



DPC: 24/30461363 DC

BSI Group Headquarters

389 Chiswick High Road London W4 4AL

Tel: +44 (0)20 8996 9000

Fax: +44 (0)20 8996 7400

www.bsigroup.com

Date: 16 October 2024

Origin: European

Latest date for receipt of comments: 09 December 2024

Project No. 2022/01904

Responsible committee: B/525/12 Design of offshore structures

Interested committees:

Title: Draft BS EN ISO 19901-7 ISO 19901-7 Oil and gas industries including lower carbon energy - Specific requirements for offshore structures. Part 7: Station-keeping systems for floating offshore structures and mobile offshore units.

Please notify the secretary if you are aware of any keywords that might assist in classifying or identifying the standard or if the content of this standard

- i) has any issues related to 3rd party IPR, patent or copyright
- ii) affects other national standard(s)
- iii) requires additional national guidance or information

WARNING: THIS IS A DRAFT AND MUST NOT BE REGARDED OR USED AS A BRITISH STANDARD. THIS DRAFT IS NOT CURRENT BEYOND 09 December 2024

This draft is issued to allow comments from interested parties; all comments will be given consideration prior to publication. No acknowledgement will normally be sent. **See overleaf for information on the submission of comments.**

No copying is allowed, in any form, without prior written permission from BSI except as permitted under the Copyright, Designs and Patent Act 1988 or for circulation within a nominating organization for briefing purposes. Electronic circulation is limited to dissemination by e-mail within such an organization by committee members.

Further copies of this draft may be purchased from BSI Shop <http://shop.bsigroup.com> or from BSI Customer Services, Tel: +44(0) 20 8996 9001 or email cservices@bsigroup.com. British, International and foreign standards are also available from BSI Customer Services.

Information on the co-operating organizations represented on the committees referenced above may be obtained from <https://standardsdevelopment.bsigroup.com/>.

Responsible Committee Secretary: Ms Asky Desta (BSI)

Direct tel: 0208 996 7171

E-mail: asky.desta@bsigroup.com

Full document details: 24/30461363 DC

Introduction

This draft standard is based on national and international discussions. Your comments on this draft are invited and will assist in the preparation of the consequent standard.

For international standards, comments will be reviewed by the relevant UK national committee before sending the consensus UK vote and comments to the international committee, which will then decide appropriate action. If the international standard is approved, it is usual for the text to be published as a British Standard.

For national standards, comments will be reviewed by the relevant UK national committee and the resulting standards published as a British Standard.

UK Vote

Please indicate whether you consider the UK should submit a negative (with supporting technical reasons) or positive vote on this draft. Please indicate if you are aware of any reason why this draft standard should not be published as a British Standard.

Submission of Comments

- **Annotated drafts are not acceptable and will be rejected.**
- All comments should be submitted online at <https://standardsdevelopment.bsigroup.com/>. You will need to register in order to comment.

Template for comments and secretariat observations

Date: xx/xx/20xx	Document: ISO/DIS xxxx
------------------	------------------------

1	2	(3)	4	5	(6)	7
MB	Clause No./ Subclause No./Annex (e.g. 3.1)	Paragraph/ Figure/Table/Note	Type of comment	Comment (justification for change) by the MB	Proposed change by the MB	Secretariat observations on each comment submitted
	3.1	Definition 1	ed	Definition is ambiguous and needs clarifying.	Amend to read '...so that the mains connector to which no connection...'	
	6.4	Paragraph 2	te	The use of the UV photometer as an alternative cannot be supported as serious problems have been encountered in its use in the UK.	Delete reference to UV photometer.	



DRAFT International Standard

ISO/DIS 19901-7

Oil and gas industries including lower carbon energy — Specific requirements for offshore structures —

Part 7: Station-keeping systems for floating offshore structures and mobile offshore units

ICS: 75.180.10

This document is circulated as received from the committee secretariat.

ISO/CEN PARALLEL PROCESSING

Reference number
ISO/DIS 19901-7:2024(en)

Full document details: 24/30461363 DC

ISO/TC 67/SC 7

Secretariat: **BSI**

Voting begins on:
2024-10-16

Voting terminates on:
2025-01-08

THIS DOCUMENT IS A DRAFT CIRCULATED FOR COMMENTS AND APPROVAL. IT IS THEREFORE SUBJECT TO CHANGE AND MAY NOT BE REFERRED TO AS AN INTERNATIONAL STANDARD UNTIL PUBLISHED AS SUCH.

IN ADDITION TO THEIR EVALUATION AS BEING ACCEPTABLE FOR INDUSTRIAL, TECHNOLOGICAL, COMMERCIAL AND USER PURPOSES, DRAFT INTERNATIONAL STANDARDS MAY ON OCCASION HAVE TO BE CONSIDERED IN THE LIGHT OF THEIR POTENTIAL TO BECOME STANDARDS TO WHICH REFERENCE MAY BE MADE IN NATIONAL REGULATIONS.

RECIPIENTS OF THIS DRAFT ARE INVITED TO SUBMIT, WITH THEIR COMMENTS, NOTIFICATION OF ANY RELEVANT PATENT RIGHTS OF WHICH THEY ARE AWARE AND TO PROVIDE SUPPORTING DOCUMENTATION.

© ISO 2024



Documents

Document Sharing Hub



COPYRIGHT PROTECTED DOCUMENT

© ISO 2024

All rights reserved. Unless otherwise specified, or required in the context of its implementation, no part of this publication may be reproduced or utilized otherwise in any form or by any means, electronic or mechanical, including photocopying, or posting on the internet or an intranet, without prior written permission. Permission can be requested from either ISO at the address below or ISO's member body in the country of the requester.

ISO copyright office
CP 401 • Ch. de Blandonnet 8
CH-1214 Vernier, Geneva
Phone: +41 22 749 01 11
Email: copyright@iso.org
Website: www.iso.org

Published in Switzerland

Contents

Page

Foreword	vi
Introduction	vii
1 Scope	1
2 Normative references	2
3 Terms, Definitions, Symbols, and Abbreviations	3
3.1 Terms and Definitions	3
3.2 Symbols	11
3.3 Abbreviations	12
4 Mooring hardware	13
4.1 General	13
4.2 Off-vessel mooring line components	14
4.2.1 Anchors	14
4.2.2 Chain	14
4.2.3 Fibre rope	14
4.2.4 Steel wire rope	15
4.2.5 Connecting hardware	15
4.2.6 Buoys	15
4.2.7 Clump weights	15
4.2.8 Mooring Connectors	16
4.2.9 Quick release connectors	16
4.2.10 Disconnectable turret buoy	16
4.3 On-vessel mooring line components	16
4.3.1 Fairleads	16
4.3.2 Bending shoes	16
4.3.3 Chain stoppers	16
4.3.4 Uni-joints	17
4.3.5 Turret	17
4.4 On-vessel tensioning equipment	17
4.5 Monitoring equipment	17
4.5.1 General	17
4.5.2 Line tension / Line Payout	18
4.5.3 Floating structure position and heading	18
5 Metocean and other site data	18
5.1 General	18
5.2 Metocean data	18
5.2.1 Wave data	18
5.2.2 Wind data	19
5.2.3 Current data	19
5.3 Bathymetry	19
5.4 Geotechnical and Geophysical data	19
5.5 Marine growth	20
5.6 Physicochemical parameters	20
5.7 Ice-related	20
6 Design and site assessment of station-keeping systems	20
6.1 Fundamental Requirements	20
6.2 Functional requirements	20
6.3 Safety requirements	21
6.4 Planning requirements	22
6.4.1 General	22
6.4.2 Design basis	22
6.4.3 Design Practices	22
6.4.4 Installation Considerations at Design Stage	23
6.4.5 Integrity Management strategy	23

6.5	Rules and regulations.....	23
6.6	Independent verification for permanent systems.....	24
6.7	Numerical tools.....	24
6.8	Design conditions.....	24
6.8.1	Limit States.....	24
6.8.2	Analysis Cases for Ultimate Limit State.....	25
6.8.3	Analysis Cases for Serviceability Limit State.....	27
6.8.4	Analysis Cases for Fatigue Limit State.....	28
6.8.5	Analysis Cases for Accidental Limit State.....	29
6.8.6	Analysis Cases for Temporary Phases.....	29
7	Design and site assessment criteria.....	30
7.1	Safety factors for mooring component strength.....	30
7.1.1	Line tensions.....	30
7.1.2	Anchor factors of safety.....	31
7.1.3	Factors of safety for buoyancy elements.....	33
7.2	Vessel offsets and heading.....	34
7.3	Requirements for clearances.....	34
7.3.1	Mooring line with seabed (thrash zone).....	34
7.3.2	Mooring line with sea surface.....	35
7.3.3	Mooring line with hull.....	35
7.3.4	Mooring line with riser, umbilical, mooring line, pipeline, seabed assets, and exclusion zones.....	35
7.3.5	Submerged turret buoy.....	35
7.3.6	Anchor with mooring line, pipeline, seabed assets, and exclusion zones.....	35
7.4	Safety factors for mooring component fatigue resistance.....	36
8	Analysis.....	38
8.1	General.....	38
8.2	Analysis methods.....	39
8.3	Coupling effects.....	39
8.4	Environmental loads on the floating structure.....	40
8.4.1	Wave forces.....	40
8.4.2	Wind forces.....	40
8.4.3	Current forces and VIM.....	41
8.5	Environmental loads on mooring lines and risers.....	41
8.5.1	Wave forces.....	41
8.5.2	Current forces.....	41
8.6	Mooring analysis for strength, offsets, and clearances.....	41
8.6.1	Basic considerations.....	41
8.6.2	Extreme value statistics.....	41
8.6.3	Design values for responses to transient wind squalls.....	42
8.6.4	Mitigating mooring line trenching effects.....	42
8.7	Mooring analysis for fatigue.....	42
8.7.1	Basic considerations.....	42
8.7.2	Analysis Approach.....	42
8.7.3	Fatigue damage calculation methods.....	43
8.8	Response based analysis.....	45
9	Dynamic positioning and thruster-assisted mooring.....	45
9.1	General.....	45
9.1.1	Dynamic positioning (DP).....	46
9.1.2	Thruster assisted mooring (TAM).....	46
9.2	Equipment.....	46
9.2.1	DP and TAM equipment.....	46
9.2.2	DP equipment classes.....	47
9.3	Available effective thrust.....	47
9.4	Determination of allowable thrust.....	47
9.5	Load sharing of TAM System.....	48
9.5.1	General.....	48

9.5.2	Mean load reduction method	48
9.5.3	Weathervaning Units.....	48
9.5.4	System dynamic analysis.....	49
9.6	Failure mode and effects analysis.....	49
9.7	Design, test and maintenance	49
9.8	Operating personnel.....	49
9.9	Determination of station-keeping capability	50
10	Installation, test load and as-installed survey	50
10.1	General.....	50
10.2	Installation considerations and storm-safe criteria.....	50
10.3	Mooring line handling and installation procedure.....	50
10.4	Test loading requirements.....	51
10.4.1	Anchor test load for permanent mooring.....	51
10.4.2	Anchor test load for mobile mooring.....	51
10.5	Installation Tolerances.....	52
10.6	Traceability Records.....	52
10.7	As-installed survey and establishment of as-installed capacity.....	52
11	Integrity Management, Survey & Inspection, and Monitoring	53
11.1	Integrity management.....	53
11.2	Surveys & Inspections.....	54
11.3	Mobile moorings.....	55
11.4	Permanent moorings.....	55
11.4.1	Annual surveys.....	55
11.4.2	Complete surveys.....	55
11.5	Evaluation & acceptance/discard criteria.....	56
11.6	Monitoring.....	56
	Annex A (informative) Mooring systems	58
	Annex B (informative) Regional information	146
	Bibliography	192

Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

ISO draws attention to the possibility that the implementation of this document may involve the use of (a) patent(s). ISO takes no position concerning the evidence, validity or applicability of any claimed patent rights in respect thereof. As of the date of publication of this document, ISO [had/had not] received notice of (a) patent(s) which may be required to implement this document. However, implementers are cautioned that this may not represent the latest information, which may be obtained from the patent database available at www.iso.org/patents. ISO shall not be held responsible for identifying any or all such patent rights.

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 67, *Oil and gas industries including lower carbon energy, Subcommittee SC 7, Offshore structures*.

This third edition cancels and replaces the second edition (ISO 19901-7:2013), which has been technically revised.

The main changes are as follows:

- Reorganisation of the table of contents for a more logical flow of requirements from material and equipment selection, site survey, design considerations, criteria and associated analysis methods to integrity management during station-keeping system installation and along the system service life.
- Addition of requirements for a formal mooring integrity management system;
- Emphasis on Operator performance standard expectations definition;
- Inclusion of fibre ropes as a standard material such as chain and steel wire ropes;
- Extensive transfer of information material into the informative [Annex A](#);
- Deletion of informative sections related to geotechnical design of anchors to incorporate the same in 19901-4;
- Inclusion of OPB fatigue guidance and Squall design cases guidance;
- Some minor corrections.

A list of all parts in the ISO series 19901 can be found on the ISO website.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

The series of International Standards applicable to offshore structures, ISO 19900 to ISO 19906, constitutes a common basis covering those aspects that address design requirements and assessments of offshore structures used by the petroleum, petrochemical and natural gas industries worldwide. The intention in their application is to achieve reliability levels appropriate for manned and unmanned offshore structures, irrespective type of structure and the nature or combination of materials used.

It is important to recognize that structural integrity is a concept comprised of models that describe actions, structural analyses, design rules, safety elements, workmanship, quality control procedures and national requirements, all of which are mutually dependent. The modification of one aspect of design in isolation can disturb the balance of reliability inherent in the overall design or structural system. The implications involved in modifications therefore need to be considered in relation to the overall reliability of all offshore structural systems.

The series of International Standards applicable to types of offshore structures are intended to provide a wide breadth of choice for structural configurations, materials and techniques without hindering innovation. Informed engineering judgement is therefore necessary in the use of these International Standards.

This part of ISO 19901 was developed in response to the worldwide offshore industry's demand for a coherent and consistent definition of methodologies to analyse, design and evaluate station-keeping systems used for floating production and/or storage platforms of various types (e.g. semi-submersibles, spar platforms, ship-shaped structures) and to assess site-specific applications of mobile offshore units (such as mobile offshore drilling units and flotels) and construction units (such as heavy lift vessels and pipelay units).

For permanent production systems operating procedures for station-keeping systems assume as a minimum the ability to shut-in wells and the facility in case of emergency (e.g., emergency shut-down valves on the seabed), otherwise the consequence of mooring failure could be significantly different.

Station-keeping is a generic term covering systems for keeping a floating structure, which is under the constant influence of external actions, at a pre-defined location and/or heading with limited excursions. Station-keeping systems resist external actions by means of any of the following:

- mooring systems (e.g., spread moorings or single point moorings),
- dynamic positioning systems (generally consisting of thrusters), and
- a combination of mooring system and thrusters (thruster assisted moorings).

The external actions generally consist of wind, wave, current and ice actions on the floating structure, mooring and/or risers.

Some background to, and guidance on, the use of this part of ISO 19901 is provided in informative [Annex A](#). The clause numbering in [Annex A](#) is the same as in the normative text to facilitate cross-referencing.

Regional information, where available, is provided in informative [Annex B](#).

Oil and gas industries including lower carbon energy — Specific requirements for offshore structures —

Part 7: Station-keeping systems for floating offshore structures and mobile offshore units

1 Scope

This part of ISO 19901 specifies methodologies for:

- a) the design, analysis and evaluation of station-keeping systems for floating structures used by the oil and gas industries to support any combination of:
 - 1) production,
 - 2) storage,
 - 3) offloading,
 - 4) drilling and well intervention.
- b) the assessment of station-keeping systems for site-specific applications of mobile offshore units and construction units.

Most station-keeping systems used with the class of floating structures covered by a) are termed “permanent mooring systems”, for which this part of ISO 19901 is applicable to all aspects of the life cycle and includes requirements relating to the manufacture of mooring components, as well as considerations for in-service inspections. Most station-keeping systems used with mobile offshore units, the class covered by b), are termed “mobile mooring systems”. Throughout this part of ISO 19901, the term “floating structure”, sometimes shortened to “structure”, is used as a generic term to indicate any member of the two classes, a) and b).

This part of ISO 19901 is applicable to the following types of station-keeping systems, which are either covered directly in this part of ISO 19901 or through reference to other guidelines:

- i) spread moorings,
- ii) single point moorings
- iii) dynamic positioning systems,
- iv) thruster-assisted moorings.

This part of ISO 19901 is not applicable to:

- station keeping systems which do not have redundancy against failure of any single component (e.g., single anchor leg moorings (SALMs)),
- station keeping systems which use any means other than mooring lines or thrusters such as tower soft yoke systems, or tension leg platforms (TLPs) that are using tendons.

The requirements for this part of ISO 19901 address spread mooring systems and single point mooring systems with mooring lines composed of steel chain, steel wire or synthetic fibre rope.

Descriptions of characteristics and typical components found in these systems are given in [Annex A](#).

This document includes requirements relating to the selection of mooring components, mooring system configuration and performance, components design, installation, post-installation survey, and as-installed assessments as needed for mooring integrity management.

The procedures for the design of permanent or site assessment of mobile mooring systems specified in this document are based on a deterministic approach where mooring system responses (such as line tensions, vessel offsets, and anchor loads) are evaluated for a design environment defined by an annual probability of exceedance or return period. Mooring system responses are then checked against acceptance criteria for mooring strength, offsets and orientation, clearances, anchor capacity, fatigue resistance, etc. The minimum acceptance criteria are either defined in this document or are to be specified by the Operator.

NOTE 1 Station-keeping systems designed based on this deterministic approach might have differing levels of reliability.

For moored structures (vessels), system responses are calculated and compared to minimum acceptance criteria for:

- **Ultimate limit states (ULS):** Mooring component strength. Vessel offset, orientation, and clearance constraints. Herein the ULS includes both intact and single failure condition for station-keeping systems.
- **Serviceability limit states (SLS):** Vessel offset, orientation, and clearance constraints. For mooring components this includes clearances with the vessel, risers, umbilicals, seabed, water surface, field infrastructure, exclusion zones, etc.
- **Fatigue limit states (FLS) :** Cumulative mooring component fatigue damage.
- **Accidental limit state (ALS):** no criteria are given for accidental or abnormal limit state which are left to owner decision or local Authorities requirements.

The methodology described in this part of ISO 19901 identifies a set of coherent analysis techniques that, combined with an understanding of the site-specific metocean conditions, the characteristics of the floating structure under consideration, and other factors, can be used to determine the adequacy of the station-keeping system to meet the functional requirements of this document.

NOTE 2 For moorings deployed in ice-prone environments, additional requirements are given in ISO 19906 subclause 13.7.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 9089, *Marine structures — Mobile offshore units — Mooring positioning windlasses and winches*

ISO 18692-1:2018, *Fibre ropes for offshore stationkeeping — Part 1: General specification*

ISO 19900, *Petroleum and natural gas industries — General requirements for offshore structures*

ISO 19901-1, *Petroleum and natural gas industries — Specific requirements for offshore structures — Part 1: Metocean design and operating considerations*

ISO 19901-3, *Oil and gas industries including lower carbon energy — Specific requirements for offshore structures — Part 3: Topsides structure*

ISO 19901-4, *Petroleum and natural gas industries — Specific requirements for offshore structures — Part 4: Geotechnical and foundation design considerations*

ISO 19901-6, *Petroleum and natural gas industries — Specific requirements for offshore structures — Part 6: Marine operations*

ISO 19901-8, *Oil and gas industries including lower carbon energy — Offshore structures — Part 8: Marine soil investigations*

ISO 19901-9, *Petroleum and natural gas industries — Specific requirements for offshore structures — Part 9: Structural integrity management*

ISO 19905-3, *Petroleum and natural gas industries — Site-specific assessment of mobile offshore units — Part 3: Floating units*

ISO 19906, *Petroleum and natural gas industries — Arctic offshore structures*

ISO 20438, *Ships and marine technology — Offshore mooring chains*

IACS UR W22, *Offshore Mooring Chains*

API RP 2MET, *“Derivation of Metocean Design and Operating Conditions” Second Edition – January 2021*

API RP 2I, *“In-service Inspection of Mooring Hardware for Floating Structures”, 3rd Edition, 2007*

API RP 2MIM, *“Mooring Integrity Management”, 1st Edition, September 2019*

API RP 2SK, *“Design and Analysis of Station-keeping Systems for Floating Structures” Fourth Edition – July 2024*

API RP 2SM, *“Recommended Practice for Design, Manufacture, Installation, and Maintenance of Synthetic Fiber Ropes for Offshore Mooring” Second Edition – July 2014*

API SPEC 9A, *“Specification for Wire Rope” 27th Edition, August 2020 -*

IMO MSC.1/Circ.1580, *Guidelines for vessels and units with Dynamic Positioning (DP) systems*, 16 June 2017, International Maritime Organization.

3 Terms, Definitions, Symbols, and Abbreviations

3.1 Terms and Definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- ISO Online browsing platform: available at <https://www.iso.org/obp>
- IEC Electropedia: available at <https://www.electropedia.org/>

3.1.1 action

external load applied to the structure (direct action) or an imposed deformation or acceleration (indirect action)

Note 1 to entry: An earthquake typically generates imposed accelerations.

EXAMPLE An imposed deformation can be caused by fabrication tolerances, settlement, temperature change or moisture variation.

[SOURCE: ISO 19900:2019, 3.3]

3.1.2 action effect

effect of actions on structural components

EXAMPLE Internal forces, moments, stresses, strains, rigid body motions or elastic deformations.

[SOURCE: ISO 19900:2019, 3.4]

3.1.3

active station-keeping system

station-keeping systems that make use of dynamic positioning, thruster assistance, line length or pretension adjustments, planned changes in vessel draught, winching (kedging) off location, disconnection, etc. - as opposed to a *passive mooring system* (3.1.33)

3.1.4

catenary mooring

mooring system where the restoring action is provided by the distributed weight of mooring lines

Note 1 to entry: Mooring system restoring forces are due to forces from both catenary and strain deformations of the mooring lines.

3.1.5

characteristic value

value assigned to a basic variable, an action or a resistance from which the design value can be found by the application of a partial factor

Note 1 to entry: The value usually has a prescribed probability of not being violated which, in the case of an action, will normally relate to a reference return period.

Note 2 to entry: Adapted from ISO 19900:2019, 3.9.

3.1.6

close proximity

mooring systems are considered to be in close proximity to a surface installation (or facility) 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

3.1.7

common mode/common cause failure

failures of similar components on different mooring legs resulting from the same direct cause, where these failures are not consequences of each other

Note 1 to entry: The potential for common cause failures reduces the effectiveness of system redundancy.

Note 2 to entry: It is generally accepted that the failures occur simultaneously or within a short time of each other.

3.1.8

damage event

event-driven damage to mooring components including physical damage, overload, excessive bending, etc., often experienced during the installation phase

3.1.9

damaged condition

state of the station-keeping system with a weakened or missing mooring line or a failure of the thruster system or a combination of both

Note 1 to entry: A missing line can have either failed or been weakened by external damage (e.g., cut in synthetic ropes or corroded chain) or been removed for maintenance or inspection.

Note 2 to entry: A total or partial loss of a buoyancy or weight element is also a damaged condition.

Note 3 to entry: For thruster assisted mooring (TAM) systems damage condition includes the most critical case of one-leg damaged or the single worst failure (SWF) of the integrated thruster control system (ITCS) as identified by the FMEA.

3.1.10

degradation mechanisms

time-based physical or chemical mechanisms or processes resulting in reduced functionality or capacity

EXAMPLE Corrosion, wear, fatigue, etc. are degradation mechanisms

3.1.11

design criteria

quantitative formulations that describe the conditions to be fulfilled for each limit state

Note 1 to entry: Adapted from ISO 19900:2019, definition 3.15.

3.1.12

design service life

assumed period for which a structure or a structural component is to be used for its intended purpose with anticipated maintenance, but without substantial repair being necessary

Note 1 to entry: Adapted from ISO 19900:2019, definition 3.13.

3.1.13

design/assessment situation or design condition

set of physical conditions for which the structure or its components are verified

Note 1 to entry: it is associated with an annual probability of exceedance, or return period, used in evaluating the relevant limit states, one of the design load cases.

[SOURCE: ISO 19900:2019, 3.16]

3.1.14

disconnectable floating structure

floating structure capable of discontinuing operation and rapidly disconnecting from its ancillary components (such as risers, moorings, and/or well systems) in response to the occurrence, forecast or to the detection of a threshold event

3.1.15

dynamic load

external load that induces acceleration of a structural component, normally specified by a spectrum, e.g. wind and wave spectra and associated parameters

3.1.16

dynamic positioning

DP

station-keeping technique consisting primarily of a system of automatically controlled on-board thrusters, which generate appropriate thrust vectors to counter the mean and slowly varying induced actions

[SOURCE: ISO 19904-1:2019(en), 3.17]

3.1.17

end-of-life break strength

ELBS

break strength of a mooring component at the end of the design service life

3.1.18

expected value

first-order statistical moment of the probability density function for the considered variable that, in the case of a time-dependent parameter, can be associated with a specific reference period

3.1.19

failure causes

includes the initiators, defects, processes and mechanisms generating damage or degradation which are the basic reasons initiating events leading to failure and may be introduced into the mooring system across all phases of the mooring system lifecycle from design to operation

3.1.20

failure mode

manifestation of loss of functionality of a mooring component and manner by which failure is observed

3.1.21

fit-for-service

fitness-for-service

fulfilling defined structural integrity (0) and performance requirements

Note 1 to entry: A structure not meeting all the specific provisions can be fit-for-service, provided it does not cause unacceptable risk to life-safety or the environment.

[SOURCE: ISO 19900:2019(en), 3.22]

3.1.22

floating structure

structure where the full weight is supported by buoyancy

Note 1 to entry: The full weight includes lightship weight, mooring system pre-tension, riser pre-tension, operating weight, etc.

[SOURCE: ISO 19900:2019, 3.25]

3.1.23

integrated thruster control system

ITCS

integrated thruster control system (ITCS) consisting of the thrusters, and the control, power generation and distribution systems

3.1.24

limit state

state beyond which the structure no longer fulfils the relevant design criteria

[SOURCE: ISO 19900:2019, 3.31]

3.1.25

maintenance

combination of all technical, administrative and managerial actions during the life cycle of an asset, intended to retain it, or restore it, to a state in which it can perform the required function

[SOURCE: ISO 50007:2017(en), 3.21]

3.1.26

minimum break strength

MBS

hardware component's certified break strength meeting requirements of an industry standard

Note 1 to entry: It is also called Minimum Break Load (MBL), Break Test Load (BTL), Reference Break Strength (RBS), and Catalogue Break Strength (CBS).

3.1.27

mobile mooring system

mooring system, generally retrievable, intended for deployment at a specific location for a short-term operation, such as those for mobile offshore units (see 0)

Note 1 to entry: Some components of a mobile mooring system might not be retrievable and should be designed following the requirements of permanent mooring system.

Note 2 to entry: mobile moorings that cannot follow the nominal inspection schedule shall be considered as Permanent mooring systems.

3.1.28

mobile offshore drilling unit

MODU

structure capable of engaging in drilling and well intervention operations for exploration or exploitation of subsea petroleum resources

3.1.29

mobile offshore unit MOU

offshore structure intended to be frequently relocated to perform a particular function

Note 1 to entry: Pipelaying vessel or barge, offshore construction structure, accommodation structure (flotel), service structure, or mobile offshore drilling units.

[SOURCE: ISO 19904-1:2019, 3.33]

3.1.30

mooring component

general class of component used in the mooring of floating structures

EXAMPLE Chain, steel wire rope, synthetic fibre rope, connector, clump weight, buoy, winch/windlass, fairlead or anchor.

3.1.31

natural period/frequency

period/frequency at which an oscillator will respond to most when subjected to a white noise excitation

3.1.32

operator

representative of the company or companies responsible for the activities at the site where the floating structure is located

Note 1 to entry: The operator is normally the oil company acting on behalf of co-licensees.

Note 2 to entry: The operator can be termed the Owner or the duty holder.

Note 3 to entry: Operator or Owner is the entity responsible for the definition of the design basis for the station-keeping system.

EXAMPLE The operator owns the development while the MODU is owned by the drilling contractor.

[SOURCE: ISO 19900:2019, 3.35]

3.1.33

passive mooring system

moorings that respond to changes in vessel draught, trim, and environmental loads without any intervention or adjustment of the mooring lines, and do not use thrusters

3.1.34

permanent mooring system

mooring system normally used to moor floating structures deployed for long-term operations, such as those for a floating production system (FPS)

3.1.35

recognized classification society (RCS)

member of the international association of classification societies (IACS), with recognized and relevant competence and experience in floating structures used in petroleum or natural gas activities, and with established rules and procedures for classification /certification of platforms located at a specific site for an extended period of time

[SOURCE: ISO 19904-1:2019, 3.38]

3.1.36

redundancy

ability of the structure to find alternative load paths following structural failure of one or more components, thus limiting the consequences of such failures

[SOURCE: ISO 19902:2020, 3.38]

3.1.37

resistance

capacity of a structure, a component or a cross-section of a component to withstand action effects without exceeding its limit state

Note 1 to entry: This definition is at variance with that specified in ISO 19900:2019, 3.41.

3.1.38

return period

average period between occurrences of an event or of a particular value being exceeded

Note 1 to entry: The offshore industry commonly uses a return period measured in years for environmental events. The return period is equal to the reciprocal of the annual probability of exceedance of the event.

[SOURCE: ISO 19900:2019, 3.42]

3.1.39

riser

part of an offshore pipeline, including any subsea spool pieces, which extends from the sea floor to the termination point on a platform

Note 1 to entry: Possible functions include drilling and well intervention, production, injection, subsea systems control and export of produced fluids.

Note 2 to entry: "risers" is meant to include a single (drilling) riser, multiple risers and/or umbilicals.

Note 3 to entry: Adapted from ISO 19900:2019, definition 3.43.

3.1.40

robustness

ability of a structure (see 0) to withstand hazardous events without being damaged to an extent disproportionate to the cause

[SOURCE: ISO 19900:2019, 3.44]

3.1.41

sea state

condition of the sea during a period in which its statistics remain approximately stationary

Note 1 to entry: In a statistical sense the sea state does not change markedly within the period. The period during which the condition exists is often assumed to be three hours, although it depends on the particular weather situation at any given time.

[SOURCE: ISO19901-1:2015,3.31]

3.1.42

semi-submersible

floating structure normally consisting of a deck structure with, typically, three or more widely spaced, large cross-section, supporting columns connected to submerged pontoons

Note 1 to entry: Pontoon/column geometry is usually chosen to reduce global motions in a broad range of wave frequencies.

[SOURCE: ISO 19904-1:2019(en), 3.46]

3.1.43

serviceability

ability of a structure or structural member to perform adequately for normal functional use

3.1.44

significant value

statistical measure of a zero-mean random variable equal to the mean of the one third highest extrema during a specific time period

Note 1 to entry: has the same dimensional properties as the variable being examined.

3.1.45

single point mooring

multiple line mooring system that allows the floating structure to which it is connected to vary its heading (weathervane)

EXAMPLE One example of a single point mooring is a turret mooring system where mooring lines are attached to a turret, which includes bearings to allow the structure to rotate.

3.1.46

ship-shaped structure

monohull floating structure having a geometry similar to that of ocean-going ships

3.1.47

spar platform

deep-draught, small water-plane area floating structure

3.1.48

splash zone

zone in which part of a structure is intermittently exposed to air and immersed in the sea

Note 1 to entry: Herein the relevant structural parts are mooring lines, fairleads and thrusters.

[SOURCE: Adapted from ISO 19900:2019, 3.48.]

3.1.49

spread mooring

mooring system consisting of multiple mooring lines terminated at different locations on a floating structure, and extending outwards, providing an almost constant structure heading

3.1.50

squall

strong wind event characterized by a sudden onset, a duration of the order of minutes and a rather sudden decrease in speed

Note 1 to entry: A squall is often accompanied by a change in wind direction, a drop in air temperature and heavy precipitation.

Note 2 to entry: The WMO classification of a squall requires the wind speed to increase by at least 8 m/s and attain a top speed of at least 11 m/s, lasting at least one minute in duration.

[SOURCE: ISO 19901-1:2015(E), 3.40]

3.1.51

Station-keeping system

system capable of limiting the excursions of a floating structure within prescribed limits

3.1.52

storm safe condition

condition of a floating structure during mooring line hook-up when the minimum number of lines are hooked up that enables the platform to meet the intact condition tension safety factors while maintaining appropriate clearances with infrastructure in a site (and seasonal) specific return period “storm” event

3.1.53

structural component

discrete part of a structure (see 0)

[SOURCE: ISO 19900:2019, 3.49]

3.1.54

Structural integrity

ability of a structure or a structural component to maintain performance throughout the total service life, with respect to structural safety, serviceability, and durability

[SOURCE: ISO 19900:2019(en), 3.50]

3.1.55

structure

combination of physically connected structural components (see 0)

[SOURCE: ISO 19900:2019, 3.53]

3.1.56

swell

wave that was wind-generated but has travelled out of its generation area and has no relationship with the local wind

[SOURCE: ISO19901-1:2015,3.44]

3.1.57

taut line mooring

mooring system where the restoring action is provided by elastic deformation of mooring lines

Note 1 to entry: The angle of taut line mooring at the mudline is typically non-zero, even in equilibrium condition.

Note 2 to entry: Mooring system restoring forces are due to forces from both catenary and strain deformations of the mooring lines.

3.1.58

thruster-assisted mooring

station-keeping system consisting of mooring lines and thrusters

Note 1 to entry: The thruster system can be manually controlled (TA) or automatically controlled (ATA).

Note 2 to entry: The automatic thruster system shall be able to automatically provide needed thrust force and moment to counter the environment loads.

3.1.59

touchdown point

location on a mooring line where the line transitions from contacting the seabed to being in the water column

Note 1 to entry: The touchdown point can change as the draught and horizontal offset of the floating structure change.

3.1.60

touchdown zone

range of all touchdown points within defined operating conditions

Note 1 to entry: the touchdown zone can also be referred to as the trash zone.

EXAMPLE The extent of the touchdown zone could be specified based on 100 years return period environmental conditions along with minimum and maximum floating structure draughts and resulting offsets.

3.1.61

tropical revolving storm

TRS

collective name for hurricanes, cyclones, and typhoons

3.1.62**verification**

examination made to confirm that an activity, product, or service is in accordance with specified requirements

3.1.63**virtual mass and inertia**

sum of mass and added hydrodynamic mass or inertia and added hydrodynamic inertia, also called effective mass and inertia

3.1.64**weathervaning**

process by which a floating structure passively varies its heading in response to time-varying environmental actions

3.2 Symbols

C	coefficient (non-dimensional unless otherwise specified)
D	annual fatigue damage,
d	diameter of the mooring line or component, in metres (m)
F	direct action, in newtons (N), or a direct action per unit length, in newtons per metre, (N/m)
f	frequency, in hertz (Hz)
K	fatigue constant (non-dimensional unless otherwise specified)
k	axial stiffness, in newtons per metre (N/m)
L	design service life, in years
l	length, in metres (m)
M	mass, in kilograms (kg)
m	inverse slope of T-N or S-N fatigue curves
N	total number of (permissible) cycles
n	number of cycles per annum, in (-/year)
P	probability of occurrence
S	offset or motion, in metres (m)
SR	stress range, in megapascals (MPa)
s	standard deviation
T	tension force, in newtons (N); or non-dimensional tension ratio
t	time, period or duration, in seconds (s)
v	velocity, in metres per second (m/s)
W	submerged weight, in newtons (N), or weight per unit length, in newtons per metre (N/m)
Γ	gamma function

γ	design safety factor
δ	bandwidth parameter for the wave frequency
ε	annual creep elongation, percent per year
σ	ratio of the standard deviation of the tension variations around the mean tension to a reference breaking strength
ρ	density, in kilograms per cubic metre (kg/m ³)

3.3 Abbreviations

AHC	anchor holding capacity
AJP	annual joint probability of occurrence
ALS	accidental limit state
ATA	automatically controlled thruster assist
CALM	catenary anchor leg mooring
CFD	computational fluid dynamics
DP	dynamic positioning
ELBS	end-of-life break strength
FEA	finite element analysis
FLS	fatigue limit state
FMEA	failure modes and effects analysis
FPS	floating production system
FPSO	floating production, storage and offloading structure
FSO	floating storage and offloading structure
HMPE	high modulus polyethylene
IACS	International Association of Classification Societies
IMCA	International Marine Contractors Association
IMO	International Maritime Organization
ITCS	Integrated Thruster Control System,
LTM	long-term mooring
MBS	minimum breaking strength
MDS	mooring design states
MIM	mooring integrity management
MODU	mobile offshore drilling unit

MOU	mobile offshore unit
MPM	most probable maximum
OD	operator defined
ORQ	oil rig quality
QTF	quadratic transfer function
RAO	response amplitude operator
RCS	recognized classification society
ROV	remotely operated vehicle
RRP	required, recommended, or permitted
SALM	single anchor leg mooring
SAW	submerged arc welding
SCF	stress concentration factor
SIM	structural integrity management
SLS	serviceability limit state
TA	manual thruster assisted
TAM	thruster-assisted mooring
TLP	tension leg platform
ULS	ultimate limit state
VIM	vortex-induced motion
VIV	vortex-induced vibration
WMO	World Meteorological Organization

4 Mooring hardware

4.1 General

Understanding of the peculiarities of mooring components is key to the correct design of a station keeping system. It is necessary to timely specify the minimum information to be acquired during site surveys (metocean, geotechnical, geophysical).

The function of mooring components is to connect a floating structure to the seabed (see ISO 19904-1 Clause 18). Mooring components are all connected items from and including the anchor up to and including the weld (or bolted joint) connecting the on-vessel mooring equipment to the floating structure.

Typical mooring components include:

- (1) off-vessel mooring line components – anchor, chain, fibre rope, steel wire rope, connecting hardware, buoys, clump weights and weight chain,
- (2) on-vessel mooring line components - fairleads, bending shoes, padeyes - and
- (3) on-vessel tensioning equipment.

Disconnectable permanent systems usually include a disconnectable (turret) buoy which provides the station keeping function and supports the risers and mooring lines.

Manufacturing of mooring hardware shall be subject to the Operator specified quality assurance.

Manufacturing process, inspection and testing shall be adequate to address mitigation of failure modes identified during a mooring integrity risk review that should occur during the design phase.

Reviews of the manufacturing tolerances (during the design stage) and physical fit-up tests (after manufacture and in advance of installation spread mobilisation) shall be undertaken for all components to verify they can be connected together as described in the installation procedure.

The design and arrangement of components shall be consistent with the mooring line and anchor installation philosophy. Typical considerations are addition of handling padeyes on H-links, triplates and arrangement of the top plate of a suction anchor.

An interface management plan shall be developed prior to the design stage which defines the process for managing the interfaces between the Operator, system designer, installation contractor and component manufacturers.

The mooring components shall be specified or approved by the operator.

4.2 Off-vessel mooring line components

Off-vessel mooring components are those mooring components that are deployed off the vessel and not permanently attached to the vessel. Examples of mooring line off vessel components include anchors, chains, fibre ropes, steel wire ropes, connectors, buoys, clump weights, and weight chain.

4.2.1 Anchors

The anchoring options considered in this standard include:

- drag embedment anchors,
- anchor piles (driven, jetted, suction embedded, torpedo (gravity-embedded) and drilled and grouted), and
- other anchor types such as gravity anchors and plate anchors.

Details of these anchors are described in [A.4.2.1](#).

4.2.2 Chain

Mooring chain shall be manufactured in accordance with IACS Unified Requirement W22 for offshore mooring chain and ISO 20438:2017.

The designer shall define the termination of the chain section (end link, enlarged link) depending on the selected connecting components, the local load, the required degrees of freedom and associated locally generated stresses.

4.2.3 Fibre rope

Fibre ropes shall be manufactured to meet or exceed the requirements of one of the following specifications: Operator specified manufacturing and testing specifications or ISO 18692-1:2018. Additional guidance for fibre rope manufacture, inspection and quality assurance is provided in API RP 2SM Section 8 and should be followed.

When using fibre rope in permanent moorings, the designer shall determine the expected permanent elongation of the rope over the life of the mooring. If the permanent elongation causes the mooring system to not meet the performance criteria, means shall be provided for adjustment of the mooring line length during the service life to compensate for the rope elongation. Alternatively, the rope can be prestretched as

part of the installation process to cause part of the permanent elongation to occur and adjust the mooring line length at that time.

4.2.4 Steel wire rope

Mooring steel wire ropes shall not have a fibre core.

The space between individual wires of a rope shall be filled with suitable blocking compound. For permanent mooring systems steel wire ropes shall be protected from the ingress of water by a sheath.

The ends of each rope section shall terminate in resin- or zinc-poured sockets.

Steel wire ropes and end sockets should be manufactured to meet or exceed the requirements of one of the following specifications:

- Operator specified manufacturing and testing specifications.
- API Spec 9A.
- RCS rules.

4.2.5 Connecting hardware

All components forming load bearing part of permanent mooring systems shall have documented fatigue life, e.g., traditionally Kenter shackles do not have sufficient fatigue capacity to be used for permanent mooring systems.

For temporary mooring systems fatigue of components shall be assessed if the scheduled inspection of the components will not be completed on time.

In order to avoid galvanic corrosion, connecting hardware materials should be compatible with each other and with the materials of the components they are connected to (including chemical composition). Incompatible materials should be electrically isolated from each other.

Excessive hardness difference between adjacent components should be avoided to limit wear in dynamic areas. Dimensional compatibility (bend radii, contact areas, etc.) is also important and should be verified ahead of the hook-up campaign.

Connecting hardware should be manufactured to meet or exceed the requirements of one of the following specifications:

- Operator specified manufacturing and testing specifications.
- ISO 20438:2017.
- RCS rules.

4.2.6 Buoys

Subsurface buoys of steel construction, designed for external pressure, shall be designed in accordance with a pressure containment standard for use at the maximum operational depth identified by the mooring analysis.

Steel buoys shall be protected against internal and external corrosion.

4.2.7 Clump weights

Clump weights are heavy components often used in shallow water where the restoring of a chain-only catenary mooring system is not sufficient to meet the specified offsets. These components are generally fastened to a large diameter chain segment. This segment is usually around the touch down zone or on the seabed.

Detailed design of clump weight shall ensure that these will not slide along their supporting chain segment, if designed as hollow blocs.

Detailed design of clump weight shall ensure that these will not fall off from their supporting chain segments, if designed as two bolted halves.

4.2.8 Mooring Connectors

Other types of long term mooring connectors are also available. Typically, connectors are introduced to ease connection of the mooring line to the vessel or the anchor during the installation phase.

Some connectors can be connected directly to the vessel while other types can be combined with a uni-joint. All connectors are to be treated as mooring line components and shall meet the design criteria defined in [clause 7](#).

4.2.9 Quick release connectors

Temporary mooring systems sometimes include quick release connectors in each mooring line. The connectors are assembled on shore or on an anchor handling vessel and feature a release mechanism that is mechanically or acoustically actuated and allows disconnection of the mooring lines from the floating structure.

4.2.10 Disconnectable turret buoy

Turret buoys are typically used with disconnectable turrets to support the risers, umbilicals and mooring lines during and after disconnection. They shall be designed in accordance with a pressure containment standard for use at the maximum operational depth identified by the mooring/riser analysis when disconnected.

4.3 On-vessel mooring line components

On-vessel mooring components are those mooring components that are permanently installed on the vessel. Examples of on-vessel mooring components include fairleads, bending shoes, chain stoppers, uni-joints.

On vessel mooring line components are likely to experience mooring line design loads whereas on vessel tensioning equipment will see only installation loads.

All on vessel mooring line components shall be designed to an action considering the MBS of the mooring line in the most unfavourable direction and shall not reduce the strength or fatigue endurance of the mooring lines by more than assumed in the design of the mooring lines.

4.3.1 Fairleads

Fairleads for chain shall support chain links in pockets. Fairleads for rope shall support the ropes in a shaped channel.

Fairlead wheels typically have a horizontal axis for tensioning purposes. To cater for the mooring line to pull in the most unfavourable direction, a vertical axis is typically applied to the fairlead.

4.3.2 Bending shoes

Bending shoes are normally static without any means of adjustment for the line orientation. This type of connector is therefore sensitive to wear of the bending shoe itself as well as the mooring component.

4.3.3 Chain stoppers

Chain stoppers normally restrain the chain when under tension. Re-tensioning activities are usually relatively easy since the chain is held in position completely passive by tension only.

Chain stopper can be fixed, single pivoting or double pivoting. The selection shall be based on meeting the design criteria of the chain. Fatigue endurance is typically the driving factor in this selection. A chain hawse pipe is usually part of the design creating an arm to rotate the chain stopper. Special care is to be given to prevent wear of the chain links inside this hawse pipe and not to induce bending loads higher than considered in the design.

4.3.4 Uni-joints

Uni-joints can be used to terminate the mooring line to the vessel. Uni-joints typically have 2 pivoting directions to minimize bending loads onto the mooring line component that connects to the uni-joint.

Uni-joints normally have pins, locked into position. Uni-joints do not allow for length adjustment at that end of the mooring line.

4.3.5 Turret

A turret mooring system allows a ship-shaped structure to rotate or weathervane around a

geostationary turret that is physically moored to the seabed with a multi-line spread mooring system. A suitable bearing system is provided at the interface between the floating structure and the turret.

Refer to ISO 19904-1 subclause 18.3 for detailed requirements on turret structure design.

4.4 On-vessel tensioning equipment

On vessel tensioning equipment is used to adjust mooring line length and tension.

Two types of arrangements are commonly used for on vessel tensioning equipment:

- (1) some systems are active where line load is held permanently on winches, and
- (2) other are tensioning systems exposed to line tension only when a line length adjustment is required.

The design philosophy shall be based on equipment or mooring line components failing before the equipment foundations fail.

Winches and tensioning equipment shall meet or exceed the performance standard specified by the Operator.

Structural foundation for type (1) vessel equipment shall be designed to an action resulting from a tension in excess of mooring line MBS in the most unfavourable situation.

For permanent moorings, the foundations of the tensioning equipment shall be designed to ISO 19904-1.

The tensioning equipment (type (2)) shall be designed to:

- have a suitable margin between working tension and design tension
- fail safe in the event of an overload.

The design and analysis of fairleads, bending shoes, padeyes, and stopper arrangements shall account for effects of wear, friction and movement.

4.5 Monitoring equipment

4.5.1 General

Objectives of a monitoring system can be:

- For serviceability purpose,
- A means of failure detection (alarm),

- A “black box” type system for incident investigation,
- A means to evaluate the mooring system performance, including (but not limited to) station-keeping capability, anchor leg fatigue accumulation, polyester stretch.

Monitoring equipment comprises sensors, electronics, cabling, cabinet and software. Depending on the mooring system, a part of the system can be underwater.

4.5.2 Line tension / Line Payout

If the operation of the floater requires active mooring line adjustment, line tensions and line pay-out shall be continuously displayed at the winch and in the control room.

For permanent floating structures that do not require a tension measurement device, a means of detecting mooring failure shall be installed.

For structures with thrusters that are intended to reduce tension in mooring lines, a means of indicating line tension and/or floating structure offset shall be provided. This means shall be suitably redundant to cover the single failure condition.

4.5.3 Floating structure position and heading

Passive and active mooring systems shall be equipped with a monitoring system that at a minimum displays and records vessel position, heading, and where relevant, draught.

Where vessel position information is critical to operations, the position reference system(s) shall provide redundancy.

For MODUs, a positioning system shall be deployed to monitor the structure's distance from the wellhead or the point of riser attachment.

For floating structures with TAM, position measurement shall be suitably redundant to cover the single failure conditions.

For units with active heading control (manual or automatic) at least two independent heading references of different types shall be provided.

The accuracy and update rate of both devices shall be adequate to meet automatic control requirements. If heading control is critical, three independent heading references of different types shall be provided so a drifting reference can be rejected without a heading excursion.

For MODUs, reference should be made to appropriate IMO and IMCA specifications, see [Clause 9](#).

5 Metocean and other site data

5.1 General

This clause addresses the main site-specific data to be considered in the design of station-keeping systems. Part 1 of ISO 19901 provides procedures and guidance for the determination of environmental conditions and their relevant parameters to be used in this part of ISO 19901.

5.2 Metocean data

5.2.1 Wave data

The metocean design basis shall include regional metocean phenomena as appropriate but not be limited to:

- Annual and if necessary seasonal / monthly statistics of wave height, period, direction and where appropriate distinct characterization of wind sea and swell components.

- Applicable wave spectra and associated parameters for wind seas and swell as applicable.
- Time series of free surface elevation for extreme wave events, or a normalized representation thereof, and the duration of extreme sea states, suitable for the determination of numerical simulations or wave basin tests used for the estimation response statistics for peak wave environments.

5.2.2 Wind data

The metocean design basis shall include regional metocean phenomena as appropriate but not be limited to:

- Annual and if necessary seasonal / monthly statistics of wind speed and direction.
- The reference height above mean sea level and averaging interval of the wind criteria for all phenomena, including identification of the wind profile, gust factors and spectra to be applied to the wind phenomena.
- Time series of squall / thunderstorm wind events (including speed and direction) and associated conditions, if identified as a hazard for the site.

5.2.3 Current data

The metocean design basis shall include regional metocean phenomena as appropriate but not be limited to:

- Annual and if necessary seasonal/monthly statistics of currents through the depth of the water column, including the profiles and directions/directional trends of such associated with significant current phenomena.
- Any regional current phenomena risk for a site, such as the occurrence of solitons/internal waves or shallow water river plume intrusions, should be identified and documented on a criteria basis, with clear indications as to the speeds, depths, directions and durations of such events.

5.3 Bathymetry

The site bathymetry over the extent of the riser connection to flowlines and anchor points shall be provided.

The design water depth for the mooring system shall account for sea level variations due to astronomical tides and storm surges associated with return period metocean events appropriate to the operation in question.

5.4 Geotechnical and Geophysical data

Seafloor and soil conditions at sites intended for permanent mooring systems shall be investigated and characterized to provide the necessary soil properties and design parameters for geotechnical design of the anchors. Details about equipment and procedures for marine soil investigations are provided in ISO 19901-8. Guidance on high resolution geophysical data acquisition and integration of geophysical and geotechnical data is provided in ISO 19901-10.

The site investigation and characterization must extend from the seafloor to a depth sufficient to include the zone of influence of the actions imposed by the anchor body and the base of the anchors on the underlying soil sediments. The underlying soils, to depths of between one to three fluke widths or pile diameters (depending upon the soil conditions and reliance on reverse end-bearing), are mobilized as the anchor is loaded and affect the anchor ultimate holding capacity.

The site characterization shall include the relevant soil engineering properties of each significant stratigraphic layer within the zone of influence of the proposed anchors. The site characterization must also ensure that the provided soil engineering properties and parameters address the design load cases. In some locations where site soil conditions and design load cases are uncomplicated, soil density and drained and undrained strength parameters may be sufficient. If design load cases are complex - such as requiring reliance on mobilization of soil reverse end-bearing, seismicity, short period (cyclonic) and long period (loop current) cyclic loading – and where geologic conditions themselves are complex due to faulting, tilted and interlayered stratigraphy, and unusual soil types (e.g., carbonates, debrites, lithified deposits), then the site investigation

and characterization must ensure that the relevant soil engineering properties and parameters are provided. These could include and not be limited to strength anisotropy, hydraulic conductivity, cyclic degradation, rate effects, and compressibility characteristics. Additional recommendations are provided in [A.5.4](#).

To assist in the assessment of degradation mechanisms (e.g., chain corrosion or wear and synthetic rope particle ingress) that may affect the integrity of anchoring line components, seafloor sediments should be characterised in terms of depth and particle size.

For permanent moorings a seafloor survey shall be performed to document amongst others any debris, seafloor elevations, depressions, cavities, etc.

5.5 Marine growth

The type and accumulation rate of marine growth at the design site can affect mass, weight, hydrodynamic diameters, and drag coefficients of a floating structure's hull, risers and mooring lines. Marine growth specific density, and depth-dependent thickness shall be specified. Any marine growth management program which may influence these parameters shall be considered.

5.6 Physicochemical parameters

Parameters influencing degradation mechanisms such as corrosion should also be defined. Typically, statistics of water temperature, dissolved oxygen, dissolved inorganic nitrogen and organic content at various water depths should be established.

5.7 Ice-related

Where applicable, an assessment shall be made of atmospheric icing, including sea spray icing as they may impact floater displacement and wind loading on the floater.

6 Design and site assessment of station-keeping systems

6.1 Fundamental Requirements

Offshore station-keeping systems shall be planned, designed, constructed, operated, and assessed in such a way that they meet all functional requirements ([6.2](#)), for all phases of their life (see [6.3](#)– [6.5](#)), while ensuring and maintaining adequate integrity (see [Clause 7](#)).

Requirements set by regional, national, and local regulations and standards can be different from those given in this document. While such requirements take precedence, conformance to this document can be claimed only if the requirements of this document are also met.

NOTE Requirements for personnel safety set by flag states and coastal state authorities can have a substantial effect on the design of a floating structure station-keeping system.

6.2 Functional requirements

The function of a station-keeping system is to restrict the horizontal excursions of a floating structure within prescribed limits and to provide means of active or passive directional control when the structure orientation is important for safety or operational considerations.

The limiting criteria for excursions and orientation are generally established either by the Operator of the floating structure or by direct derivation from design requirements including those related to

- safety of personnel,
- protection of the environment,
- stability and serviceability of the floating structure,

- serviceability of the topsides equipment,
- integrity and serviceability of drilling, production, export or other types of risers and umbilicals,
- access to and clearances with respect to nearby subsea or surface installations, and
- any other special positioning requirement.

Those criteria (performance standards for the station keeping system) shall be translated into individual components performance standards for integrity management ([Clause 11](#)).

Design and site assessment of station-keeping systems shall account for the types of systems, which include:

- mobile and permanent systems, and
- passive and active systems.

The design service life of permanently moored facilities is typically in range of 15 to 30 years.

The Operator should consider corrosion, abrasion, and wear rates from existing mooring installations in the same geographic region when selecting a corrosion, wear, and abrasion rate for a new development. It is common to add corrosion allowances also to account for the duration of anchor leg components storage and pre-installation before actual operation start.

NOTE 1 Service life also applies to pre-installed disconnectable mooring systems which also need extra allowances for fatigue life.

Unless designed for disconnection for adverse metocean conditions like tropical cyclones, icebergs, etc., permanent station-keeping systems shall be designed for all year metocean conditions.

NOTE 2 Permanent mooring systems are designed for intact and one-line damaged conditions for the design environment prescribed in this part of ISO 19901. The purpose of the one-line damaged condition is a redundancy check to prove that the station keeping system will not suffer a progressive collapse or unzipping leading to unit loss of position for such a case in design environmental conditions under [Clause 7](#) criteria.

Mobile offshore units themselves typically have a design life of 30 or more years; however, they may be on a particular location for only a few weeks or months. Consequently, a MOU site assessment and the mooring design may be based on seasonal metocean conditions, e.g., MOU operations may be planned to avoid the winter storm season or the tropical revolving storm season. See ISO 19905-3.

Mobile and permanent station-keeping systems may be either passive or active. A floating system with a passive mooring system responds to the environment without any requirement for any line adjustment or external forces like those provided by thrusters. An active mooring system could be thruster assisted or require adjustment of line lengths to modify the stiffness and response of the mooring system. Some passive permanent mooring systems may require adjustment to account for changes in the mooring system over time, e.g., permanent elongation of polyester rope, change in the inverse catenary profile, or trenching, or to mitigate for wear and fatigue.

Compliance of the station-keeping system design with the requirements outlined above shall be established using design criteria specified in [Clause 7](#) and analysis methodologies in [Clause 8](#).

6.3 Safety requirements

Safety of life, protection of environment and property shall be the main principles to be respected at all times through:

- competent design or assessment, which ensures the ability of the floating structure and its station-keeping system to withstand environmental and other external actions likely to occur during the design service lives of the structure and station-keeping system, or duration of site-specific deployment of a MOU,
- definition of safe operating procedures so that risks of injuries to personnel are identified and minimized,

- identification and assessment of possible accidental events, as summarized in ISO 19900, and their consequences minimized,
- performance of a risk assessment to ensure that possible malfunctions do not pose a danger to life or structure integrity, and
- compliance with all relevant regulations, see ISO 19904-1.

The implications of the above items shall be incorporated in the station-keeping system design or assessment, and in the development of the operational philosophy. Specific guidance on Station-keeping systems hazards and risk assessment are given in the informative Annex [A.6.3](#).

6.4 Planning requirements

6.4.1 General

Planning shall be carried out before actual design or assessment is started in order to ensure that the station-keeping system is able to perform its intended function according to [6.2](#). The initial planning shall include the determination of all conditions and criteria, in accordance with the general requirements and conditions specified in ISO 19900.

These concepts and definitions apply to the design of floating structures with permanent mooring systems. For mobile offshore units, planning requirements are defined in ISO 19905-3. For construction units, planning requirements are defined in ISO 19901-6.

6.4.2 Design basis

At the outset of the station-keeping system's design process, documents (design basis) shall be created to summarize:

- definition of design practices and applicable standards, regulations, codes,
- definition of site-specific data such as seabed topography, geohazards, soil conditions and environmental conditions, including ice, as appropriate,
- applicable limit states, design situations and design criteria,
- fabrication, transportation and installation philosophy,
- inspection, monitoring, maintenance and repair philosophy including any intervention strategy and availability of spare parts,
- service and operational philosophy, and
- mooring system removal philosophy.

6.4.3 Design Practices

Regulations, codes, standards, and Recognized Class Society (RCS) rules, (collectively referred to as "standards" hereafter) applicable to the design, manufacturing, construction, and installation of the station-keeping system shall be clearly identified at the commencement of the project.

For innovative station-keeping systems, or applications of unproven structural concepts where limited or no direct experience exists, a formal Technology Qualification process should be followed under the oversight of an independent third party with a demonstrated experience of performing this service. The technical qualification plan may require appropriate numerical analyses and/or physical testing be performed to demonstrate that the inherent safety level of the design is no lower than the safety level implicit in this part of ISO 19901 when applied to traditional structural forms or concepts.

6.4.4 Installation Considerations at Design Stage

The Operator shall develop the installation tolerances, procedures, and acceptance criteria to ensure that the installed mooring system satisfies the assumptions made in the design or site assessment.

Where the performance of the mooring system is dependent on specific tasks to be performed during installation, the mooring designer shall provide the following criteria and tolerances during the design and installation planning stage, where applicable:

- Define the floater target box (UTM position, heading and tolerances), considering riser system offset limits,
- Anchor final positions and tolerances,
- Requirements for cutting out the inverse catenary at the anchor,
- Requirements for straightening of grounded sections of the mooring line, to prevent unrecovered slack in the mooring system which may only come out during extreme weather events. This could be aspects such as defining laydown azimuth corridor tolerances, minimum layback tension, test loading, etc.,
- Requirements for pre-stretching of polyester mooring ropes to manage the rope permanent elongation that is expected to occur during the service life
- Maximum allowable twist in individual mooring line segments,
- Requirements for cutting anchor leg sections at specific radius from either the (as-installed) anchor position, or from the floater target position (related to ensuring even load sharing)
- Sizing of (permanent) installation equipment capacity onboard the facility.

Further requirements and discussion on installation tolerances are provided in [Clause 10](#).

6.4.5 Integrity Management strategy

At planning stage, an Integrity Management strategy shall be developed and documented to ensure full consistency with the design basis of the station-keeping system and its components. The requirements for monitoring, sparing philosophy, residual capacity and emergency repair plan, corrosion control, and inspection planning shall be consistent with the design service life of the floating structure established as part of the planning activities.

Any requirements for residual capacity, i.e., a design situation characterizing the station-keeping system in a temporary impaired state after a single mooring line breakage or a failure of one or more thrusters as appropriately assessed by the FMEA, should be addressed at planning stage considering:

- the requirements to continue operations or site-specific activities,
- the anticipated time required to perform the relevant repair or replacement based on the actual emergency response preparedness (availability of spares, marine spread, procedures etc.), and
- the national regulations.

The designer shall verify that the intended inspection, monitoring, maintenance, and repair objectives are achievable. Relevant provisions related to Integrity Management requirements are given in [Clause 11](#).

6.5 Rules and regulations

The Operator in conjunction with the national regulator where one exists, shall compile the complete list of standards, which are regulatory documents, contractual agreements and company specifications whose requirements shall be met, clarifying areas of possible overlap, and specifying the order of precedence in the enforcement of such requirements.

6.6 Independent verification for permanent systems

For permanent mooring systems, independent verification that the station-keeping system design, manufacturing, and installation complies with the provisions of this part of ISO 19901 should be carried out as a combination of independent calculations, document reviews, audits, surveys, and inspections, etc., as required by this document, rules and regulations and the standards listed in [Subclause 6.5](#). The scope and extent of the verification carried out, the procedures employed, and relevant reports should become part of the integrity management system.

The above requirements may be satisfied in part, or in full, by classing the station-keeping system by an RCS.

6.7 Numerical tools

The designer shall document that the tools and modelling protocols used in the design and analysis activities have been shown to provide results considered acceptable in terms of consistency and accuracy when compared to test data, field measurements, or to the results of other verified tools.

Most of the analysis procedures and calculations described, specified and referenced in this part of ISO 19901 are commonly performed with numerical analysis tools. Many of these consist of commercially available, widely used software suites which, when employed by experienced and well-trained users, may be considered *de facto* industry standards. For these software systems, the software developer is expected to have performed adequate validation and verification, and to maintain evidence thereof.

In other cases, particularly in technological areas undergoing rapid evolution, innovative analytical and numerical approaches and techniques are often embedded in original, proprietary software solutions. In such cases, the software developer is expected to validate the adequacy of the results by, for instance, comparison with model test data or field measurements.

6.8 Design conditions

6.8.1 Limit States

The methodology for the design of permanent or site assessment of mobile mooring systems in this document is based on performing mooring system analyses and comparing specific mooring system responses with acceptance criteria defined in this document or specified by the operator. [Clause 9](#) provides design and operational guidance for DP systems.

For moored vessels, system responses are calculated and compared to acceptance criteria for:

- **Ultimate Limit State (ULS):** This limit state corresponds to the station-keeping system's resistance to the most probable maximum responses, such as those arising from environment conditions up to the design environmental events. ULS covers the cases related to the mooring component strength and constraints that could be detrimental to the integrity of the mooring components, e.g., clearance with seabed or vessel hull. Herein, the ULS includes both intact condition and damaged condition.
- **Serviceability Limit State (SLS):** This limit state is related to the criteria governing normal functional use of the floating structure. The station-keeping design should comply with the serviceability requirements of the floating structure, risers, drilling equipment, production facilities, etc., as defined by the Operator.
- **Fatigue Limit State (FLS):** This limit state covers the cases related to the cumulative mooring component fatigue damage due to environmental or other effects.
- **Accidental Limit State (ALS):** This limit state covers events with lower probability of occurrence than the ULS condition and other site-specific accidental events. No ALS event is specified for station-keeping systems in this part of ISO 19901, but some considerations are provided in [6.8.5](#).

An example of analysis cases and acceptance criteria for a permanent system mooring line strength and seabed clearance is illustrated in [Table A.2](#), and an example for a site assessment of a mobile mooring is illustrated in [Table A.3](#)

The analysis cases for the design of permanent and site assessment of mobile systems are described and summarized in the following subclauses. The acceptance criteria are in [Clause 7](#). Methods of analysis and analysis requirements are in [Clause 8](#).

In this document where an N-year return period metocean condition is specified this shall include all metocean conditions up to and including N-year return period conditions (return periods $\leq$ N-years), or more generally all conditions with an annual joint probability of occurrence greater than or equal to $1/N$ (annual joint probability $AJP \geq 1/N$). The calculation of the joint annual probability of simultaneous occurrence of two independent events is described in **XXXX**.

Robustness of the system should be checked beyond ULS design conditions. Such an assessment may identify an unexpected behaviour or a weak point in the system that could lead to catastrophic failure of the station-keeping system. Annex [A.6.8.1](#) provides additional information on robustness of floating systems.

6.8.2 Analysis Cases for Ultimate Limit State

6.8.2.1 General

The minimum analysis cases for the evaluation of the intact and damaged strength of passive and active permanent station-keeping systems are listed in this subclause.

All load-bearing components of the mooring system shall satisfy the acceptance criteria of [Clause 7](#), i.e., at anchors, fairleads, stoppers, end points of each mooring line segment, connectors, buoys, clump weights, etc., where applicable. For mooring lines that include buoys, clump weights or loop/weight chains, the loss of the buoy, clump weight, or loop/weight chain, due to total or partial loss of expected action effect (buoyancy or weight) without the failure of the line itself shall be considered as a damaged mooring line scenario.

To develop a more complete understanding of the performance of the station-keeping system the Operator may perform analyses for additional cases and define corresponding design criteria. An overview of the analysis matrix is defined here and additional cases that could be defined by Operator are provided in Annex [A.6.8.2.1](#).

Additional cases related to the integrity of the mooring components shall be considered under ULS.

6.8.2.2 Strength analysis cases for permanent systems

Permanent moorings shall be designed with redundancy to withstand the design situations even after the loss of any one mooring line or any one or more thrusters as assessed by FMEA. This can be the consequence of accidental breakage, planned maintenance, or local failure.

6.8.2.2.1 Passive permanent mooring systems

Passive permanent mooring systems shall satisfy the strength criteria for intact and damaged mooring systems for metocean conditions with return period of 100 years.

6.8.2.2.2 Thruster assisted moored permanent systems

Thruster assisted moored (TAM) permanent systems that are not also disconnectable mooring systems shall satisfy the strength criteria for intact and damaged mooring system for metocean conditions with return period of 100-years.

6.8.2.2.3 Disconnectable permanent mooring systems

Disconnectable permanent mooring systems, with or without thruster assistance, shall be analysed for two conditions, with the vessel connected and the vessel disconnected. With the vessel connected the station-keeping system shall satisfy intact and damaged mooring system with single failure (mooring line or thruster) strength criteria, for metocean conditions up to maximum connected conditions.

Strength analyses shall also be performed for the buoy disconnected case (buoy alone) and the intact and damaged cases for metocean conditions with return period of 100 years.

6.8.2.3 Strength analysis cases for mobile systems

Analysis cases for the strength of intact and impaired mobile station-keeping systems are defined in this section. Analyses shall be performed for the vessel draughts and pretensions applicable for operating, standby, and survival modes.

Site-specific assessment criteria for MODUs operating in cyclonic areas during the cyclonic season should follow the requirements specified in Annex B.5 Gulf of Mexico mooring practices for hurricane season.

For mobile moorings where the consequences of a station-keeping failure cannot be mitigated by suspending operations and moving to the survival condition, e.g., mooring in close proximity to a permanent facility, a risk assessment should be used to determine the limiting environmental conditions, for the operation.

The consequences of a failure to keep station depend upon the proximity of the moored system to other surface and subsea structures, and environmentally sensitive areas such as reefs and seafloor habitats; this is implicit in the types of MOU operations; specifically,

- Away from other structures means negligible risk of hitting other structures during progressive failure of the mooring system, nominally greater than 25 miles.
- In vicinity of other structures means possibility of hitting other structures during progressive failure of the mooring system, nominally greater than 1 mile.
- In close proximity to other structures means likely to hit other structures during progressive failure of the mooring system (Tender Assisted Drilling, floatel, gangway connected), nominally less than 1 mile.

Passive and thruster assisted mooring systems shall satisfy the strength criteria, [Clause 7](#), for intact and single failure cases and metocean conditions defined below:

- Away from other structures: metocean conditions with return periods up to and including 5-years,
- In vicinity of other structures: metocean conditions with return periods up to and including 10-years,
- In close proximity to other structures: metocean conditions with return periods up to and including 25-years.

Disconnectable mobile mooring systems, with or without thruster assistance, shall be analysed with the vessel connected for intact and single failure cases for the maximum connected environmental conditions.

Passive and thruster assisted mooring systems shall satisfy the strength criteria, [Clause 7](#), for intact and single failure cases for the maximum operating environmental conditions defined by the Operator.

Components of a mobile mooring that cannot be subjected to a close visual inspection and NDT within the stipulated inspection schedule shall be assessed based on the requirements in [subclause 6.8.2.2](#) (permanent mooring).

Provisions of ISO 19901-6 apply to mobile mooring systems for construction vessels such as heavy lift vessels and pipelay vessels.

6.8.2.4 Mooring Component Integrity Cases

6.8.2.4.1 Clearance of suspended wire and fibre rope with seabed

Steel wire or fibre ropes ends (and connectors) may be damaged by wear, abrasion or fatigue through repetitive contacts with the seabed when located in the thrash zone.

The mooring line clearance with seabed analysis cases apply to the slack mooring lines, in particular the bottom end of the wire or fibre rope segment in the water column of permanent mooring systems. That is, wire or fibre ropes in the water column that are on the slack side of the mooring system which could contact

the seabed (be in the thrash zone). For the permanent mooring systems, the analysis cases for clearance with seabed are the same as the strength analysis cases for intact condition (see [7.3.1](#)).

6.8.2.4.2 Mooring line clearance with hull

Mooring lines may damage or be damaged by wear or abrasion in case of repetitive contacts with hull side or bottom shell.

Therefore, mooring system design shall document absence of interference between mooring lines and hull in all design conditions.

For external turret moored vessels, the clearance between the mooring lines and vessel are usually smallest in benign metocean conditions when the vessel orientation places it over a line or group of lines, and clearances generally increase with the severity of the environment.

For other types of permanent moorings and for MOUs, clearances between the mooring line and hull, or anchor bolster are generally a minimum for slack lines in extreme environmental conditions.

6.8.2.4.3 Surface and subsurface buoys

Surface and sub-surface buoys may be used in intact and damaged cases to manage clearances where a mooring line crosses over a pipeline or another installation's mooring line, or to maintain clearance between the line and the hull or anchor bolster.

Analyses shall be performed for permanent and mobile systems to calculate the maximum submergence of a surface buoy or maximum depth below the water surface of a sub-surface buoy for intact and single failure (mooring line or thruster) case in environmental conditions as per the strength analysis cases.

6.8.2.4.4 Mooring line clearance with sea surface

The mooring line clearance with sea surface analysis cases applies to systems with fibre rope segments in water column. The fibre rope could be susceptible to marine growth or excessive UV exposure and additional considerations, e.g., frequent cleaning, may be required to protect the rope. Typically, a suitable length of steel wire or chain is provided at the top end of the fibre rope mooring leg. The upper steel mooring line segment can be used to adjust the mooring line tension as needed to allow for rope elongation throughout the mooring system's life, or for repositioning of permanent and/or mobile vessels. It is recommended that the Operator of the permanent mooring system establishes clearance requirements between the top of the fibre rope and the sea surface.

6.8.2.4.5 Seabed Trenching

Trenches that develop close to the anchor can reduce the anchor's holding capacity (AHC). Design methods and codes for predicting the depth and width of a trench near to an anchor at the end of field life, and for evaluating the anchor's holding capacity in the presence of a trench are not presently available. However, the mooring system may be designed with a length of mooring line adjacent to the anchor in contact with the seabed, so that the distance between trench and anchor does not reduce the anchor's holding capacity.

When trenches develop, they may also impact the global performance of the mooring system.

6.8.3 Analysis Cases for Serviceability Limit State

The analysis cases related to the serviceability limit state of the mooring system are related to the functionality of the mooring system's ability to provide station-keeping to the riser system. An overview of the analysis matrix defined here and additional cases that could be defined by operator is provided in [A.6.8.3](#)

Additional project specific cases may need to be analysed based on the floating system serviceability limit state.

6.8.3.1 Permanent mooring systems

Offset analysis cases of permanent mooring systems, passive and TAM, that are not disconnectable shall include intact and single failure (mooring line or thruster) cases for metocean conditions with return periods up to and including 100-years.

6.8.3.2 Disconnectable permanent mooring systems

Offset analysis cases of disconnectable permanent mooring systems, with or without thruster assistance, in connected condition shall include intact and single failure (mooring line or thruster), for metocean conditions up to and including the maximum vessel connected environmental condition.

6.8.3.3 Mobile mooring systems

For MOUs the serviceability offset limit state is associated with the maximum environmental conditions for which the operations (riser connected, gangway connected, etc.) can be performed. The analysis shall include cases for intact and single failure (mooring or thruster) conditions. The limiting environmental conditions will control the amount of time that is spent waiting on weather and therefore have a direct impact on the economics of the operation.

As a minimum, offset analysis cases of MODUs shall include two main cases:

- Riser connected and drilling (rotating) with intact case and associated environmental condition defined by operator,
- Riser connected and non-drilling (non-rotating) with single failure (mooring or thruster) case and associated environmental condition defined by the Operator.

Where needed, analyses shall identify the weather threshold to suspend operation and move to survival condition before winch capacity (and not the winch brake capacity) is exceeded.

Vessel offset analysis cases and acceptance criteria applicable for other types of MOU operations, such as diving support, construction, pipe-laying, etc., shall be specified by the Operator.

6.8.4 Analysis Cases for Fatigue Limit State

For permanent systems, the fatigue life of all components of the mooring system (line segments, connectors, anchors, on-vessel line foundations) shall be evaluated. The total fatigue damage caused by low and wave frequency motions of the installed system and where applicable by vortex induced motions (VIM) of the floating platform shall be calculated. Acceptance criteria and methods for calculating fatigue damage are in [Clauses 7](#) and [8](#), respectively.

Analysis cases for assessing fatigue damage of permanent systems shall include intact system with the environmental load cases based on site-specific long-term distribution of winds, wind-waves, currents, and swell-waves. It is recommended that a multi-year hindcast, of daily (normal) wind, wave, and current conditions and their global directions, be used directly in the station-keeping fatigue analysis. Alternatively, a set of fatigue weather bins may be developed from a site-specific multi-year hindcast that is statistically representative of the long-term distribution of wind, wave, and current conditions and their simultaneous global directions. For some turret moored systems, thrusters are used to control the vessel heading in daily or normal environmental conditions. For these systems the effect of the thruster heading control on the vessel relative environmental directions and total fatigue damage shall be included in the fatigue analysis.

A permanent system may be configured with different numbers of risers, umbilicals, and offloading lines during different phases of its life resulting in different pretensions, dynamic responses, and rates of fatigue damage accumulation for each configuration. The fatigue analysis shall account for the various system configurations and the historic or expected number of years for each system configuration.

For moored systems that are subject to vortex induced motions (VIM) fatigue damage from long-term distribution of current conditions shall be added to the fatigue damage resulting from wind and wave conditions. Additionally, the fatigue damage due to the single event with a VIM response with an annual

probability of exceedance of 10^{-2} or greater shall also be calculated. This event may not coincide with the 100 years loop current.

For driven anchor piles the dynamic loads due to hammer impact during pile installation shall be calculated and added to the in-place fatigue damage resulting from the dynamic mooring line tensions at the anchor.

For long-duration MOU operations (i.e., when scheduled mooring line inspection in dry condition cannot be performed as per inspection program (see [11.3](#)) or for regions with large dynamic tensions (i.e. 30-50 % of line tension is due to dynamics in reoccurring, also known as annually occurring or more frequent, events), a fatigue analysis should be conducted to assess the fatigue performance of the mooring system. Particular attention should be given to Kenter links and other components with limited fatigue resistance. When assessing the fatigue performance of MOU mooring system, the fatigue damage from previous deployments shall also be accounted for.

6.8.5 Analysis Cases for Accidental Limit State

Accidental events with return periods in excess of 10,000 years (10^{-4} per annum) may be neglected.

NOTE Design situations for ALS may also arise from a risk assessment linked to the functional and safety requirements in [Subclauses 6.1](#) and [6.3](#) or local regulations.

6.8.5.1 Permanent moorings designed for disconnection

For permanent mooring systems designed for disconnection, an appropriate ALS design situation consists of the adverse environmental event combined with a failure to safely disconnect in that environmental event. The probability of failure disconnection shall be based on quantitative reliability analysis combined with the FMEA of the disconnection system. If the joint probability of exceedance of the adverse environmental event combined with the failure to disconnect is less than 10^{-4} per annum, ALS design check is not required.

6.8.5.2 Damaged Hull Condition

The mooring system shall be designed so the damaged hull design cases as specified by the operator, do not result in loss of station keeping for environmental conditions up to and including 1-year storm return periods.

The mooring system design criteria for the damaged hull design cases shall be defined by the Operator.

6.8.6 Analysis Cases for Temporary Phases

6.8.6.1 General

Appropriate design situations shall be defined for temporary phases i.e., phases significantly shorter than design life and/or that can be weather restricted. The effects of design situations applicable to temporary phases shall be addressed during design to avoid exceedance of either ULS or SLS criteria, and to assess contributions to FLS.

6.8.6.2 Storm safe situation

The mooring system design and the installation procedures should minimize the time required to install the mooring system. The risk assessment associated with the storm safe condition definition shall consider the consequences of failure (e.g., nearby facilities, safety of people, etc.).

Where the consequence of failure is entirely financial, the Operator shall select (1) the return period of the storm, (2) the time required to achieve the storm safe condition, and (3) the safety factor.

Where the consequence of failure is not purely financial (e.g. impact on safety and/or the environment), the storm shall not be less severe than a 1-year return period site and seasonal specific storm. The time required to achieve the storm safe condition shall be specified by the Operator. To ensure no damage to the mooring components, ULS intact acceptance criteria shall be met including maximum line tension and other mooring system constraints (e.g., mooring lines crossing over risers, pipelines, or other infrastructure, polyester or

steel wire rope touching the seabed, etc.), to be assessed in the station-keeping analysis and included in the risk assessment.

6.8.6.3 Offloading

For floating structures that are intended to be offloaded directly to a tanker, the station-keeping system shall be assessed for the maximum offloading environmental design conditions defined by the Operator.

ULS intact acceptance criteria shall apply.

6.8.6.4 Degraded situation

For a floating structure to continue service activities with its station-keeping system in an impaired state (e.g., with a single line/thruster failure), the following requirements shall be met:

- A risk assessment of the station-keeping system is performed taking into consideration the status of the system and the failure root cause (common mode of failure) to ascertain the impact of the mooring failure on surface and sub-surface assets, extreme offsets and clearances,
- The station-keeping system in the impaired condition meets the ULS acceptance criteria including for an additional mooring line failure case, for environmental actions defined by the risk assessment.

7 Design and site assessment criteria

7.1 Safety factors for mooring component strength

7.1.1 Line tensions

For permanent moorings, component characteristic strength is defined as the component end-of-life break strength (ELBS). ELBS shall account for loss of strength due to degradation which may occur during the service life.

For chain, the reduction in strength due to in-service degradation (corrosion, abrasion, and interlink wear) may be estimated using standard formulae combined with a reduced bar diameter.

For mobile moorings, component characteristic strength is defined as the component catalogue break strength (CBS) as long as acceptance/discard criteria are met. (See [subclause 11.5](#)).

For both permanent and mobile moorings, where mooring components are subject to complex loading (in sheaves, fairleads, bending shoes, pile pad-eyes and turret pad-eyes, etc.) the characteristic strength of the component (ELBS for permanent mooring, CBS for temporary mooring) used in calculating the strength factor of safety shall be reduced to account for the reduction in strength due to complex loading. Guidance to determine this strength reduction is given in annex [A.7.1.1](#).

The calculation of line tensions due to vessel motions shall include the dynamic effects of the line's velocity (drag forces) and acceleration (inertial forces). In [Table 1](#) this is referred to as dynamic analysis. See also [Clause 8](#).

Tension limits for ULS (intact and damaged) conditions of permanent and mobile station-keeping systems in normal and extreme environmental conditions shall be in accordance with [Table 1](#).

Table 1 — ULS Safety Factors for Tensile Strength of Mooring Line Components

	Safety Factor Characteristic strength/max tension with dynamic analysis	
System Condition	Permanent Mooring	Mobile Mooring
Intact (mooring, thrusters)	1,67	1,67
Single Failure (mooring, thrusters)	1,25	1,25

The criteria in [Table 1](#) applies to all mooring line components (e.g., chain, steel wire rope, fibre rope, H-links, shackles, Kenters, etc.) and applies to both passive and active station-keeping systems (i.e. passive, thruster assisted moorings, and dis-connectable moorings).

Where mooring lines contain fibre rope segments, tensions are sensitive to the load-elongation properties of the fibre rope segments.

Strength analyses based on idealized mooring system properties can result in a significant under-estimation of the extreme tensions. It is important to conduct sensitivity checks and allow for the uncertainty in outboard segment lengths, pretensions, load sharing, and stiffness in the strength analysis.

For thruster assisted mooring (TAM), systems single failures include one mooring line failure or the single worst failure (SWF) of the integrated thruster control system (ITCS) as identified by FMEA (see [9.6](#)). For TAM systems definitions of intact and damaged conditions are given in [Table 2](#).

Table 2 — Definitions of intact and damaged conditions for thruster assisted mooring

Definitions of System Conditions		Mooring	Thruster
Intact		Intact	Intact
Single Failure	Case A	One Line Failed	Intact
	Case B	Intact	Single Worst Failure
	Case BB ¹	Intact	Black out (loss of all thrusters)
Double Failure ²	Case C	Two Lines Failed	Intact
	Case D	One Line Failed	Single Worst Failure

Note 1 Case BB is applicable for permanent mooring systems and environment conditions of 10-year return period can be used.

Note 2 Safety factors for double failures (lines or thrusters) and thruster blackout cases, and the associated environmental return period or annual joint probability of exceedance may be defined by the operator. The calculation of the annual joint probability of simultaneous occurrence of a thruster blackout and an environmental condition of a particular return period is described in [A.6.8.1](#).

Analysis cases, system conditions, and environmental return periods are specified in [subclauses 6.8.2.2](#) and [6.8.2.3](#).

7.1.2 Anchor factors of safety

Safety factors for conventional drag embedded anchors, plate anchors, gravity anchors, suction piles, and driven piles are specified in this Sub-Clause. Other anchor types (e.g., gravity embedded anchors, scoop anchors, etc.) may be used provided they can be documented to achieve similar levels of reliability to the anchors discussed below.

For plate and gravity embedded anchors where it has been demonstrated by field tests or other methods that the overloading behaviour (failure mode) is similar to conventional drag anchors, drag anchor factors of safety may be used.

The anchor holding capacity (AHC) should be based on site-specific soil properties.

Reference shall be made to ISO 19901-4.

7.1.2.1 Drag embedded anchors

The anchor holding capacity (AHC) of a drag anchor is the horizontal component of the steady pull that can be resisted by the anchor at continuous drag. This includes the soil resistance on the buried portion of the chain or of the steel wire rope but excludes the friction of the chain or steel wire rope lying on the sea floor.

Safety factors for drag anchors used in permanent and mobile station-keeping systems are specified in [Table 3](#). Safety factors for vertically loaded plate anchors are in [Subclause 7.1.2.2](#).

Table 3 — Safety Factors for Drag Anchor

System Condition	Safety Factor (AHC/max load, with dynamic analysis)		
	Permanent Mooring	Mobile Mooring, in Close Proximity or with Riser Connected or Anchors in Drag Path	Mobile Mooring, Away from Other Structures without Riser Connected and Anchors not in Drag Path
Intact (Mooring and thrusters)	1,5	1,0	0,8
Single Failure (Mooring, thrusters)	1,0	Operator Defined	Operator Defined

For MOU moorings in the survival condition anchor slippage can result in redistribution of mooring line loads, with the most loaded line shedding load to adjacent lines, and therefore increasing the chance of surviving a storm event. However, for close proximity MOU mooring (see [6.8.2.3](#)), or MODUs in the operating condition, with the drilling riser connected, or where subsea infrastructure lies in the drag path of the anchor (e.g., pipeline), anchor movement should be avoided. That is, the safety factor for MOU drag anchors depends on the consequence associated with anchor movement. See also Annex [A.6.8.2.3](#) (Strength analysis cases for mobile systems) and [A.6.8.2.4](#) (Clearance Analysis cases) and Offset Analysis cases.

The minimum outboard mooring line length shall be determined to prevent vertical load at the anchor (uplift) under any of the conditions covered by [subclause 6.8.2](#), unless it can be demonstrated that the anchor has sufficient vertical resistance to withstand this vertical load. Guidance on the use of drag embedded anchors to resist vertical forces is provided in Annex [A.7.1.2](#).

7.1.2.2 Vertically loaded plate anchors (VLAs)

Acceptance criteria for vertically loaded plate anchors (suction or drag embedded) used in permanent and mobile systems are given in [Table 4](#). The safety factor is defined as the anchor holding capacity (AHC) divided by the maximum anchor load from a dynamic analysis, where the AHC is for the direction in which the anchor is loaded, i.e., the direction of loading in the failure envelope.

Table 4 — Safety factors for vertically loaded plate anchors

System Condition	Safety Factor (AHC/max load with dynamic analysis)	
	Permanent Mooring	Mobile Mooring
Intact (mooring, thrusters)	2,0	1,5
Single Failure (mooring, thrusters)	1,5	1,2

7.1.2.3 Anchor piles and gravity anchors

For anchor piles (suction, driven, or dynamically embedded) and gravity anchors, the maximum vertical and horizontal components of the extreme mooring line tensions derived from dynamic analysis shall not exceed the vertical and horizontal resistances divided by the safety factors in [Table 5](#).

Table 5 — Safety factors for pile anchors and gravity anchors

System Condition	Safety Factor (AHC/max load with dynamic analysis)			
	Permanent Mooring		Mobile Mooring	
	Vertical	Horizontal	Vertical	Horizontal
Intact (mooring, thrusters)	2,0	1,6	1,5	1,2
Single Failure (mooring, thrusters)	1,5	1,2	1,2	1,0

7.1.3 Factors of safety for buoyancy elements

Surface and sub-surface buoys may be used to manage clearances where a mooring line crosses over a pipeline or another installation mooring line, or to maintain clearance with anchor bolsters or any other object. Buoys may also be used to limit vertical loads at the unit. Analyses shall be performed to calculate the maximum submergence of a surface buoy or maximum depth below the water surface of a sub-surface buoy as specified in part E of [Table A.6](#).

Buoy motions shall be considered in the design of connecting links to the buoy and the mooring line dynamic responses.

If the buoy is not an inline component, the buoy design shall also include the hardware required to prevent entanglement of the pennant line around the mooring line due to torque responses of the system during installation and in-service operation.

A sensitivity study with respect to the consequences of the loss of buoyancy (loss of a buoy and/or loss of one compartment if compartmentalized) shall be performed. Buoys may be filled with foam or incorporate measures such as compartmentalization to reduce the consequences in the event of a single compartment being flooded.

Surface and sub-surface buoys shall be designed for the maximum buoy submergence depth for the analysis cases in part E of [Table A.6](#). The maximum safe working depth for mid-line buoys should be based on analyses and/or testing using applicable design and manufacturing codes.

7.1.3.1 Surface buoys

Surface buoys shall be designed to remain at the surface with a maximum 67 % of volume submerged in all intact and single failure conditions, unless specifically designed for submergence, see [7.1.3.2](#).

7.1.3.2 Subsurface buoys

Subsurface buoys of steel construction shall be designed for external pressure in accordance with ASME VIII Div.1 [Rules for construction of pressure vessels] provides detailed engineering requirements for subsurface buoys of steel construction designed for external pressure.

For foam type buoys, an allowable hydrostatic pressure shall be determined by dividing the hydrostatic collapse pressure by a design safety factor. The choice of the design safety factor depends on the design service life and criticality of the buoy.

The long-term water absorption rate of the foam material at its service depth shall be determined and end of life loss of buoyancy included in the design stage of the mooring system.

7.2 Vessel offsets and heading

Vessel offset, and if applicable heading, limits for permanent and mobile systems shall be established by the Operator.

Offset and heading limits shall be based on the requirements of equipment such as drilling or production risers, umbilicals, gangways, etc. as well as the requirement for safe disconnection of dis-connectable systems. Generally, different criteria will apply to operating, standby, and survival conditions and for intact, damaged, and transient cases. For example, MODU offset limits for the riser connected drilling (rotating), riser connected non-drilling (non-rotating), and survival (riser dis-connected) cases are usually different, and these are typically based on the riser and wellhead mechanical limits.

For MOU operations, such as diving support, construction, pipe-laying, etc., offset criteria for operating, standby, and survival conditions shall be specified by the Operator.

For position monitoring system requirements, see [11.6](#).

7.3 Requirements for clearances

Clearances between the vessel, its mooring lines, and anchors with other surface, subsurface, or seabed structures shall be calculated for the design conditions specified in [Section 6.8](#) and shall satisfy the requirements in this subclause.

Clearance checks shall include design installation tolerances of the mooring system and shall be determined by a dynamic analysis.

7.3.1 Mooring line with seabed (thrash zone)

Fibre or steel wire ropes and their terminations may be damaged by repeated contact with the seabed. Consequently, it is recommended that chain be used at the touchdown, or thrash zone, of the mooring line. The clearance requirements between steel wire or fibre ropes and the seabed in [Table 6](#) apply to the bottom end of steel wire or fibre rope segments (including connector) that are in the water column, i.e., to prevent steel wire or fibre rope of the slack lines repeatedly contacting the seabed (wire or fibre rope in the thrash zone).

Table 6 — Minimum clearances between the bottom of the suspended steel wire or fibre rope and the seabed.

Clearance, Rope with Seabed	Permanent Mooring		Mobile Mooring	
	RRP	Minimum Distance	RRP	Minimum Distance
A) Steel wire rope				
Intact (mooring, thrusters)	Required	>1 m	Permitted	OD
Single Failure (mooring, thrusters)	Permitted	OD	Permitted	OD
B) Fibre Rope				
Intact (mooring, thrusters)	Required	>1 m	Recommended	>1 m
Single Failure (mooring, thrusters)	Recommended	>1 m	Permitted	OD
OD: Operator Defined				

The susceptibility to damage of a fibre rope due to seafloor contact depends on the fibre rope's jacket, design of the filter barrier, the seafloor characteristics, and the line's motions at the touchdown point. Also, because fibre ropes are close to neutrally buoyant, or slightly negatively buoyant, they are susceptible to movement and possible damage on the seafloor. Minimum requirements for soil ingress protection are available in ISO 18692-1:2018. Recommendations for rope construction, seabed survey, and soil conditions are specified in API RP 2SM Section 5.4 and Section 9.4 for fibre ropes in contact with the seabed and should be followed.

7.3.2 Mooring line with sea surface

Fibre ropes may be damaged by long term exposure to elevated water temperatures, UV radiation and marine growth. The mooring designer shall verify that the minimum operating depth of the fibre rope is compatible with the specified rope design. Unless the rope is designed specifically for shallow waters, a minimum operating depth of 50 meters shall be maintained over the life of the mooring.

7.3.3 Mooring line with hull

For external turret moorings, contact between mooring lines and the hull shall be avoided in metocean conditions up to and including 1-year return period conditions. The calculation of the minimum clearance between the hull and mooring line, shall be performed for the most onerous combination of vessel draught and trim and will take into consideration the effects of low and wave frequency vessel motions in metocean conditions up to and including 1-year return period conditions.

For permanent mooring systems the Operator may define the minimum allowable clearances for the intact cases beyond 1-year return period conditions. For permanent systems with a single failure (line or thruster) the Operator may also define the minimum allowable clearance for the slack lines.

For MOUs the clearance requirements and associated vessel draughts, pretensions, and environmental conditions may be established by the Operator:

For permanent or mobile systems with two failures (lines or thrusters) analyses may be performed to determine the limiting environmental conditions for which the mooring lines remain clear of the hull.

7.3.4 Mooring line with riser, umbilical, mooring line, pipeline, seabed assets, and exclusion zones

Mooring lines shall remain clear of risers, umbilicals, the mooring lines of other installations, pipelines, seabed infrastructure, and exclusion zones (part D of [Table A.6](#)).

Minimum clearances shall be specified by the Operator following a risk assessment.

Mooring lines should remain clear of other mooring lines, pipelines, seabed infrastructure and exclusion zones in the single failure conditions. Surface or sub-surface buoys and fibre rope line segments may be used to maintain clearances between a failed mooring line and other mooring lines, pipelines, seabed infrastructure and exclusion zones.

7.3.5 Submerged turret buoy

Submerged turret buoys are typically used on FPSOs with an internal disconnectable turret.

This system is providing station keeping function to the FPSO in connected mode and to the riser/mooring system in disconnected mode.

The net buoyancy of the buoy should be adequate to support the risers, umbilicals and mooring lines before FPSO hook-up, during, and after disconnection.

In the disconnected mode the buoy shall be submerged deep enough not to pose a hazard to ships.

The buoy shall be designed to survive accidental flooding of any one compartment with environmental loads with a return period of not less than 1 year.

The design of the buoy shall ensure no design limits are exceeded of the mooring lines, risers, umbilicals and turret buoy structure.

7.3.6 Anchor with mooring line, pipeline, seabed assets, and exclusion zones

7.3.6.1 Clearance between a drag anchor and other installations

Anchor clearances for permanent and MOU systems are based on two considerations, whether the anchor's holding capacity is greater or less than the mooring line's break strength, and the direction of potential

anchor dragging with respect to seabed infrastructure or other installations and exclusion zones, specifically:

- Anchors with $AHC < \text{mooring line strength}$ and a drag path towards another object: Minimum clearance of 300 m
- Anchors NOT having a drag path towards another object: Minimum clearance of 100 m
- Anchors with $AHC > \text{mooring line strength}$: Minimum clearance of 100 m

7.3.6.2 Clearance between other types of anchors

Other types of anchors may also have clearance requirements which are unique to their holding capacities and installation method. It is important to understand how the anchor achieves its holding capacity and consider common failure mechanisms to adequately account for the needed clearance between other types of anchors.

7.4 Safety factors for mooring component fatigue resistance

Fatigue resistance of mooring components shall be based on Miner's Rule. Miner's Rule calculations shall be either based on tension range (the so-called T-N approach) or stress range (the so-called S-N approach). More information about the differences between these two approaches is provided in Annex A.7.4. Selection of either methodology shall be Operator decision.

For the T-N approach, the curves provided in Table 7 shall be considered, using a fatigue factor of safety of 3. For the S-N approach, the curves provided in Table 8 shall be considered, using a fatigue factor of safety of 5-8.

In case of dedicated S-N or T-N curves with associated safety factors are available for a component, these may be used when approved by Operator. Guidance on the use of dedicated fatigue curves can be found in Annex A.7.4

Polyester and HMPE rope manufactured in compliance with ISO 18692-1, the fatigue endurance for tension ranges, T , of less than 50 % of CBS, is at least six times that of spiral strand wire rope with a mean load ratio, Q , of 0,3, API RP 2SM, API TR 2FC-2[2].

For moored systems that are subject to vortex induced motions (VIM) fatigue damage due to the long-term distribution of current conditions shall be added to the fatigue damage resulting from wind and wave conditions.

In addition, the fatigue damage due to the worst single VIM event with a return period of 100-years or less (an annual probability of occurrence of 10^{-2} or greater) shall be calculated, the required fatigue safety factor for this event alone is 3,0.

To account for the effects of corrosion and wear over the design life when determining the reference breaking strength of common chain or connecting links, the diameter should be taken equal to the nominal diameter minus half of the corrosion and wear allowance. That is, the mid-life or average diameter of chain links and connectors should be used when calculating fatigue damage. More guidance can be found in A.7.4.

The T-N fatigue curves used to calculate fatigue lives of mooring components is given by equation 7.1.

$$N = \frac{K}{R^m} \quad (7.1)$$

Where:

N Number of cycles,

R Ratio of tension range (double amplitude) to reference breaking strength (RBS).

For chain and connecting links, RBS in kN is $0,021 \cdot 1 \cdot d^{2*}(44 - 0,08 d)$ where d is the nominal bar diameter in mm.

For Steel wire rope and fibre rope, RBS is the same as CBS.

Values of m and K for common mooring line components are provided in [Table 7](#).

Table 7 — T-N Fatigue Curve Parameters, m and K for Use with a Fatigue Safety Factor of 3,0.

Component	m	K
Common stud-link	3,00	$1,000 = 10^3$
Common studless link	3,00	$316 = 10^{2,5}$
Baldr and Kenter connecting link	3,00	$178 = 10^{2,25}$
Six / multi-strand wire rope (corrosion protected)	4,09	$10^{(3,20 - 2,79 Q)}, K = 231$, when $Q = 0,3$
Spiral strand wire rope (corrosion protected)	5,05	$10^{(3,25 - 3,43 Q)}, K = 166$, when $Q = 0,3$
Polyester rope (6 x spiral strand, tension range, R , less than 50 % CBS)	5,05	$1,000 = 10^3$
NOTE 1 Q is the ratio of mean tension to CBS of the steel wire rope.		
NOTE 2 For fibre ropes, only Polyester is mentioned for fatigue verification. More guidance for other fibres in A.7.4		

Fatigue assessments performed considering S-N curves instead of T-N curves consider stress ranges instead of tension ranges. The nominal stress ranges, S (in Megapascals), are computed by dividing the corresponding tension ranges in Newton by the nominal cross-sectional area of the component, in square millimetres, i.e.

$$\begin{aligned}
 &— \frac{2\pi d^2}{4} \text{ for chain; and} \\
 &— \frac{\pi d^2}{4} \text{ for steel wire rope.}
 \end{aligned}$$

where d is the component diameter, in millimetres (mm). For chain, d is the diameter of the bar forming the chain link; for steel wire rope, it is the outside diameter of the wire bundle excluding any covering.

The relationship between the stress range (double amplitude), S , and the number of permissible cycles, N , of stress range S , follows an identical format to the T-N relationship given in [Equation \(7.2\)](#) below, i.e., the equation for the representative S-N curve is:

$$N = \frac{K}{S^m} \quad (7.2)$$

Values for m and K are given in [Table 8](#) for a selection of chain link, connecting link and steel wire rope components in sea water.

Table 8 — S-N Fatigue curve parameters, m and K

Component	m	K
Common stud-link	3,0	$1,2 \times 10^{11}$
Common studless link	3,0	$6,0 \times 10^{10}$
Six / multi-strand wire rope (corrosion protected)	4,0	$3,4 \times 10^{14}$
Spiral strand wire rope (corrosion protected)	4,8	$1,7 \times 10^{17}$

The minimum factors of safety for S-N curves presented in [Table 8](#) shall satisfy the following:

$$5,0 \quad \text{when } DF \leq 0,8$$

$$5,0 + 3,0 (DF - 0,8)/0,2 \quad \text{when } DF > 0,8$$

where DF is the adjacent fatigue damage ratio, which is the ratio between the representative fatigue damage D in two adjacent lines taken as the lesser damage divided by the greater damage, ($DF \leq 1,0$). The above T-N curves and S-N curves are based on pure tension-tension loading, i.e. tension loading without bending or torsion. The fatigue life of mooring components (chain, steel wire rope, connectors, etc.) that are

subject to loading that is not pure tension, e.g., chain in the fairlead, on bending shoes, in the thrash zone, at articulations and terminations, out of plane bending (OPB), etc., should be determined using other methods.

For complex loading (e.g., tension, bending, and or torsion) or for mooring line components, where fatigue test data does not exist (e.g., shackles, H-links, tri-plate, and specialty connectors), fatigue resistance shall be demonstrated through the use of Operator approved S-N curves for the base material with hot spot stresses or Stress Concentration Factor (SCF) derived from FEA. (See Annex [A.7.4](#)).

Where mooring lines contain fibre rope segments, the calculated fatigue life of the steel components of the mooring line are sensitive to the load-elongation properties of the fibre rope segments. The non-linear elastic properties of the fibre rope shall be modelled based on representative test data for the rope. Differences in fibre rope segment lengths due to permanent elongation can result in unequal load sharing for lines within a group and thus have an impact on mean tensions and tension ranges in the fibre and steel segments.

Fatigue analyses based on idealized mooring system properties can result in a significant under-estimation of the fatigue damage. It is important to conduct sensitivity checks and allow for the uncertainty in the lengths of outboard segments, load sharing, and stiffness in the fatigue analysis (see [A.7.4](#)).

The T-N curves for steel wire rope are for steel wire ropes protected from corrosion. Elements for corrosion protection include galvanizing, sheathing, blocking compound, and zinc filler wires. Careful investigation considering the design life, inspection, and change-out strategy should be carried out to determine the combination of these elements needed for a specific project. Mean load has a significant influence on steel wire rope fatigue life and therefore should be included in the design curve equations. A mean load of 0,3 RBS is considered to be representative for conventional mooring systems.

For driven anchor piles the dynamic loads due to hammer impact during pile installation shall be calculated and added to the in-place fatigue damage resulting from the dynamic mooring line tensions at the anchor pile.

8 Analysis

8.1 General

Mooring analysis shall be performed to calculate system responses for the design conditions provided in [subclauses 6.8](#).

The calculated system responses shall be compared to the acceptance criteria provided in [clause 7](#).

In addition to the global performance requirements provided in [Clause 7](#), the designer shall be aware of the capacities of individual mooring components (compression, contact, curvature, torsion, etc.) and confirm that output of the analysis can be used to verify that all components meet their individual design requirements.

A sensitivity analysis shall be performed on the most critical design cases, assuming a realistic combination of worst-case installation tolerances, to verify that the mooring system will meet the performance requirements given the installation tolerances. See also [10.5](#).

The mooring analysis shall take into consideration the effect of risers on system responses (stiffness, damping, mean load). The influence of the risers on the mooring system response may be ignored if doing so results in a more conservative mooring design.

The analyses shall cover representative riser configurations based on the anticipated installation and decommissioning sequences for base-case risers and planned future risers.

The analyses shall cover representative topsides configurations based on the anticipated installation sequence of base case, and future topsides equipment.

The physical properties of the mooring line components, weight, stiffness, diameter, etc. that are used in the mooring analyses shall be the nominal values (i.e., catalogue values with no deduction for corrosion, abrasion or wear).

For permanent systems not subject to any regular marine growth removal, marine growth on the hull, risers and mooring system shall be accounted for in the mooring analysis. The more conservative case (i.e., either with or without marine growth) shall be identified and used in the mooring analysis. Details regarding the characterization of marine growth are provided in [subclause 5.5](#).

The variation in pretension due to change in vessel draught and trim or pay-out of lines shall be accounted for in the mooring analysis. The variation in vessel properties (virtual mass and inertia, damping coefficients, projected areas, etc.) and wind, wave, and current force coefficients, and wave motion RAOs due to changes in draught and trim shall be accounted for in the mooring analysis.

In the case of fibre rope, load-elongation properties required to perform the mooring analysis shall be defined based on an understanding of the mooring system behaviour and the use of representative fibre rope test data.

Recommendations for determining the load-elongation properties of fibre rope can be found in ISO 18692 while recommendations for testing and modelling fibre mooring ropes for mooring analysis purposes can be found in API RP 2SM Section 6 and Section 7.

The sea floor bathymetry and slope shall be accounted for in the mooring analysis. The effect of any mooring line trenching on the mooring system shall be evaluated for all stages of the design service life (including no trenching at the start of the service life and maximum trenching at the end of the design service life).

8.2 Analysis methods

The methods generally used to compute the system responses of a moored floating structure are:

- the frequency-domain approach,
- the time-domain approach,
- a combination of frequency domain and time domain analysis.

These methods involve different degrees of approximation and are affected by different limitations and therefore do not necessarily yield consistent results. When using frequency domain analysis, the assumptions made for the stiffness and damping linearization shall be documented. Furthermore, the effect of the vessel heading (mean and low-frequency variations) shall be taken into account when calculating the wave frequency responses. Even though time domain analysis is usually more time-consuming, priority should be given to time domain analysis when non-linear effects have a significant influence on the responses of the system. If verification of the approach selected for the mooring analysis is required, an alternative approach, model test data or full-scale measurements should be used.

A line dynamic method of analysis shall be used, that is the analysis shall account for dynamic loads on the mooring lines and risers associated with mass, drag and acceleration.

Quasi-static methods where dynamic loads are neglected shall not be used for final design of permanent or final site-specific assessment of MOU moorings.

When low-frequency damping is added as a user defined input, the amount of damping that is added shall be documented.

8.3 Coupling effects

Interaction or coupling between the floating structure and the mooring and risers in the form of inertia, damping, mean load, and stiffness affects the responses of the floating structure. The impact of the coupling on the resulting system responses will vary depending on the size and type of floating structure and the response mode being evaluated. The coupling between the floating structure and the mooring and risers can be captured to varying degrees. Both frequency domain and time domain can be coupled or decoupled, and line dynamics can be taken into account in both coupled and decoupled analysis. For decoupled analysis, the mooring designer should evaluate the impact of mooring line and riser damping, and riser stiffness if not included, in the system response. For CALM buoys without an offloading vessel connected, the effects of

coupling are generally significant and shall be included when calculating the buoy wave frequency motion response.

8.4 Environmental loads on the floating structure

The floating structure offsets and motions to be used in the station-keeping system design shall be evaluated for all relevant combinations of wind, wave and current, consistent with the target return period and the site-specific metocean characteristics. Both collinear and non-collinear combinations shall be considered in case the site-specific information is lacking. Multiple wave trains with different directions (e.g., sea and swell) may have to be used to properly describe the total wave environment at the site. The ability of the floating structure to change heading in response to different environmental conditions shall be taken into account.

The sensitivity of the extreme responses to variations of the peak wave period shall be assessed and accounted for. Where an H_s - T_p contour plot is available, sufficient points along the contour shall be evaluated to find the governing combination.

In squall dominated areas, measured time histories of wind speed and direction are to be used in combination with background environmental conditions. For each measured squall time history the squall direction is defined as the wind direction at the time of maximum wind speed.

For floating structures which are small compared to the incident waves (e.g., CALM buoy without an offloading vessel connected) non-linear regular waves (e.g., Dean Stream Function) shall be used to calculate extreme responses.

8.4.1 Wave forces

Wave-induced forces (steady, low-frequency, and wave-frequency) shall be determined by relevant analytical methods or empirically based on model testing with consideration of water depth effects. Approximate analytical methods include diffraction and radiation theory and slender member hydrodynamics.

The mean and slowly varying wave force components shall be accounted for in the analysis. In addition, vessel wave frequency responses shall also be included, by input of wave displacement RAOs or wave force RAOs, hydrostatic stiffness, mass, added mass and damping.

The effect of current on wave forces shall be considered. This includes the change in intrinsic wave frequencies to apparent wave frequencies (encounter frequency effect) as well as changes in the magnitude of wave-induced forces.

For structures with slender members (semisubmersibles, SPARs) viscous wave drift forces should be considered as they may be larger than the diffraction-radiation forces.

In shallow water, the effect of water depth on the wave kinematics and forces shall be included.

8.4.2 Wind forces

Wind induced forces shall be determined by wind tunnel tests, CFD, or numerical analysis methods. (See Annex [A.8.4.2](#)).

The wind field contains energy near the natural frequency of a floating structure, which can produce a significant dynamic response. The wind dynamics (except for squalls) can be described by a steady component, based on the 1-hour average velocity, plus a time varying component calculated from a suitable wind spectrum. The wind spectrum shall be defined over the full range of natural frequencies of the moored structure. The wind spectrum can be used directly in frequency domain analysis or can be used to generate realizations, dependent on a (random) wind seed of time histories of wind speed for use in time domain analyses.

Recommendations for wind profile, gust factors, and wind spectra can be found in [Clause 5.2.2](#). See Annex [A.5.2.2](#) for a more detailed discussion.