooring analysis, when swell intensity is significantly lower than wind seas, these conditions may be omitted in most cases, subject to documentation to the satisfaction of the Society.

4.5.2 Data for the selections of return periods are given in Tab 2.

Figure 2 : Reduction factors  $r_v$  and  $r_c$

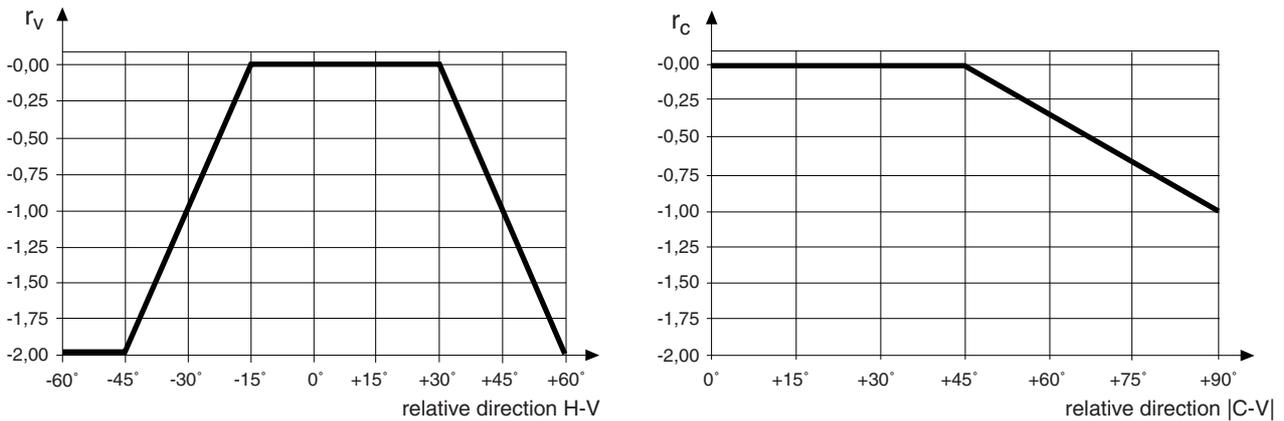


Table 2 : Extratropical conditions with swell - Reduction factor  $r$  and return period  $RP_0$  for  $N = 100$  years

Type of combination	Swell S		Waves W		Wind V		Current C	
	$RP_0$ (years) or pe	$r$	$RP_0$ (years) or pe	$r$	$RP_0$ (years) or pe	$r$	$RP_0$ (years) or pe	$r$
W governed	–	–	100	$r_v + r_c$	50	$r_v + r_c$	10	$0,8 r_c$
V governed	–	–	50	$r_v + r_c$	100	$r_v + r_c$	10	$0,8 r_c$
C governed	$p_{asi}$	–	10	$0,8 (r_v + r_c)$	10	$0,8 (r_v + r_c)$	100	$r_c$
S governed	100	0	$p_{asi}$	–	$p_{asi}$	–	$p_{asi}$	–
S and V + W	1	0	1	$0,6 r_v$	1	$0,6 r_v$	$p_{asi}$	–
S and C	1	0	$p_{asi}$	–	$p_{asi}$	–	1	$0,6 r_c$

## 5 Equatorial conditions

### 5.1 Applicability

5.1.1 Climate in equatorial conditions (e.g. West Africa) is characterised by long distance swells, local winds and currents, all three having distinct sources, thus being almost uncorrelated.

In addition, some distinct local events, typically not represented in the statistical distributions, are to be considered (see [5.2.3]).

### 5.2 Typical design conditions

5.2.1 Three base combinations may be defined as follows:

- swell governed
- wind governed
- current governed.

5.2.2 Three intermediate combinations are also to be considered:

- swell and wind
- swell and current
- current and wind.

Alternatively, these three combinations can be conservatively merged in a single one.

**5.2.3** Additional combinations include:

- squall wind condition, as defined in App 4
- local current (e.g. surface current) condition, see Tab 3.

**5.3 Waves and wind**

**5.3.1** Waves are described in this sub-article as a combination of swell and wind-sea.

**5.3.2** Swell is often a combination of several independent swell systems, but the strongest sea states usually show unimodal swell.

Then the swell governed condition could be separated in:

- a main swell governed condition (with unimodal swell)
- concomitant swells condition (multimodal).

**5.3.3** Winds (other than squalls) are rather weak, and the higher frequency part of wave spectra, often denominated as “wind seas”, is not well correlated with wind.

Note 1: However, for practicality, wind-sea is hereafter assumed correlated with wind.

**5.4 Selection of return periods**

**5.4.1** Data for the selections of return periods are given in Tab 3, for N = 100 years.

In the combinations, the associated values of non governing parameters may be taken as a “frequent value” (see [3.3.4]).

**Table 3 : Equatorial conditions - Return period  $RP_0$  or  $p_e$  (in years) for N = 100 years**

Type of combination	Swell S	Waves W (1)	Wind V	Current C
S governed	100	–	$P_{asi}$	$P_{asi}$
V / W governed	$p_{asi}$	100	100	$P_{asi}$
C governed	$p_{asi}$	$p_{asi}$	$p_{asi}$	100
S and V / W	1	1	1	$P_{asi}$
S and C	1	$p_{asi}$	$p_{asi}$	1
C and V / W	$p_{asi}$	1	1	1
Local current	$p_{asi}$	$p_{asi}$	$p_{asi}$	100 (2)
(1) If present. See [5.5.2].				
(2) Following the relevant distribution.				

**5.5 Directions**

**5.5.1** Owing to lack of correlation, swell, wind (or squall) and current (or local current) are to be taken as acting together in any combination of directions, each over all possible directions, and no reduction factor r is applicable (i.e. r = 0 is to be taken in [3.3]).

**5.5.2** The relative direction of wind-sea with wind may be assumed not to exceed 45°. In addition W = 0 (i.e. no wind sea) can be considered when its anticipated direction is falling in a sector in which no wind-sea was observed.

**6 Tropical storm conditions**

**6.1 Applicability**

**6.1.1** Extreme conditions in areas affected by tropical storm (e.g. Gulf of Mexico, South East Asia, North West of Australia) are governed by occasionally passing hurricanes/typhoons, causing strong wind, waves and current, with rapid variations of both intensity and direction over a limited time.

In this case, associated values are better defined by a ratio to the specified extreme, and the wave direction is used for reference. Directional data are to be used with caution. Their derivation needs special care.

For non tropical storm conditions, see extratropical conditions (Article [4]) and equatorial conditions (Article [5]).

**6.2 Typical design conditions**

**6.2.1** Three typical conditions may be defined as follows:

- wave governed, with the following relative headings:  
V-H between -45° and +45°, and  
C-H between -30° and +30°

- wind governed, with the following relative headings:  
 V-H between  $-45^\circ$  and  $+45^\circ$ , and  
 C-H between  $-30^\circ$  and  $+30^\circ$
- current governed, with the following relative headings:  
 V-H between  $-45^\circ$  and  $+45^\circ$ , and  
 C-H between  $-120^\circ$  and  $-60^\circ$ .

Intermediate situations between the H governed and the C governed cases (with C-H between  $-30^\circ$  and  $-60^\circ$ ) may be considered if needed.

Note 1: In a mooring analysis, the wind governed condition may be omitted in most cases, subject to documentation to the satisfaction of the Society.

**6.2.2** In addition, conditions for winter/monsoon seasons, and those for local currents (e.g. eddy currents) are to be separately considered, as defined above, when relevant.

**6.3 Data for the intensity of the elements**

**6.3.1** For each parameter (H, V or C), the intensity X may be taken as:

$$X = c_x \cdot X_N$$

where:

$X_N$  : Intensity at the specified return period N

$c_x$  : Reduction factor to account for both the degree of correlation and the relative direction between elements.

Data for reduction factors  $c_H$ ,  $c_V$  and  $c_C$  are given in Tab 4.

If needed, reduction factors  $c_H$ ,  $c_V$  and  $c_C$  for intermediate situations (C-H between  $-30^\circ$  and  $-60^\circ$ ) may be obtained by interpolation between the H and C combinations.

**6.3.2 Reduction factor  $q_v$**

The reduction factor  $q_v$  is given by:

$$q_v = 1 \quad \text{when } |V-H| \leq 30^\circ$$

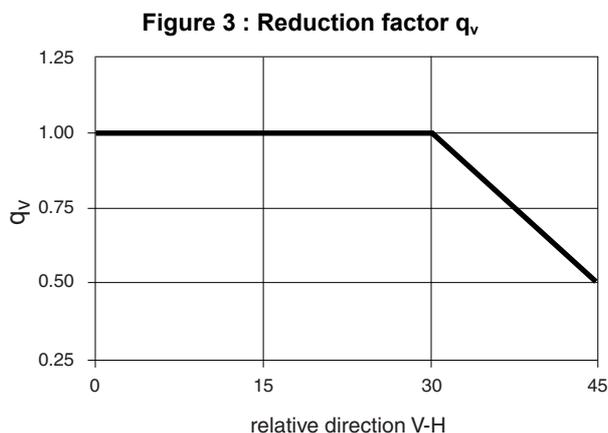
$$q_v = 2 - \frac{|V-H|}{30} \quad \text{when } 30^\circ < |V-H| \leq 45^\circ$$

The reduction factor  $q_v$  is shown in Fig 3.

**Table 4 : Reduction factors  $c_H$ ,  $c_V$  and  $c_C$  for tropical storm conditions**

Type of combination	$c_H$ (Waves)	$c_V$ (Wind)	$c_C$ (Current)
H governed	1,0	0,9 $q_v$	0,5
V governed	0,9 $q_v$	1,0	0,5
C governed	0,7 $q_v$	0,6 $q_v$	1,0

**Note 1:** Reduction factor  $q_v$  defined in [6.3.2]



# Appendix 3      Structural Strength Criteria

## 1 General

### 1.1 Subject

**1.1.1** This Appendix is applicable to the steel components of a mooring system such as:

- non standard connection and termination fittings (see Sec 4, [6])
- anchors (see Sec 4, [7])
- supporting structures in Unit hull or turret (see Sec 4, [8])
- ancillary components (see Sec 4, [9]).

**1.1.2** Requirements and guidance are given on structural strength criteria, as a complement to the criteria specified in Sec 4 and NR445, Part B, Chapter 2 and Chapter 3. It is organized as follows:

- design loads in Article [2]
- assessment of strength based on linear analysis in Article [3]
- assessment of strength based on non-linear analysis in Article [4].

**1.1.3** Fatigue strength and, where relevant, buckling strength are not covered by this Appendix and are to be duly considered following the applicable requirements of NR445 and those of the present Rule Note.

## 2 Design loads

### 2.1

**2.1.1** As a minimum, the design of the steel components of the mooring system is to be checked against the breaking strength of the mooring line, considered as "load case 3" (accidental) for checking the strength criteria defined in [3.1.2].

**2.1.2** If deemed necessary by the Society, the following design loads are also to be considered for the design assessment of the steel components of the mooring system:

- design line tension  $T_D$ , in the intact conditions of the mooring system, considered as a "load case 2" (design)
- design line tension  $T_D$ , in the damaged condition of the mooring system, considered as a "load case 2" (design)
- design line tension  $T_D$ , in the transient (line failure) condition of the mooring system, considered as a "load case 3" (accidental).

**2.1.3** The line of action of the design load is generally dictated by the geometry of the component.

**2.1.4** For items fixed to the Unit or to the anchor, the angular variations resulting from tolerances in system geometry, Unit offset and Unit motions are to be duly considered. Suitable ranges of orientation are to be specified, with consideration of the loads induced in each part of the item.

**2.1.5** For structures on the Unit end, that may be subject to loads from several adjacent lines, combinations of loads may be derived from mooring analysis. In each of the condition of the mooring system, load combinations are to be categorised as in [2.1.2].

Several combinations of line loads in each case may be needed to assess strength.

**2.1.6** Other loads acting simultaneously as the line loads are to be considered where applicable (e.g. soil reactions, for anchors).

Generally, self weight is negligible and can be omitted.

**2.1.7** In case of multi-purpose mooring line components, such as for type approval of mooring line component, the calculations are to consider the most critical succession of components, to be agreed with the Society.

### 3 Elastic design

#### 3.1

**3.1.1** When assessment of strength is based on elastic analysis, the strength criteria in NR445, Pt B, Ch 3, Sec 3 are applicable.

**3.1.2** The following criteria are to be complied with:

$$\sigma_c \leq 1,1 \alpha R_f \quad \text{and} \quad \sigma_a \leq \alpha R_f$$

where:

$\sigma_c$  : Equivalent stress (as specified in NR445, Pt B, Ch 3, Sec 3, [5.3]), under the design loads defined in [2.1]

$\sigma_a$  : Axial stress (i.e., pure tension solicitation of the element), under the same conditions

$\alpha$  : Allowable stress factor, as defined in NR445, Pt B, Ch 3, Sec 3, [5.4.4], for the load case considered (see [2.1.1] and [2.1.2])

$R_f$  : Reference stress (as specified in NR445, Pt B, Ch 3, Sec 3 [5.2.1]).

**3.1.3** In case of assembly with contact between several elements, non-linear contact analysis may be omitted, provided the distribution of stresses in the body of the element is not sensitive to the distribution of pressure over the contact area.

**3.1.4** Local high compressive stresses in contact areas can be generally ignored, if the geometry ensure confinement of the area, so that shear failure is not foreseeable, and if the above condition is also satisfied.

### 4 Design Based on Elasto-plastic calculations

#### 4.1

##### 4.1.1 General

The evaluation of the structural strength of the component may be based on elasto-plastic calculations. These calculations are to be based on the actual hardening law (stress-strain relation) of the considered material.

Elasto-plastic calculation is to be performed on finite element analyses solvers qualified for elasto-plastic evaluation, accounting for the effects of contacts and large deformations.

Contacts between mooring line components are to be adequately modeled. The finite element model is to consider the actual succession of components in the mooring line in order to ensure that the line loads are adequately transferred at contact areas to the mooring line component.

Strength analyses through elasto-plastic calculations are not to be performed for welded structures, or limited to area away from welded area, except otherwise agreed by the Society.

##### 4.1.2 Material stress-strain curve for elasto-plastic calculations

The material curve is to meet the minimum guaranteed material properties of the component.

It has to be implemented in the elasto-plastic FEM calculation by considering the Cauchy “true” stresses  $\sigma_{true}$  and logarithmic “true” strain  $\epsilon_{true}$  corresponding to the minimum guaranteed “engineering” material properties provided by the manufacturer ( $\sigma_{eng}$  and  $\epsilon_{eng}$ ).

$$\sigma_{true} = \sigma_{eng} \times (1 + \epsilon_{eng})$$

$$\epsilon_{true} = \ln(1 + \epsilon_{eng})$$

The use of bilinear material curve, even if more conservative, may induce numerical divergences. Therefore, a Ramberg-Osgood (R-O) strain hardening law is recommended.

R-O curves describe a non linear relationship between stress and strain.

As a guidance, the R-O relationship and a generic representation Fig 1 of the stress-strain curve are presented below.

$$\epsilon = \frac{\sigma}{E} + \alpha \times \left(\frac{\sigma_0}{E}\right) \left(\frac{\sigma}{\sigma_0}\right)^n$$

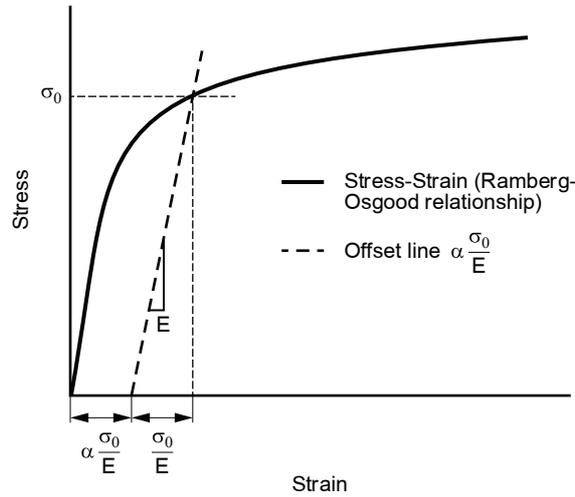
Where:

$\sigma_0$  : Reference stress (generally  $\sigma_0 = \sigma_y$ , yield stress)

E : Young’s Modulus

$\alpha$  and n : Material constants.

Figure 1 : Representation of the stress-strain curve (Ramberg Osgood relationship)



The material hardening curve is to meet the following characteristics (or to be proven more conservative):

- The minimum required yield stress is met at 0,2% plastic strain.
- The material is considered as linear below this limit.
- The tensile stress is met at  $\epsilon_m$ , the minimum guaranteed logarithmic (true) strain at tensile stress
- The material curve may be extended in the calculation for computational stability reasons, or in order to cope with meshing singularities in contact areas between components.

The minimum guaranteed logarithmic (true) strain at tensile stress  $\epsilon_m$  is to be provided by the manufacturer, based on tensile tests of the same grade of material for equivalent component sizes.

Comparison of guaranteed minimum strain at tensile stress with Factory Acceptance Tests (FAT) tensile tests results of components with equivalent material grades and size may be required by the Society.

The minimum guaranteed material properties used in the calculation are to be verified during the FAT of the component, in particular the yield stress at 0,2%, the tensile stress and the corresponding strain level.

In absence of more detailed data, the logarithmic (true) strain at tensile stress  $\epsilon_m$  may be evaluated as follows, as a function of the elongation at break A in percent:

$$\epsilon_m = 0,5 \ln (1 + A)$$

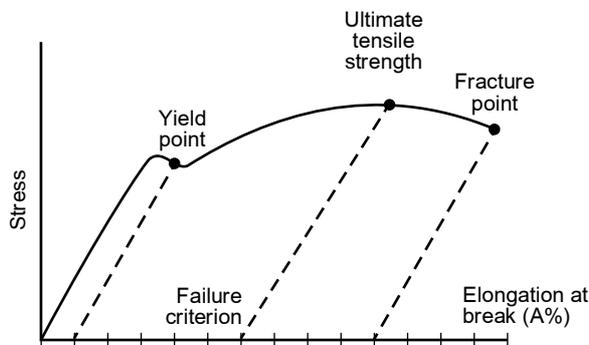
Note 1: This value of  $\epsilon_m$  can be updated based on tensile tests results of previously certified products, to the satisfaction of the Society.

A example of stress-strain curve is given in Fig 2.

**4.1.3 Design criterion**

Due to the thickness of mooring line components, necking is not able to develop in large components, as it may develop in tensile test specimens. Due to this inability of the material to cope with tensile and shear loads, instability of the material will occur that will eventually result in the failure of the material. Due to the unpredictable behavior of the material after necking, the allowable equivalent strain is limited to the minimum guaranteed strain at tensile stress.

Figure 2 : Example stress-strain curve



For a mooring line component, the failure criterion can thus be defined:

- as a local equivalent plastic strain exceeding the strain at tensile stress
- as the onset of large deformation of the component, impairing the functional requirements of the components
- as the excessive loads with regards to material toughness.

The load is to be applied by increment until the failure criterion is met. The failure criterion is not to be met for loads lower than the minimum required failure load in the elasto-plastic calculation, defined as following:

$$L_f = \frac{\beta L_d}{\alpha}$$

where:

$L_d$  : Design load

$L_f$  : Minimum required failure load

$\beta$  : Factor to be taken equal to 1,05 for line components and 1,15 for on-vessel supporting structure and for anchoring pad-eyes

$\alpha$  : Allowable stress factor, as defined in NR445, Pt B, Ch 3, Sec 3.

Note 1: The analysis may be stopped when the minimum required failure load  $L_f$  is met. It is however recommended to continue calculations till failure criterion or first computational instability in order to evaluate calculated breaking load and compare it with minimum breaking load.

#### 4.1.4 Data to be provided for review

The following data are to be provided for the design review:

- The minimum guaranteed material curve used in elastic-plastic calculations and the material tensile tests it is based upon
- Stress and plastic strain outputs at design load and at minimum required failure load, including graphical outputs with relevant cross sections and tabulated results. As a general matter, Von Mises stresses and equivalent plastic strain will be required. Additional stress and strain outputs may be required by the Society on a case-by-case basis
- Charts of stress, plastic strain, and deformations of relevant points of the model with load increment during elasto-plastic calculation.

# Appendix 4 Permanent Mooring Design in Squall Conditions

## 1 General

### 1.1 Purpose and scope

#### 1.1.1 Definition of squall phenomena

The World Meteorological Organization (WMO) defines squall phenomena as sudden wind speed increase of at least 8 m/s with a top speed of at least 11 m/s lasting at least one minute in duration. This definition is usually applied to winds at 10m above Mean Sea Level (MSL), or ground.

**1.1.2** This Appendix provides requirements for the design of permanent mooring systems of floating production units against the effects of squalls, see also Sec 3, [3.1] and Sec 3, [6]. This Appendix includes analysis methodologies and safety factors that are in line with these methodologies for specified target reliability levels.

Note 1: The methodology and requirements for permanent mooring design in squall conditions presented in this Appendix were developed in the SquallMoor Joint Industry Project (JIP) (2016-2022) aim to develop a robust design methodology for a squall governed environment that can be used for mooring system design in general.

The characteristics of the squall time series are defined in Article [2], i.e., the methodology to extract the pure squall from the measurements, and the way to combine it with the background wind are defined.

The considerations for background environment and heading in a squall condition are defined in Article [3].

The Article [4], the design procedure (including calculation of characteristic response, the mooring design equations and specification of safety factors) is defined in Article [4].

### 1.2 Application

#### 1.2.1 Need for site specific squalls database

The SquallMoor JIP studies (see [1.3]) have concluded that both squall wind speed statistics and squall time series are dependent on location/region.

As a rule, site specific squall time series are to be used when applying the design procedure and safety factors in this Appendix. If no time series are available for the location/region in question, an alternative method based on synthetic squalls may be used, as defined in [4.1.6].

#### 1.2.2 Geographical application

As defined in [1.3], the SquallMoor JIP test cases are limited to West African mooring systems in geographical location Congo/Angola and Nigeria. Outside this zone, applicability of some of this Appendix's requirements may be reviewed.

### 1.3 SquallMoor JIP supporting studies and references

**1.3.1** Major assumptions of the studies carried out in the SquallMoor JIP, i.e. used to define the guidance and requirements given in this Appendix, are defined in [1.3.2] [1.3.7].

#### 1.3.2 Squall databases

Extensive mooring analyses have been carried out of a total of 662 squalls (for a database with 331 recorded squall time series from the Congo/Angola region, and 331 time series from Nigeria).

#### 1.3.3 Analyses performed and design methods investigations

Several design methods have been investigated in order to determine the recommended design procedure. They are based on detailed time domain analyses and structural reliability analyses.

#### 1.3.4 Mooring systems considered

Eight moored units have been studied; three spread-moored units and five turret-moored units. The systems are located in areas with varying water depth, from -65 m to -1650 m. The mooring lines composition differ from all chain systems to chain and wire, and chain and polyester systems.

**1.3.5 Ultimate Limit State (ULS) target reliability level**

For the Ultimate Limit State (ULS), two different design procedures are given in this Appendix. The corresponding safety factors are determined for an annual target failure probability of  $P_f = 10^{-5}$ .

**1.3.6 Accidental Limit States (ALS) target reliability level**

For the Accidental Limit State (ALS), a design procedure is given in this Appendix. The corresponding safety factors are determined for an annual target conditional failure probability of  $P_f = 7,5 \cdot 10^{-4}$ .

**1.3.7 Serviceability Limit States (SLS) target reliability level**

For the Serviceability Limit State (SLS), a design procedure is given in this Appendix. The corresponding safety factors are determined for an annual target exceedance probability of  $P_e = 10^{-2}$ .

**2 Squall characterization****2.1 General**

**2.1.1** A set of parameters that characterize squall events, and how to apply a squall times series in an analysis are detailed in [2.2] to [2.4].

The requirements to obtain squall wind speed statistics are detailed in [2.5] to [2.8].

**2.1.2 Conventions**

In this Appendix, wind speed refers to 1-minute average at 10m above MSL. Measured time series may be changed to 1-minute average wind speed when applied to mooring analysis.

It is assumed that measurements contain both background wind and squall.

**2.1.3 Synthetic squalls definition**

A synthetic squall, is a squall time series where the pure squall wind speed increases linearly from 0 to  $V_{MAX}$  (see [2.2.1]) in a time  $T_{rise}$  and then remains constant with time.

The synthetic squall wind direction is constant with time.

**2.2 Squall characterization parameters****2.2.1 General**

A set of squall characterization parameters are defined to characterize a squall event, and to extract the pure squall from the measurements.

Note 1: The pure squall is then recombined with different background wind conditions, see [2.4.4] and Article [3].

Squall specifications include:

- squall steady state parameters
- squall specification parameters.

Squall steady state parameters are as follows:

$V_{max}$  : Means maximum wind velocity. It is defined as the largest wind velocity during the squall event

$\theta_{max}$  : Means squall direction. It is defined as the wind direction at maximum wind velocity  $V_{max}$ .

Squall specification parameters are as follows:

$T_{INC}$  : Means time at the increase point time. The point in time where there is a sudden increase in wind speed due to the squall event.

$T_{1st}$  : Means the Time at the first velocity peak the point in time, after  $T_{INC}$  with a first distinct velocity peak.

$V_{1st}$  : Means wind velocity at the first velocity peak. It is the velocity at  $T_{1st}$ . In many squalls this is the largest velocity peak during the squall event.

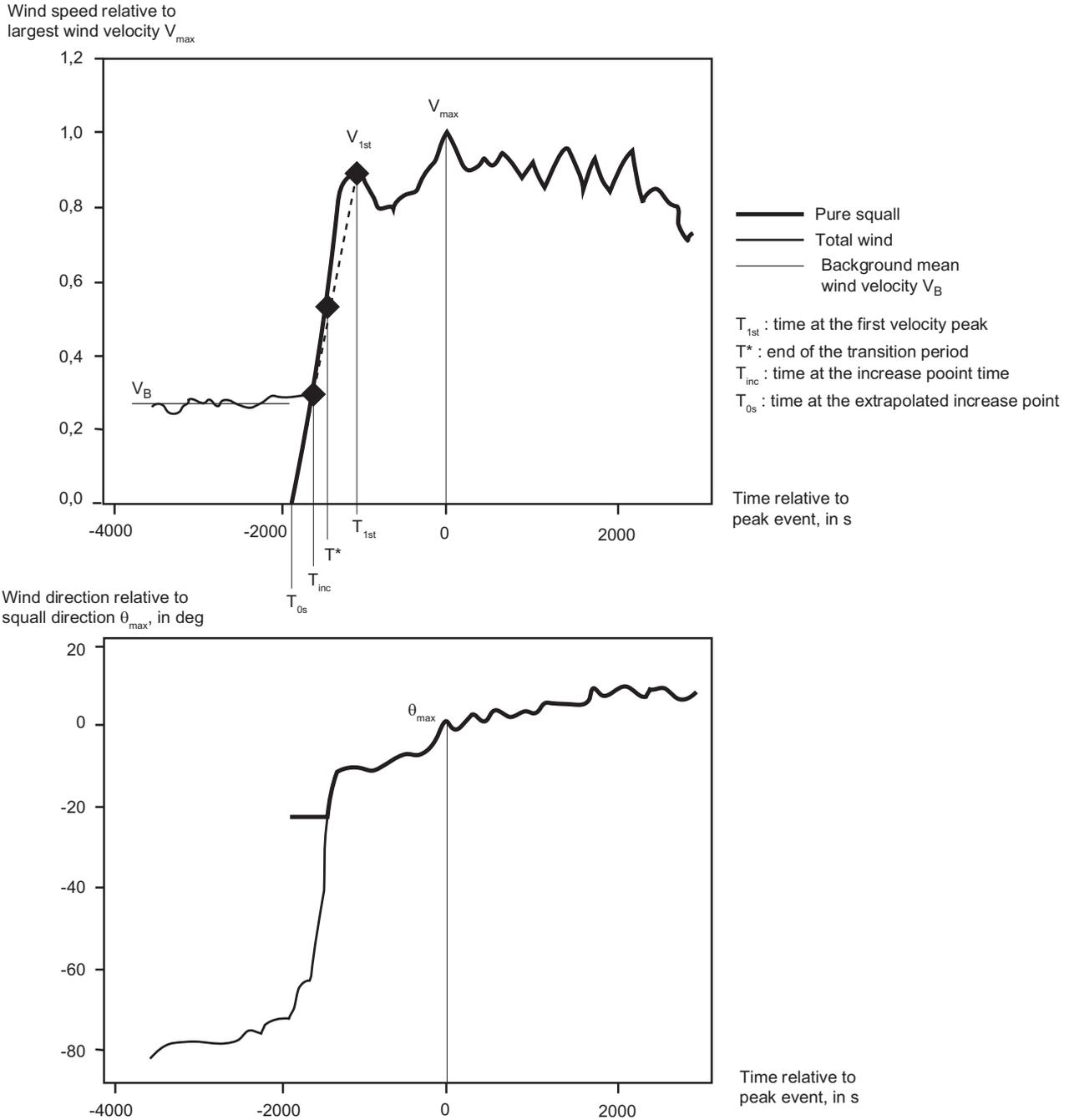
$T_{OS}$  : Means time at the extrapolated increase point. It is found by a straight line from  $V_{1st}$  through the increase point and down to zero velocity. This point identifies the beginning of the squall event, i.e. the switch between initial and transition period defined in [2.3].

In addition to the squall characterization parameters defined above, the following parameters are relevant for the squall characterization and processing:

- $T^*$  : From the processing of the squall event, the time  $T^*$ , representing the end of the transition period, see Tab 1.
- $V_{Br}$  : The background mean wind velocity,  $V_{Br}$  in the initial period, defined as the average wind during the 15 minutes before the extrapolated increase point,  $T_{0s}$ .

These parameters are illustrated in Fig 1.

**Figure 1 : Squall characterization parameters**



## 2.3 Processing of squall event

### 2.3.1 Periods of a squall event

A squall event is defined in 3 consecutive periods defined in Tab 1:

- an initial period
- a transition period
- a pure squall period.

**Table 1 : Periods of a squall event**

Period	Definition
Initial period	Corresponds to the period before onset of the squall, when there is only background wind (pre squall wind). The initial period is the period before the extrapolated increase point, $T_{05}$ is reached. The wind velocity is the background wind velocity, $V_B$ . It is considered as a steady wind.
Transition period	Corresponds to the period when the background wind and the squall wind sum up to a total wind. This is often this transition period that creates a large turn in the wind direction. The transition period is defined as follows: <ul style="list-style-type: none"> <li>• Start: The transition period starts at the extrapolated increase point, <math>T_{05}</math></li> <li>• End: The end of transition period, <math>T^*</math>, depends on the wind velocity at the first velocity peak <math>V_{1st}</math> relatively to the background mean velocity <math>V_B</math>: <ul style="list-style-type: none"> <li>- If <math>V_{1st} &gt; 3V_B</math>, the end of transition period is at the point in time when the measured wind exceeds <math>2V_B</math>.</li> <li>- If <math>V_{1st} &lt; 3V_B</math>, the end of transition is at the point in time when the measured wind exceeds: <math>0,5 (V_B + V_{1st})</math>.</li> </ul> </li> </ul>
Pure squall period	Corresponds to the period after the transition period (i.e. starts at $T^*$ ), when there is only pure squall wind velocity (1). It is assumed that no background wind is present. The wind speed and direction of the pure squall are the one measured.
(1) The pure squall wind velocity is defined before the pure squall period, and start at $T_{05}$ (see Fig 1)	

## 2.4 Application of pure squall

### 2.4.1 Squall direction

The pure squall, identified with the squall direction  $\theta_{max}$ , can be applied from any direction, see also [3.6.5].

### 2.4.2 Scaling of squall

The pure squall can be scaled in terms of  $V_{MAX}$ . The time axis is not to be scaled, as rise time and squall wind speed are uncorrelated.

### 2.4.3 Pure squall wind parameters during the transition period

During the transition period the pure squall wind parameters are as follows:

- The pure squall velocity follows the straight line down to the extrapolated increase point.
- The pure squall wind direction is constant and equal to the direction at the end of transition.

### 2.4.4 Combine pure squall with background wind

At any time, the wind speed equals the maximum of background wind and pure squall. In addition:

- The end of the transition period,  $T^*$ , is found based on the selected background wind speed.
- A linear change in direction is to be applied between the background wind direction at  $T_{05}$  and pure squall direction at  $T^*$ .

### 2.4.5 Squall wind vertical profile

A squall wind vertical profile is to be applied. Unless otherwise specified, the Society, the vertical profile defined in API RP 2MET:2021, Annex A.7.3.4 is to be used. Other vertical profile defined in other standard may be used subject to agreement by the Society.

## 2.5 Squall peak wind speed statistics

### 2.5.1 General

Characteristic squall peak wind speeds are needed for the design criteria defined in Article [4]. As a rule, the following steps are to be considered:

- Wind speed extrapolation, as defined in [2.6].
- Annual frequency calculation, as defined in [2.7].
- Wind speed contours calculation, as defined [2.8].

## 2.6 Squall wind speed extrapolation

### 2.6.1 Fit and long-term distribution

The long-term distribution of squall peak wind speeds is to be determined by a Peak-Over-Threshold analysis.

Note 1: A Weibull distribution gives a good fit to peak squall wind speed data in both the Congo/Angola and Nigeria regions.

### 2.6.2 Directionality

Directionality of squalls is usually important. It is recommended to fit a joint distribution on wind speed and direction which enables to derive directional contours, as defined in [2.8]. If directional data are not available, omni directional statistics complying with [2.8.2] may be applied.

### 2.6.3 Threshold model

Sensitivity analyses are to be performed with respect to the following aspect:

- The threshold of the lowest wind speed included in the analysis
- The fitting procedure (e. g. least square, maximum likelihood or method of moments).

A duly conservative threshold model is to be used, at the Society's satisfaction.

### 2.6.4 Effect of measurement period

Statistical uncertainty in the wind speed extrapolations depends on the duration of the measurement period.

Note 1: Measurement period effect on safety factors is considered in [4.9.7].

### 2.6.5 Application to Congo/Angola and Nigeria

Examples of joint distributions are given here for Congo/Angola and Nigeria.

$$f_{v,\theta}(\theta, V) = f_{\theta}(\theta)f_{V|\theta}(V|\theta)$$

With:

$$f_{\theta}(\theta) = \frac{1}{\sigma\sqrt{2\pi}} \sum_{k=-\infty}^{\infty} \exp\left[-\frac{(\theta - \mu + k \times 360)^2}{2\sigma^2}\right]$$

$$f_{V|\theta}(V|\theta) = \frac{\xi}{\lambda(\theta)} \left(\frac{V-\gamma}{\lambda(\theta)}\right)^{\xi-1} \exp\left[-\frac{(V-\gamma)^{\xi}}{\lambda(\theta)}\right]$$

**Table 2 : Parameters of joint distributions functions for Congo/Angola and for Nigeria**

Parameters of joint distributions functions	
Congo/Angola	Nigeria
$\sigma = 85,1^{\circ}$	$\sigma = 63,2^{\circ}$
$\mu = 53,1^{\circ}$	$\mu = 77,5^{\circ}$
$\zeta = 1,36$	$\zeta = 1,30$
$\gamma = 12$	$\gamma = 15$
$\lambda(\theta) = 2,60 + 0,85^{\circ} \cos(\theta - 45^{\circ})$	$\lambda(\theta) = 2,50 + 1,70^{\circ} \cos(\theta - 80,6^{\circ})$

## 2.7 Annual frequency

### 2.7.1 General

Annual squall frequency  $f_{\text{annual}}$  is an important parameter in order to calculate the design wind speed for specified return periods, when applying [2.8]. The annual squall frequency  $f_{\text{annual}}$  to be used is the annual frequency of squalls having a maximum wind speed higher than the threshold used in the wind speed extrapolation fitting process (see [2.6]).

### 2.7.2 Seasonal variations

The squall frequency is generally season dependent. When estimating the frequency from measurements, the seasonal variation of measurement campaigns and possible downtime of the measuring device, may be considered.

Monthly variations are considered in the expressions in [2.7.3] and in [2.7.4].

**2.7.3 Annual frequency calculations**

Frequency of squall events is based on measurements from several locations and years. For each calendar month, the frequency of squall occurrences  $f_{\text{month}}$  is found as follows:

$$f_{\text{month}} = \frac{N_{\text{squall}}}{N_{\text{months}}}$$

where:

$N_{\text{months}}$  : For a given calendar month (e.g., April), the total number of months with available squall data, considering all years and all locations from the squall database

$N_{\text{squall}}$  : For a given calendar month (e.g., April), the total number of squalls with a wind speed higher than a given threshold, considering all years and all locations from the squall database

Note 1: See also [4.1.6] for the use of squalls from several locations.

The annual frequency is the sum of all the frequency in each month, calculated as follows:

$$f_{\text{annual}} = \sum_{\text{month}} f_{\text{month}}$$

**2.7.4 Application to Congo/Angola and Nigeria**

The annual frequency is 16,2 for Congo/Angola and 21,6 for Nigeria.

**2.8 Wind speed contours**

**2.8.1 Inputs**

The directional wind speed contour is to be computed from the joint wind speed and direction distribution and the annual frequency, for the return period given in the design procedure (see Article [4]).

**2.8.2 Omni-directional contour**

The omni-directional wind speed is computed using the marginal wind speed distribution and the annual frequency, without using any information on squall directions.

**2.8.3 Allowed directional contour methodologies**

The allowed options for directional wind speed contour methodologies are as follows:

- BV reference directional contour methodology, as defined in App 2, [2.2]
- NORSOK directional contour methodology (based on NORSOK N-003:2017 Actions and actions effects, see App 2, [2.2])
- a directional contour more conservative than the NORSOK contour.

On a case-by-case basis, to the satisfaction of the Society, another type of directional contour may be considered. In any case, the safety factors considered for the different limit states verifications are to reflect the type of contour considered, see [4.9.6].

**2.8.4 Example of Congo/Angola and Nigeria**

Examples of directional contours for 10, 100 and 1000 years return period are given for Congo/Angola in Tab 3 and Fig 2 and Nigeria in Tab 4 and Fig 3. Squall direction is defined clockwise from North, using a “coming from” direction convention.

These contours have been derived from a total measurement duration  $D = 22,4$  years in Congo/Angola and  $D = 17,0$  years in Nigeria.

**Table 3 : Wind speeds for Congo or Angola mooring regions**

Squall direction	BV contour model			NORSOK contour model		
	RP = 10 years	RP = 100 years	RP = 1000 years	RP = 10 years	RP = 100 years	RP = 1000 years
omni	22,2	25,6	28,9	22,2	25,6	28,9
0	21,1	24,4	27,4	22,0	25,4	28,5
15	21,7	25,0	28,2	22,2	25,6	28,9
30	22,0	25,5	28,7	22,2	25,6	28,9
45	22,2	25,6	28,9	22,2	25,6	28,9
60	22,1	25,5	28,7	22,2	25,6	28,9
75	21,8	25,1	28,3	22,2	25,6	28,9
90	21,3	24,5	27,5	22,2	25,6	28,7
105	20,6	23,7	26,6	21,5	24,7	27,6
120	19,9	22,8	25,4	20,7	23,7	26,4
135	19,1	21,7	24,2	19,8	22,6	25,2

Squall direction	BV contour model			NORSOK contour model		
	RP = 10 years	RP = 100 years	RP = 1000 years	RP = 10 years	RP = 100 years	RP = 1000 years
150	18,2	20,7	23,0	18,9	21,5	23,9
165	17,5	19,8	21,9	18,1	20,5	22,7
180	16,8	19,0	20,9	17,4	19,6	21,6
195	16,3	18,3	20,1	16,8	18,9	20,8
210	15,9	17,9	19,6	16,5	18,5	20,3
225	15,7	17,7	19,4	16,3	18,3	20,1
240	15,8	17,8	19,5	16,4	18,4	20,2
255	16,1	18,1	20,0	16,7	18,8	20,7
270	16,6	18,7	20,7	17,2	19,4	21,4
285	17,2	19,5	21,7	17,9	20,3	22,5
300	18,0	20,5	22,8	18,7	21,3	23,7
315	18,8	21,5	24,0	19,6	22,4	24,9
330	19,6	22,6	25,3	20,5	23,5	26,3
345	20,4	23,5	26,4	21,3	24,5	27,5

**Table 4 : Wind speeds for Nigeria mooring region**

Squall direction	BV contour model			NORSOK contour model		
	RP = 10 years	RP = 100 years	RP = 1000 years	RP = 10 years	RP = 100 years	RP = 1000 years
omni	28,7	33,4	37,8	28,7	33,4	37,8
0	22,9	26,1	29,1	24,2	27,5	30,5
15	24,6	28,2	31,7	26,1	29,8	33,3
30	26,1	30,2	34,0	27,8	31,9	35,8
45	27,4	31,7	35,8	28,7	33,4	37,8
60	28,3	32,8	37,1	28,7	33,4	37,8
75	28,7	33,4	37,8	28,7	33,4	37,8
90	28,6	33,2	37,6	28,7	33,4	37,8
105	28,0	32,5	36,8	28,7	33,4	37,8
120	27,0	31,3	35,3	28,7	33,1	37,2
135	25,6	29,6	33,3	27,2	31,3	35,0
150	24,0	27,5	30,9	25,4	29,1	32,4
165	22,3	25,4	28,3	23,5	26,7	29,6
180	20,6	23,3	25,7	21,7	24,4	26,8
195	19,1	21,3	23,3	20,0	22,2	24,2
210	17,8	19,6	21,2	18,6	20,4	22,0
225	16,9	18,3	19,6	17,5	18,9	20,2
240	16,3	17,5	18,6	16,8	18,0	19,1
255	16,0	17,1	18,1	16,5	17,5	18,5
270	16,1	17,2	18,2	16,5	17,7	18,6
285	16,5	17,8	18,9	17,0	18,3	19,4
300	17,3	18,8	20,1	17,9	19,4	20,7
315	18,3	20,2	21,9	19,1	20,9	22,6
330	19,7	21,9	24,0	20,6	22,9	25,0
345	21,2	24,0	26,5	22,3	25,1	27,7

Figure 2 : Wind speeds for Congo/Angola

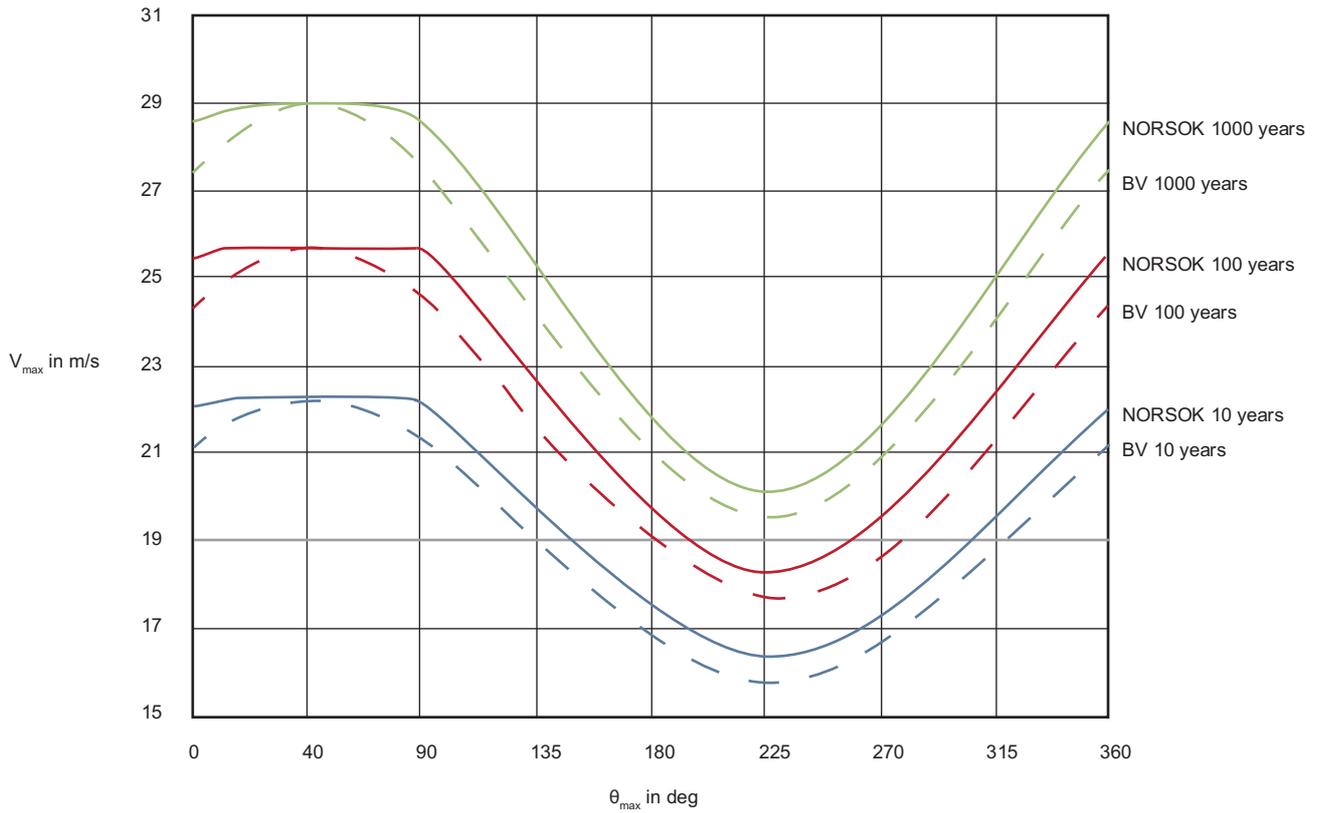
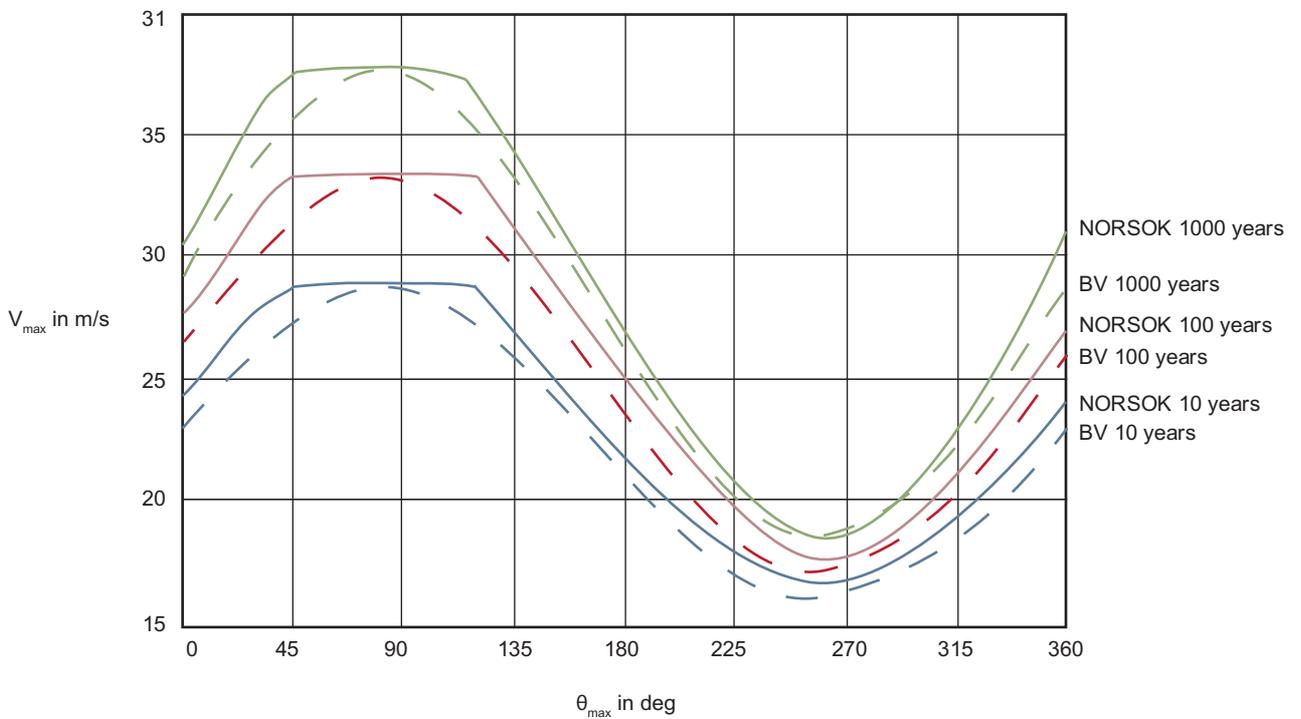


Figure 3 : Wind speeds for Nigeria



### 3 Background environment conditions and heading

#### 3.1 General

**3.1.1** This Article defines a methodology to account for the background environment and heading when performing mooring analysis with squalls:

- Background environment is defined in [3.2].
- Requirements for heading angles selection in line with this background environment are defined in [3.3].
- The overall procedure for background environment combinations is defined in [3.4].
- Requirements for background environment intensities and directions are defined in [3.5] and [3.6]. Application to Angola location is defined in [3.7].

Note 1: Environmental conditions for ULS/ALS/SLS design to non-squall events are covered by Sec 3.

#### 3.2 Background environment

##### 3.2.1 General

The background environment,  $\psi$ , is defined as the combination of:

- Waves (swells, wind seas), as defined in [3.2.2] and [3.3.3]
- Current, as defined in [3.2.4]
- Background wind, at the time of squall occurrence, as defined in [3.2.5].

The background environment is defined in terms of both intensity and direction.

##### 3.2.2 Waves definition

Waves are described as a combination of swell and wind-sea.

Swell is often a combination of several independent swell systems, but the strongest sea states usually show unimodal swell.

##### 3.2.3 Waves parameters

Wave parameters ( $H_s$ ,  $T_p$ ) intensities and wave directions are to be selected as per [3.5] and [3.6].

In addition, as for non squall events, the followings apply:

- Several realizations of the sea states (characterized by a number of seeds) are needed to consider short-term variability of the wave conditions.
- Sea state modelling is to comply with Sec 3, [3.1.1].  
Associated wave parameters are to comply with Sec 3, [10.4.4] and with applicable requirements of App 2, [2.3].

##### 3.2.4 Current

Current speed and direction are to be selected as per [3.5] and [3.6].

##### 3.2.5 Background wind

As defined in [2.2] and in [2.3], the background wind is defined as the wind before the squall event occurs. It is considered as a steady wind (no turbulence). The background wind is combined with the pure squall wind as specified in [2.4.4].

### 3.3 Heading distribution

#### 3.3.1 General principles

The following general principles for headings are to be assumed:

- For turret mooring systems, the initial vessel heading before a squall event depends on the background environment,  $\psi$ .
- The probability distribution of initial heading (referred to as the heading distribution), can be obtained based on the long-term conditions of  $\psi$ .
- The heading distribution can be established by performing static calculations for all sea states,  $\psi$ , available for design.

#### 3.3.2 Influence of environmental parameters

The probability distribution of heading depends on the intensities and directionality of the components of  $\psi$ . The followings may be seen for the peaks in the heading distributions:

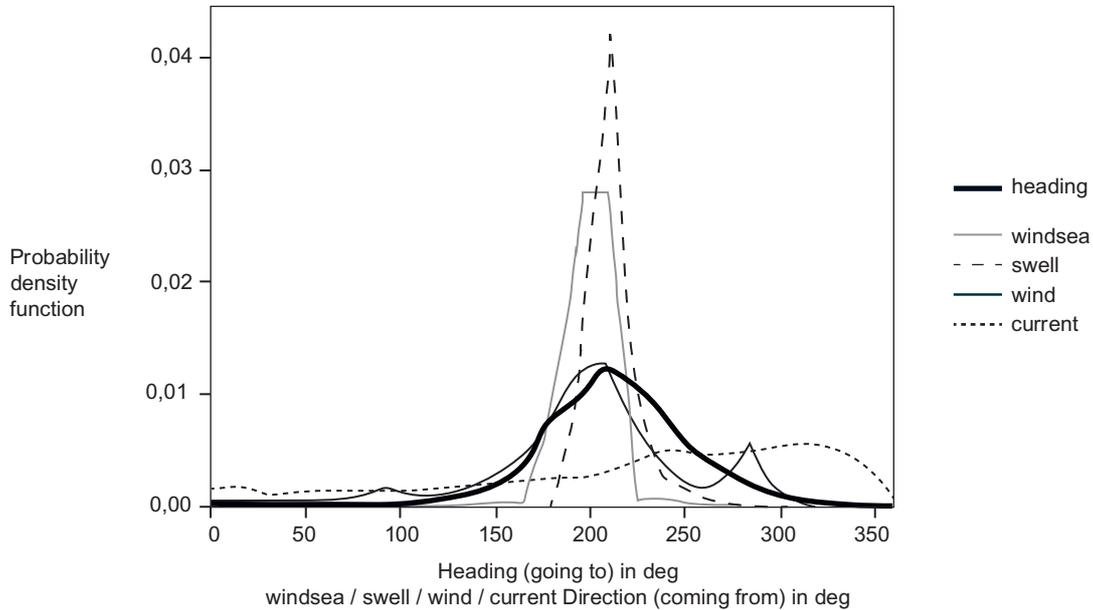
- With swell dominant from one direction, and background wind from another, two distinct peaks might occur for the heading distribution. If currents prevail from a 3rd direction, three peaks may be seen.
- The current may have less directional preference than background wind and swell and tends to widen the peaks in the resulting heading distribution.
- If current with no directional preference governs the heading distribution, this may result in a heading distribution with no distinct peaks.

**3.3.3 Design headings**

The heading distribution is useful for the only-squall condition, as all effects of  $\psi$  are simplified into one new parameter, the heading. All distinct heading peaks are to be considered for the analysis. If there are no available data, or if the heading distribution is uniform, all headings of 30deg spacing may be considered.

A precise definition of what is a distinct heading peak is not given herein. The design headings to consider may be agreed with the Society, based on the available heading distribution. Fig 4 illustrates an example of a distinct heading peak, as well directionality of other components of  $\psi$ .

**Figure 4 : Example of a distinct heading peak based on 2 years of measurements in Angola**



**3.4 Procedure for background environment combinations**

**3.4.1 Only-squall condition**

The only-squall condition, as defined in Step 1 of the characteristic response calculation procedure defined in [4.3], may be calculated. This provides a reference case analysis before the effect of background environment,  $\psi$ , is introduced.

**3.4.2 Background environment combinations**

All relevant combinations of background environment,  $\psi$  are to be considered, as defined in [3.5] and [3.6]. The most severe background condition,  $\psi_b$ , with respect to tension is to be identified. This may be done by estimation using a reduced set of squalls, as defined in the steps 2 and 3 of the characteristic response calculation procedure (see [4.3]).

**3.4.3 Final design tension**

The final design tension is to be recalculated for the entire squall database applying the estimated most severe background condition. A reduction in tension relative to the only-squall condition is allowed.

**3.5 Background environment intensities**

**3.5.1 Correlation with squall event**

Squall events are uncorrelated with the background environment  $\psi$ . Background environment may therefore be considered fully independent from the squall event.

Note 1: The reason of this lack of correlation is the time scale of the squall event being far too short to have a significant influence on wave and current.

The background environment may then be added with only mild intensities, as defined in [3.5.2].

**3.5.2 Intensity levels to consider**

The intensities of 10%, 50% and 90% for components within  $\psi$  may be considered. Intensities other than median (50%), may be considered for the components within  $\psi$  only one by one while remaining components are kept at the median value.

These intensities are to be considered as probability of non-exceedance for an environmental parameter, see App 2, [2.2].

**3.5.3 Seasonal effects**

If seasonal background conditions during squall season are more severe than all-year background conditions, these seasonal conditions may be applied instead of all-year background conditions.

Note 1: Seasonal effects are typically relevant for the Congo/Angola and Nigeria regions.

### 3.6 Background environment directions

#### 3.6.1 Correlation

Owing to lack of correlation, the background wind, the swell and the current are to be taken as acting independently. Any combination of directions may be considered, each over all possible directions. The wind sea may be considered correlated to the background wind.

#### 3.6.2 Directions to consider

As function of each environmental parameter distribution available information and features, the following approaches are to be considered:

- Distribution with one distinct peak: a single direction of the distinct peak is to be considered.
- Distribution with several distinct peaks: the direction of each peak is to be considered.
- Distribution is uniform or not available: all directions are to be considered.

#### 3.6.3 Inconsistent combinations for turrets

For turrets, any combination of  $\psi$  leading to an initial heading that is inconsistent with the heading distribution may be disregarded. For a heading distribution with one peak, inconsistent results are considered those outside the range of 10% to 90% in the cumulative distribution of heading.

#### 3.6.4 Worst directions

Depending on the directionality of components within  $\psi$ , there may be many combinations of  $\psi$  to be considered.

Reductions of background environment combinations may be considered (see screening phase in [4.3]), if the directional combinations that typically lead to severe squall events are considered:

- Spread: The worst direction is typically what is referred to as beam on, from the same side as the severe squall wind speed.
- Turret: The worst squall direction,  $\theta_{max}$ , from the only-squall condition may be identified.  
Further, the combination of  $\psi$  may result in a heading that points in the opposite direction of  $\theta_{max}$ , so that the vessel must rotate towards  $\theta_{max}$  and possibly get  $V_{max}$  beam on during the rotation.

#### 3.6.5 Squall directions angle step

Squall directions are to be applied in the mooring analysis for every 15deg.

### 3.7 Example of background environment combinations for Angola

#### 3.7.1 Suggested combinations

Tab 5 gives the combinations suggested for Angola. F(X) denotes the intensity that is used for each parameter, while Dir denotes the direction.

For the directions, the following conventions are used:

- “Peak” means the distinct peak in the respective directional distributions. For Angola, it is applicable for the direction of background wind and swell, see Fig 4.
- “All” means that all directions are considered due to the more uniform directional distribution. For Angola, it is applicable for current.

The other assumptions are as follows:

- The wind sea is considered correlated to the background wind, as defined in [3.6.1].
- The variation of intensity is not carried out for the background wind and wind sea, because the wind sea is low, and the tension is found insensitive to the intensity of background wind.

**Table 5 : Background environment combinations suggested for Angola**

Background wind		Swell		Current	
F(x)	Dir	F(x)	Dir	F(x)	Dir
50%	Peak	50%	Peak	10%	All
50%	Peak	50%	Peak	90%	All
50%	Peak	10%	Peak	50%	All
50%	Peak	50%	Peak	50%	All
50%	Peak	90%	Peak	50%	All

#### 3.7.2 Vessel initial heading

For the Angola data, it is the wind that governs the initial vessel heading. The most severe current direction is found aligned with  $\theta_{max}$ , which further increases the tension of the mooring line.

## 4 Design procedure and design criteria

### 4.1 General considerations

#### 4.1.1 Design criteria considered

Procedure and criteria for different limit states are defined in this Article. The criteria considered are as follows:

- Ultimate Limit States (ULS). It is a criterion for mooring line strength verification with an intact mooring system.
- Accidental Limit States (ALS). It is a criterion for mooring line strength verification with a damaged mooring system.
- Serviceability Limit States (SLS). It provides a characteristic response for mooring line, mooring force and offset calculation, see [4.1.2].

#### 4.1.2 Use of SLS characteristic responses

As defined in Sec 3, [6], the SLS characteristic responses (tension  $T_{SLS}$ , offsets, mooring forces) are to be considered as the representative design responses to be used in any design verification as for non-squall events, such as:

- The design tension  $T_D$  for the anchors criteria, defined in Sec 3, [11.2]
- The design tension  $T_D$  for the anchors and mooring lines load testing criteria, defined in Sec 3, [11.5]
- The design tension  $T_D$  for the mooring equipment design criteria, defined in Sec 4, [8.2]
- The design tension  $T_D$  and the load cases for the foundations of the items mentioned in Sec 4, [8], as per the applicable rules.

Note 1: For a FPSO, the mooring equipment foundations requirements are defined in NR445, Pt D, Ch 1, Sec 14, [1].

- The minimum characteristic tension for fibre ropes elements, when applicable, see [4.5.6] and Sec 3, [11.1.4]
- The mooring line positions for the minimum clearance criteria, defined in Sec 3, [11.3].

The squall design tension  $T_D$  is not to be used for the mooring line strength criteria for non squall events defined in Sec 3, [11.1], and is not to be used for the fatigue criteria defined in Sec 3, [11.4].

#### 4.1.3 Definitions

The following definitions are assumed for the characteristic response evaluation and the application of the design criteria:

- Squall direction: As defined in [2.2], it corresponds to the direction of the squall at the time when the maximum (peak) wind speed occurs
- Synthetic squall: As defined in [2.1.3], it corresponds to an idealized pure squall event from 0 to  $V_{max}$  in a time  $T_{rise}$
- Vessel heading: The initial heading of the vessel when the squall phenomenon starts at  $T_{OS}$
- Heading distribution: As defined in [3.3], for a turret unit only, it corresponds to the long-term distribution of vessel heading based on the background environmental conditions
- Background environment combinations: As defined in Article [3], the combinations corresponding to the 10%, 50% and 90% probability of non-exceedance for the background environment
- Mooring force: Horizontal mooring force, denoted mooring force for simplicity in this Article, being equals to the total restoring force from all mooring lines in the horizontal direction.

#### 4.1.4 Symbols

The following symbols are considered in this Article:

- N : number of available squall time series used in the design procedure
- RP : return period for squall wind speed used to compute the characteristic response
- Q : quantile used to compute the characteristic response
- n : reduced number of squall time series used in the screening phase (see [4.3])
- $X_{char}$  : characteristic response (tension, offset, mooring force) computed by the design procedure
- $T_{Char}$  : characteristic tension computed by the design procedure
- $Q_n$  : quantile used in the screening phase (see [4.4.4]).

#### 4.1.5 Mooring analyses

For the characteristic response calculation, defined in [4.3] and in [4.4], the followings are to be considered for the mooring analyses:

- Environment conditions, including background environment and squall event, are to be modelled as defined in this Appendix, and supplemented by Sec 3, [3.1] and by App 2, [2.3].
- Environment loads are to be modelled as defined in Sec 3, [3.2].

- c) For the methods of evaluation defined in Sec 3, [2], a fully coupled analysis and, when applicable, a dynamic analysis or a quasi-dynamic analysis may be performed.

Note 1: Applicability of quasi-dynamic analysis is defined in Sec 3, [2.3] and in Sec 3, [5.3].

- d) For the unit response, time domain analyses are required, or a combination of time domain and frequency domain, as defined in Sec 3, [2] and in Sec 3, [3].
- e) Line tensions are to be computed in the time domain, as defined in Sec 3.
- f) As a rule, sensitivity studies to the different parameters that may affect the results, are to be performed as defined in Sec 3, [10.8].

#### 4.1.6 Squall conditions inputs data

To correctly account for the squall effects, the followings aspects are to be considered:

a) Squall time series

- A database of N unique squall time series is generally required.  
The background wind may be removed from the signal prior to the response analysis, as defined in Article [2].
- Squall time series from a single location/region may be used in the design procedure.

Note 1: As defined in [1.3.2], squall time series are dependent on location/region.

- If no time series are available for the location/region in question, an alternative method based on synthetic squalls is to be used, with synthetic squall parameters defined for each limit state in [4.6] to [4.8].

The applicability of the measured time series or the synthetic squall is given for each limit state in [4.6] to [4.8], as function of the available number of squall time series.

b) Squall wind speed contour

In any cases, the squall wind speed directional contours at different return periods are required (see also [4.2.2]).

Note 2: As defined in [1.3.2], squall wind speed statistics are dependent on location/region.

## 4.2 Inputs data for characteristic response evaluation

### 4.2.1 Squall time series

The squall time series to be used in the computation of the characteristic response is either the N available squall time series, or the synthetic squall (N=1 in this case), where applicable (see [4.1.6]).

### 4.2.2 Squall wind speed contour

The directional squall peak wind speed contours, at the different return period RP (that may differ for the different criteria, see Tab 5), are to be given. The directional contour is to comply with [2.8]. If the directional contour is not available, the omnidirectional wind speed at the return period RP is to be considered.

### 4.2.3 Squall wind speeds rescaling

The wind speed of all the squall time series is to be rescaled, as per [2.4.2], to the directional dependent wind speed of the specified return period RP.

Note 1: It is reminded that the time axis is not to be scaled. The direction is not to be scaled.

## 4.3 Characteristic response evaluation procedure

### 4.3.1 General

The characteristic response is computed for each limit state (SLS, ALS, ULS), and for each unit state conditions (see Sec 3, [10.2]) in different steps as follows:

- Step 0 - Inputs data rescaling  
Processing of the squall time series database and squall wind speed contours as per [4.2], considering the return periods defined in [4.6] to [4.8].
- Step 1 - Squalls-only selection of n squall time series for worst background environment identification, see [4.3.3].  
The first step performs only-squall conditions mooring analyses, i.e. without background environment. It aims at selecting a reduced number of squalls n for the worst background.
- Step 2 - Worst background environment identification, see [4.3.4]  
The second step is a screening phase, where all the background environment combinations are used together with the n squall time series selected in the step 1.
- Step 3 - Characteristic response calculation on the worst background environment, see [4.3.5]  
The third step is the characteristic response calculation ( $X_{Char}$  and  $T_{Char}$ ) on the worst background environment  $\psi_b$ , for all the N squall time series.

The characteristic responses and tensions ( $X_{Char}$  and  $T_{Char}$ ) are then to be used in the mooring design equations (see [4.5]).

Details on the characteristic response computations associated to this procedure are defined in [4.4].

### 4.3.2 Analyses to consider

For a given scaled squall time series and a given background environment combination, the response analyses (e. g. for tension, offset, mooring force) are to be calculated considering the followings:

- all squall directions (see [3.6.5])
- all selected initial headings of the vessel (see [3.3])
- all sea states realizations (also referred to as seeds), see [3.2.3] and [4.4.2].

### 4.3.3 Process for step 1

For the step 1, the followings apply:

a) Squall time series and background environment:

- The complete squall data base of N time series is to be considered
- The background environment is not considered (squall-only conditions).

b) Analyses to perform:

For each squall time series, the analyses to consider are given in [4.3.2].

In particular, for a turret unit, the initial selected headings of the vessel are to be selected as follows:

- Heading distribution with one distinct peak: most probable heading is to be selected.
- Heading distribution with several distinct peaks: all significant distinct peaks are to be selected.
- Heading distribution is not available: all headings are to be used in the analysis, with step of 30deg.

c) Maximum responses calculation:

The N maximum responses  $\{x_i, i=1, \dots, N$  are calculated by application of [4.4.2], and ordered in an increasing order.

d) Outputs:

The n squall time series are selected by application of [4.4.3].

This step 1 is not applicable for synthetic squalls.

### 4.3.4 Process for step 2

For the step 2, the followings apply:

a) Squall time series and background environment:

- The selected n squall time series from step 1 are to be applied
- The different background environment combinations, following application of Article [3], are considered

b) Analyses to perform:

For each squall time series and for each background environment, the analyses to consider are given in [4.3.2].

In particular, the initial heading of the vessel is the equilibrium heading computed in each background environment.

c) Output:

The worst background environment combination  $\psi_b$  is obtained by application of [4.4.4].

Note 1: The worst background environment combination is unique, i.e. it is the same for all the squall time series.

### 4.3.5 Process for step 3

For the step 3, the followings apply:

a) Squall time series and background environment:

- The entire squall database time series (i.e. N) are to be applied
- The single worst background environment  $\psi_b$  calculated in step 2 is considered

b) Analyses to perform:

For each squall time series, the analyses to consider are given in [4.3.2].

In particular, the initial heading of the vessel is the equilibrium heading computed in the selected background environment.

c) Output:

The characteristic response and tension ( $X_{Char}$  and  $T_{Char}$ ) are found by application of [4.4.5]

## 4.4 Characteristic response calculation

### 4.4.1 Calculation of characteristic value from an empirical distribution

In general, for a sample of N squalls, the characteristic response  $x_Q$  corresponding to a given quantile Q is calculated by the following steps:

a) Calculations of the N maximum responses through:

- Running different analyses, see [4.3.2]
- Performing the N maximum value identification, as defined in [4.4.2]

b) Ordering of the N values  $\{x_i\}, i=1, \dots, N$  and calculation of the empirical distribution  $F(x_i)$ , determined as follows:

$$F(x_i) = \frac{i}{N+1}$$

c) Calculation of the characteristic response  $x_Q$  by evaluating the empirical distribution  $F(x_i)$  at a specified quantile Q, as follows:

$$x_Q = F^{-1}(Q)$$

- If Q is not a multiple of  $1/(N+1)$ , the characteristic response is calculated e.g. by linear interpolation.
- If  $Q > N/(N+1)$  the maximum response of all squalls is to be used.

**4.4.2 Maximum value identification**

For all the analyses mentioned in [4.3.2], the maximum response for a given squall event and a given background environment is calculated as follows:

- For a given analysis, the maximum response is to be identified (over all lines for tensions, or over all directions for offsets or mooring forces).
- For a given squall time series, a characteristic response to capture the wave conditions short term variability is to be calculated.

This characteristic response is calculated from a set of  $n_{seeds}$  using the short-term estimator defined in Sec 3, [6.2.3].

- For a given squall time series, the maximum response over all the squall directions and all the selected initial headings of the vessel is identified.

Each squall then produces one single value for each response of interest (e.g.tensions, offset, mooring force).

**4.4.3 Calculations for step 1**

The n among the N squall time series to be selected in the first step (see [4.3.3]) are the squall time series corresponding to the ordered responses  $x_{j+1-n}$  to  $x_j$ , where j is defined as follows:

$$j = \min \left\{ \left[ Q \times (N + 1) + \frac{n}{2} \right], N \right\}$$

The value of j is to be rounded down to the nearest integer.

n is not to be less than 5.

**4.4.4 Calculations for step 2**

In the step 2 (see [4.3.4]) the worst background environment is calculated as follows:

- a) For each background environment, the characteristic response is calculated by the application of [4.4.1]:
- Calculation of the maximum values  $\{x'_i\}, i=1, \dots, n$ , by application of [4.4.2], and ordering of the responses  $\{x'_i\}, i=1, \dots, n$ ,
  - Empirical distribution calculation  $F(x'_i)$ , determined as follows:

$$F(x'_i) = \frac{i}{n+1}$$

- Calculation of the adjusted quantile  $Q_n$  for the n selected squall time series,  $Q_n$  is an adjustment of the quantile Q as only a subset of squalls is considered, and it is defined as follows:

$$Q_n = \frac{Q(N+1) + n - j}{n+1}$$

- Design response estimation from  $F(x'_i)$  and  $Q_n$ ,

The characteristic response  $x'_Q$  is estimated by reading off the value of  $F(x'_i)$  at  $Q_n$  as follows:

$$x'_Q = F^{-1}(Q_n)$$

If  $Q_n$  is not a multiple of  $1/(n+1)$ , the characteristic response  $x'_Q$  is calculated e.g., by linear interpolation

If  $Q_n > n/(n+1)$  the maximum response of all squalls is to be used to get the characteristic response  $x'_{Qn}$

- b) The worst background environment combination  $\psi_b$  is the background environment giving the highest estimated characteristic response  $x'_{Qn}$ .

**4.4.5 Calculations for step 3**

In the step 3, the empirical distribution is computed from all the N squall time series in the worst background environment.

The characteristic response and tension ( $X_{Char}$  and  $T_{Char}$ ) is found by application of [4.4.1] with the N squall time series.

**4.5 Design criteria format for ULS, ALS and SLS**

**4.5.1 ULS**

For ULS, two design criteria are defined, using the same design format but two different characteristic tensions and different partial safety factors.

These two criteria, referred to as ULS1 and ULS2 in this Article, constitute two possible alternatives for the ULS mooring line strength verification.

Only one of the criteria is to be used, ULS1 or ULS2, see [4.5.2].

The sets of safety factors, defined in [4.9], are given for the same annual target failure probability of  $P_f = 10^{-5}$ , see also [1.3].

**4.5.2 ULS2 and ULS1**

The ULS2 design criteria, based on 1000 yr RP environmental conditions, may preferably be used over ULS1 design criteria (based on 100 yr RP and relatively larger base case safety factors, as defined in [4.9.5]).

Note 1: ULS2 provides a more consistent reliability level across various units and various site conditions.

**4.5.3 ALS**

For ALS, a design equation is proposed.

The safety factors, defined in [4.9], are given for the annual target conditional failure probability of  $P_f = 7,5 \cdot 10^{-4}$ , see also [1.3].

**4.5.4 ULS and ALS mooring line strength design format**

The following design equation is to be applied for ULS and ALS to determine the maximum allowable tension in the mooring lines for mooring line strength:

$$MBL = \gamma_m \gamma_{fibre} (\gamma_p T_{pre} + \gamma_{env} T_{env})$$

MBL : Minimum breaking load, as defined in Sec 3, [9].

$T_{pre}$  : Pretension

$T_{env}$  : Environmental tension, defined as follows:

$$T_{env} = T_{Char} - T_{pre}$$

$T_{char}$  : Characteristic tension, as calculated by the procedure defined in [4.3], for the return periods and response quantile defined in [4.6] for ULS and in [4.7] for ALS

$\gamma_m$  : Safety factor on material strength, see [4.9.1]

$\gamma_{fibre}$  : Additional safety factor for fibre ropes elements, as defined in [4.9.3]

$\gamma_p$  : Safety factor on pretension, see [4.9.2]

$\gamma_{env}$  : Safety factor on environmental tension, see [4.9.4].

**4.5.5 SLS design format**

For the Serviceability Limit State (SLS), the characteristic response is to be calculated as follows:

$$X_{SLS} = \gamma_p X_{pre} + \gamma_{env} X_{env}$$

With:

$X_{SLS}$  : Characteristic response (e.g., tension, offset or mooring force) for SLS

$X_{pre}$  : Pretension, equals to 0 for offset and mooring force

$X_{env}$  : Environmental tension, offset or mooring force, defined as:

$$X_{env} = X_{Char} - X_{pre}$$

$X_{char}$  : Characteristic tension, offset or mooring force (see [4.3] and [4.8]).

$\gamma_p, \gamma_{env}$  : See [4.5.4]

The safety factors, defined in [4.9], are given for the annual target exceedance probability of  $P_f = 10^{-2}$ , see also [1.3].

Note 1: The characteristic response in SLS is sometimes incorrectly referred to as 100 years return period response. This would be correct for pure aleatory uncertainties in the estimation of SLS response, however epistemic uncertainties are also taken into account.

For the minimum tension criteria, the characteristic tension is to be calculated as defined in [4.5.6].

**4.5.6 SLS minimum tension**

For mooring system with fibre ropes elements, a minimum tension may be required, see NR432, Sec 7, [4,2]. The SLS characteristic tension  $T_{SLS,min}$  to be used in this minimum tension verification, is to be calculated as follows:

$$T_{SLS,min} = \frac{1}{\gamma_p} T_{pre} - \gamma_{env} T_{env,min}$$

with:

$T_{env, min}$  : Minimum environmental tension, defined as:

$$T_{env, min} = T_{Char, min} - T_{pre}$$

$T_{Char, min}$  : Characteristic tension, obtained as the minimum value instead of the maximum value when applying the procedure defined in [4.3], with return periods and response quantile defined in [4.8].

$\gamma_p, \gamma_{env}$  : See [4.5.4]

### 4.6 Characteristic values for ULS1 and ULS2

#### 4.6.1 ULS1

For ULS1, the following assumptions are to be considered:

- The squall wind speed return period is 100 years.
- As function of the number of available unique squalls in the squall database, different approaches are to be followed for ULS1 characteristic tension computation:
  - If  $N < 10$  the characteristic tension is to be computed with the synthetic squall with  $T_{rise} = 108s$
  - If  $N \geq 10$  the characteristic tension is to be computed with the squall time series, and the response quantile  $Q = 95\%$

#### 4.6.2 ULS2

For ULS2, the following assumptions are to be considered:

- The squall wind speed return period is 1000 years.  
If the 1000 years wind speed contour is not available, the 100 years wind speed contour is to be multiplied by 1,13.
- As function of the number of available unique squalls in the squall database, different approaches are to be followed for ULS2 characteristic tension computation:
  - If  $N < 25$  the characteristic tension is to be computed with the synthetic squall with  $T_{rise} = 102s$
  - If  $N \geq 25$  the characteristic tension is to be computed with the squall time series, and the response quantile  $Q = 97\%$ .

### 4.7 Characteristic values for ALS

#### 4.7.1 Design conditions and system configurations

The characteristic tension is to be computed with one mooring line removed. Sec 3, [10.3].

Note 1: Mooring line failure conditions (transient between intact conditions and damaged conditions), as defined in Sec 3, [6.4] is not applicable to design against squall wind conditions.

#### 4.7.2 Return period

The characteristic values in ALS are to be calculated using a squall wind speed return period of 100 years.

#### 4.7.3 Number of squalls and appropriate approach

As function of the number of available unique squalls in the squall database, different approaches are to be followed for ALS characteristic tension computation:

- If  $N < 10$  the characteristic tension may be computed with the synthetic squall with  $T_{rise} = 117s$
- If  $N \geq 10$  the characteristic tension may be computed with the squall time series, and the response quantile  $Q = 95\%$ .

### 4.8 Characteristic tension, offset and mooring force in SLS

#### 4.8.1 Characteristic values for SLS and associated criteria

The characteristic value of tension, offset and mooring force is used in various verification mentioned in [4.1.2].

#### 4.8.2 Return period

The characteristic values in SLS are to be calculated using a squall wind speed return period of 10 years.

#### 4.8.3 Number of squalls and appropriate approach

As function of the number of available unique squalls in the squall database, different approaches are to be followed for SLS characteristic response computation:

- If  $N < 10$  the characteristic tension may be computed with the synthetic squall with  $T_{rise} = 135s$ .
- If  $N \geq 10$  the characteristic tension may be computed with the squall time series, and the response quantile  $Q = 94\%$ .

### 4.9 Safety factors

#### 4.9.1 Material safety factors

The material safety factor  $\gamma_M$  is set to reflect the uncertainty in material strength:

$$\gamma_M = 1,05.$$

**4.9.2 Safety factor on pretension**

The safety factor on pretension is set to reflect the uncertainty in pretension:

$$\gamma_p = 1,05.$$

**4.9.3 Additional safety factor for fibre ropes**

The additional safety factor for fibre ropes elements only  $\gamma_{fibre}$  is defined in NR432, Sec 7, [4.1.2]. It applies to the rope itself, but not to any other part of the line.

**4.9.4 Safety factor on environmental tension**

The safety factor on environmental tension is set to reflect the uncertainty in the environmental tension. It is calibrated to reflect the effect of statistical uncertainty:

$$\gamma_{env} = \gamma_0 \times \gamma_N(N) \times \gamma_D(D)$$

$\gamma_0$  : Base case safety factor, as defined in [4.9.5]

$\gamma_N$  : Safety factor enhancement for the limited number of squall time series, as defined in [4.9.8]

N : Number of squall time series, see [4.9.8]

$\gamma_D$  : Safety factor enhancement for wind speed uncertainty in relation to the measurement period, as defined in [4.9.7]

D : Measurement duration, see [4.9.7].

**4.9.5 Base case safety factor**

The base case safety factor  $\gamma_0$  depends on the option used to compute the characteristic response (Squall return period), and on the directional contour methodology (BV or NORSOK, see [4.9.6]). Its value is given in Tab 6.

**Table 6 : Base case safety factor  $\gamma_0$**

T <sub>Char</sub> and X <sub>Char</sub> computation				
	RP	Contour methodology	Q	$\gamma_0$
ULS1	100	BV or unknown	95%	2,20
		NORSOK or Omni	95%	2,10
ULS2	1000	BV or unknown	97%	1,35
		NORSOK or Omni	97%	1,30
ALS	100	BV or unknown	95%	1,10
		NORSOK or Omni	95%	1,05
SLS	10	BV or unknown	94%	1,10
		NORSOK or Omni	94%	1,05

**4.9.6 Directional contour type effect on base case safety factor**

Safety factors on mooring line tension, offset and moorings force are given for directional wind speed contours following either the BV or NORSOK methodology, see [2.8].

The safety factors determined for the NORSOK contour apply if an omni-directional wind speed is used or if a directional contour more conservative than NORSOK is used.

On a case-by-case basis, if the directional contour methodology is not known or different to the possibilities mentioned in [2.8], the safety factors determined for the BV contour apply.

**4.9.7 Finite measurement period uncertainty**

$\gamma_D$  reflects the uncertainty in the wind speed due to a finite measurement period. It is a function, the measurement duration D in years of the squall data that have been used to derive the wind speed contour. If not available a default value D = 5 may be selected.  $\gamma_D$  is defined in Tab 7.

**Table 7 : Safety factor enhancement for wind speed uncertainty**

	ULS	ALS	SLS
$\gamma_D$	1+1/D	1+0,4/D	1+0,15/D

If the synthetic squall method is used to compute the characteristic tension, then  $\gamma_D = 1,0$

**4.9.8 Limited number of realizations uncertainty**

$\gamma_N$  reflects the uncertainty due to the limited number N of squall time series used for computation of the characteristic tension.

The value of  $\gamma_N$  depends on the quantile Q used to compute the characteristic response, as follows:

$$\gamma_N = \max \left[ 1, \left( \frac{Q}{N(1-Q)} \right)^{0,16} \right]$$

If the synthetic squall method is used to compute the characteristic tension, then  $\gamma_N = 1,0$ .



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