

OFFSHORE STANDARD
DNV-OS-E301

POSITION MOORING

OCTOBER 2010

DET NORSKE VERITAS

FOREWORD

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- B) Materials Technology
- C) Structures
- D) Systems
- E) Special Facilities
- F) Pipelines and Risers
- G) Asset Operation
- H) Marine Operations
- J) Cleaner Energy
- O) Subsea Systems

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General

This document supersedes DNV-OS-E301, October 2008.

Main changes in October 2010:

- **Ch.2 Sec.1**

- B306: Included a definition of extreme value for mooring line tensions during a squall event.
- B700: Adjusted the required drag coefficients for steel wire ropes.

- **Ch.2 Sec.2**

- B101: Added fibre rope degradation method.
- B110 (previous item B106): updated guidance regarding e-modules of studless chain based on information from VICINAY.
- E201: Updated Table E1 with respect to in-service assessment.
- F800: Requirements to investigate the possibility of VIM on steel wire and fibre ropes included. If VIM is a possible load effect, the effect shall be included in fatigue assessment.

- **Ch.2 Sec.4**

- Sub-section J, Added 103 and 200: design criteria for fibre ropes and yarn for fibre ropes.
- Q105: Added requirement to measuring ranges for tension measuring equipment.
- R403: Added design requirement to element between MLBE and mooring line.

- **Ch.2 Sec.5**

- A100: Added requirements for anchor shackles for mobile mooring that are not of R-quality.

- **Ch.3 Sec.1**

- B100: Added that temporary mooring is not a class requirement for DP units with **DYNPOS-AUTR** or **AUTRO** notations. Towing arrangements for ship shaped units shall be according to DNV Rules for Classification of Ships.
- D602: It is emphasized that it is the technical part of the standard that could be replaced by e.g. API RP2SK and ISO 19901-7, and that equipment and material shall be certified by DNV.

- **Ch.3 Sec.2**

- A200: Chain qualities R4S and R5 are included in the standard.
- G200: Requirements added regarding in-service condition assessment for fibre ropes.

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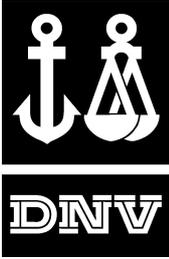
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CHAPTER 1

INTRODUCTION

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SECTION 1 GENERAL

A. General

A 100 Introduction

101 This offshore standard contains criteria, technical requirements and guidelines on design and construction of position mooring systems.

102 The standard is applicable for and limited to column-stabilised units, ship-shaped units single point moorings, loading buoys and deep draught floaters (DDF) or other floating bodies relying on catenary mooring, semi-taut and taut leg mooring system. The standard is also applicable for soft yoke systems.

A 200 Objectives

201 The objective of this standard shall give a uniform level of safety for mooring systems, consisting of chain, steel wire ropes and fibre ropes.

202 The standard has been written in order to:

- give a uniform level of safety for mooring systems
- serve as a reference document in contractual matters between purchaser and contractor
- serve as a guideline for designers, purchasers and contractors
- specify procedures and requirements for mooring systems subject to DNV certification and classification services.

A 300 Scope and application

301 The standard is applicable to all types of floating offshore units, including loading buoys, and covers the following mooring system components:

- stud chain
- studless chain
- Kenter shackles, D-shackles with dimension according to ISO 1704
- LTM shackles
- suction-friction components
- purpose built connection elements
- buoyancy and weight elements
- steel wire ropes
- fibre ropes
- windlass, winch and stopper
- fairleads
- anchors.

B. Normative References

B 100 General

101 The standards in Table B1 include provisions, which through reference in this text constitute provisions of this standard.

<i>Reference</i>	<i>Title</i>
DNV-OSS-101	Rules for Classification of Offshore Drilling and Support Units
DNV-OSS-102	Rules for Classification of Floating Production, Storage and Loading Units
DNV-OS-B101	Metallic Materials
DNV-OS-C101	Design of Offshore Steel Structures, General (LRFD method)
DNV-OS-C201	Structural Design of Offshore Units (WSD Method)
DNV-OS-D101	Marine and Machinery Systems and Equipment
DNV-OS-C401	Fabrication and Testing of Offshore Structures
DNV-OS-D201	Electrical Installations
DNV-OS-D202	Instrumentation and Telecommunication Systems
DNV-OS-E302	Offshore Mooring Chain

Table B1 DNV offshore service specifications, offshore standards and rules (Continued)	
<i>Reference</i>	<i>Title</i>
DNV-OS-E303	Offshore Mooring Fibre Ropes
DNV-OS-E304	Offshore Mooring Steel Wire Ropes
	Rules for Classification of Ships
	Rules for Planning and Execution of Marine Operations, Part 2: Operation Specific Requirements

C. Informative References

C 100 General

101 The documents in Table C1 and Table C2 include acceptable methods for fulfilling the requirements in the standard. Other recognised codes and standards may be applied provided it is shown that they meet or exceed the level of safety of the actual standard.

Table C1 DNV Recommended Practices and Classification Notes	
<i>Reference</i>	<i>Title</i>
DNV-RP-A201	Plan Approval Documentation Types – Definitions
DNV-RP-C103	Column Stabilised Units
DNV-RP-C203	Fatigue Design of Offshore Steel Structures
DNV-RP-E301	Design and Installation of Fluke Anchors in Clay
DNV-RP-E302	Design and Installation of Plate Anchors in Clay
DNV-RP-E303	Geotechnical Design and Installation of Suction Anchors in Clay
DNV-RP-C205	Environmental Conditions and Environmental Loads
DNV-RP-F205	Global Performance Analysis of Deepwater Floating Structures
DNV Classification Note 41.2	Calculation of gear rating for marine transmissions, May 2003

Table C2 Other References	
<i>Reference</i>	<i>Title</i>
API RP 2A	Recommended Practice for Planning, Designing and Construction of Fixed Offshore Platforms
API RP 2SK	Recommended Practice for Design and Analysis of Station-keeping Systems for Floating Structures,
API RP 2SM	Recommended Practice for Design, Analysis, and Testing of Synthetic Fibre Ropes in Offshore Applications
API RP 95F	Interim Guidance for Gulf of Mexico MODU Mooring Practice - 2007 Hurricane Season, 2 nd edition
ISO 1704	Shipbuilding – Stud link anchor chains
ISO 19901-1	Petroleum and natural gas industries - Specific requirements for offshore structures - Part 1: Meteocean design and operating considerations
ISO 19901-7	Petroleum and natural gas industries - Specific requirements for offshore structures - Part 7 Station keeping systems for floating offshore structures and mobile
NORSOK M-001	Material selection
NORSOK N-003	Actions and Action Effects
OCIMF	Prediction of Wind and Current Loads on VLCCs. 2 nd Edition 1994

D. Definitions

D 100 Verbal forms

101 *Shall*: Indicates a mandatory requirement to be followed for fulfilment or compliance with the present standard. Deviations are not permitted unless formally and rigorously justified, and accepted by all relevant contracting parties.

102 *Should*: Indicates a recommendation that a certain course of action is preferred or particularly suitable. Alternative courses of action are allowable under the standard where agreed between contracting parties, but shall be justified and documented.

103 *May*: Indicates a permission, or an opinion, which is permitted as a part of conformance with the standard.

104 *Can*: Requirements with can are conditional and indicate a possibility to the user of the standard.

D 200 Terms

- 201** *ALS*: An accidental limit state to ensure that the mooring system has adequate capacity to withstand the failure of one mooring line or one thruster or thruster system failure for unknown reasons.
- 202** *CALM Buoy*: Catenary anchor leg mooring. The CALM system consists of a buoy that supports a number of catenary chain legs.
- 203** *Classification note (CN)*: The classification notes cover proven technology and solutions which are found to represent good practice by DNV, and which represent one alternative for satisfying the requirements stipulated in DNV rules or other codes and standards cited by DNV. The classification notes will in the same manner be applicable for fulfilling the requirements in the DNV offshore standards.
- 204** *Collinear environment*: Wind, waves and current are acting from the same direction.
- 205** *Creep*: Change in length due to stretching of the polymer in a fibre rope.
- 206** *Design brief*: An agreed document where owners requirements in excess of this standard should be given.
- 207** *Dynamic stiffness*: Is defined as the maximum stiffness of the mooring lines, which is predicted when the mooring system is subject to a maximum design storm.
- 208** *FLS*: A fatigue limit state to ensure that the individual mooring lines have adequate capacity to withstand cyclic loading.
- 209** *HMPE*: High-modulus polyethylene.
- 210** *Horizontal low frequency motion*: Horizontal resonant oscillatory motion of a moored unit induced by oscillatory wind and second order wave loads. Low frequency motion may also be non-resonant and other hydrodynamic forces (viscous) and non-linearities (restoring force may contribute to excitation).
- 211** *Long term mooring*: Mooring of a unit at the same location for more than 5 years.
- 212** *Marine growth*: Caused by soft (bacteria, algae, sponges, sea quirts and hydroids) and hard fouling (goose, barnacles, mussels and tubeworms).
- 213** *Mobile mooring*: Anchoring at a specific location for a period less than 5 years. Includes long term and mobile mooring.
- 214** *Net thrust capacity*: Thrust capacity after all types of loss in thrust capacity are considered.
- 215** *Offshore Service Specification (OSS)*: Provide principles and procedures of DNV classification, certification, verification and consultancy services.
- 216** *Offshore standard (OS)*: The DNV offshore standards are documents which present the principles and technical requirements for design of offshore structures. The standards are offered as DNV's interpretation of engineering practice for general use by the offshore industry for achieving safe structures.
- 217** *Operation condition*: Conditions when drilling/production risers or gangway are connected, and/or production of hydrocarbons are in progress
- 218** *Plate anchor*: Anchors that are intended to resist applied loads by orientating the plate approximately normal to the load after having been embedded.
- 219** *Position mooring*: Mooring of a unit at an offshore location.
- 220** *Post installation stiffness*: Resulting static stiffness that may be used in analysis for the case where the maximum design storm occurs immediately after installation.
- 221** *Pristine curve*: the force versus elongation plot as determined by direct loading to break, of a new previously unloaded rope.
- 222** *Recommended practice (RP)*: The recommended practice publications cover proven technology and solutions which have been found by DNV to represent good practice, and which represent one alternative to satisfy the requirements stipulated in the DNV offshore standards or other codes and standards cited by DNV.
- 223** *Redundancy*: The ability of a component or system to maintain its function when one failure has occurred. Redundancy can be achieved, for instance, by installation of multiple components, systems or alternative means of performing a function.
- 224** *Spiral rope*: Assembly of at least two layers of wires laid helically over a centre round wire, built-up strand or parallel-lay strand, with at least one layer of wires being laid in the opposite direction, i.e. contra-lay, to that of the outer layer(s) e.g. spiral strand, half locked coil, full locked coil.
- 225** *Splash zone*: The extension of the splash zone is from 4 m below still water level to 5 m above still water level.
- 226** *Static stiffness*: Ratio of change in force to change in length when tension is either increased or reduced
- 227** *Stranded rope*: Assembly of several strands laid helically in one (single layer rope) or more (rotation-resistant or parallel-closed rope) layers around a core or centre e.g. 6x19, 6x36, 6x61.
- 228** *Temporary mooring*: Anchoring in sheltered waters or harbours exposed to moderate environmental loads.

229 ULS: An ultimate limit state to ensure that the individual mooring lines have adequate strength to withstand the load effects imposed by extreme environmental actions.

230 Unit: is a general term for an offshore installation such as ship-shaped, column-stabilised, self-elevating, tension leg or deep draught floater.

231 Wave frequency motion: This motion is induced by first order wave loads in the frequency range of the incoming waves.

E. Abbreviations and Symbols

E 100 Abbreviations

101 Abbreviations as shown in Table E1 are used in this standard.

Table E1 Abbreviations	
<i>Abbreviations</i>	<i>In full</i>
API	American Petroleum Institute
ALS	accidental limit state
BS	British Standards
CI	The Cordage Institute
DFE	Design Fatigue Factor
DIA	Vertical design inlet angle
DNV	Det Norske Veritas
DWR	design working rank
FLS	fatigue limit state
IACS	International Association of Classification Societies
IMO	International Maritime Organization
ISO	International Organisation for Standardisation
IWRC	Independent wire rope core
JONSWAP	Joint North Sea Wave Project
MBL	Minimum Breaking Load
MLBE	Mooring Line Buoyancy Element
MPM	Most Probable Maximum
NDE/NDT	Non destructive examination/testing
NMD	Norwegian Maritime Directorate
NPD	Norwegian Petroleum Directorate
OCIMF	Oil Companies International Marine Forum
PSA	Petroleum Safety Authority Norway
RAO	Response Amplitude Operators
SCF	Stress Concentration Factor
STL	Submerged Turret Loading
STP	Submerged Turret Production
ULS	ultimate limit state

E 200 Symbols

201 *Latin characters*

a_D	Intercept parameter of the S-N curve
C_D	Drag coefficient.
C_{D0}	The initial hull drag coefficient, including strakes, but without VIM
D	Cylinder diameter
d_c	Characteristic accumulated fatigue damage during the design life
d_{CSi}	The fatigue damage in one environmental state calculated by the combined spectrum method
d_d	Winch drum diameter
d_{DNBi}	The fatigue damage in one environmental state calculated by the dual narrow-banded approach
d_F	Accumulated fatigue damage ratio between the lesser and more heavily loaded of two adjacent lines
d_i	Fatigue damage in one environmental state

d_{NBi}	Fatigue damage in one environmental state, based on a narrow banded assumption
D_{nom}	Nominal chain or wire diameter
d_p	Diameter of the anchor shackle pin
d_s	The diameter of the anchor shackle
d_w	Nominal wire diameter
$E[S_i^m]$	Expected value of the nominal stress range raised to the power of m in environmental state i
FC	Fibre core
f	Average breaking load of one wire in kN
f_l	Material factor
F_D	Towing design load
f_m	Method factor
f_n	Natural frequency of the transverse rigid body mode
f_s	Vortex shedding frequency
$f_{Si}(s)$	The probability density of nominal stress ranges of magnitude s in environmental state i
F_T	Towing force
f_{tow}	Towing design load factor
F_X	Mean environmental surge load
F_Y	Mean environmental sway load
h	Water depth
h_g	Depth of fairlead groove
H_s	Significant wave height
$H(\omega)$	Transfer function
k	Restoring force coefficient (N/m)
k_l	Amplification factor for transverse VIM
k_l	Lay factor of steel wire ropes
$k_p(l)$	Correction factor evaluated for fatigue test set with l test specimens
K1	Stud links chain cable for bow anchors according to IACS, see DNV Rules for Classification of Ships Pt.3 Ch.3 Sec.5 E. Anchor chain cables
K2	Stud links chain cable for bow anchors according to IACS, see DNV Rules for Classification of Ships Pt.3 Ch.3 Sec.5 E. Anchor chain cables
K3	Stud links chain cable for bow anchors according to IACS, see DNV Rules for Classification of Ships Pt.3 Ch.3 Sec.5 E. Anchor chain cables
l	Number of fatigue test results
l_p	Free length of anchor shackle pin
L_{oa}	The length overall of a ship shaped unit
LTM	D-shackles where the locking device normally consists of a nut and a locking pin through the bolt
M	The unit's mass included added mass
m	Slope parameter of the S-N curve
M_E	Maximum yaw motion between the target and the equilibrium heading
M_T	Yaw moment that can be generated by the thrusters
M_Z	Mean environmental yaw moment
n	The number of tests, not less than 5
n_i	Number of stress cycles in one environmental state
$n_c(s)$	Number of stress ranges of magnitude s that would lead to failure of the component
N_{LF}	Number of low frequency oscillations during the duration of a sea state
N_{WF}	Number of wave frequency oscillations during the duration of a sea state
P	Pitch diameter
P_i	Probability of occurrence of environmental state i
r_g	Radius of fairlead groove
R	The ratio of tension range to characteristic strength
R3	Chain quality according to IACS, see DNV-OS-E302
R3S	Chain quality according to IACS, see DNV-OS-E302

R4	Chain quality according to IACS, see DNV-OS-E302
R4S	Chain quality according to IACS, see DNV-OS-E302
R5	Chain quality according to IACS, see DNV-OS-E302
s	Stress range (double amplitude)
$S(\omega)$	Wave spectrum
$S_R(\omega)$	Response spectrum
S_C	Characteristic strength of the mooring line segment
S^*_C	Reduced characteristic strength
S_{mbs}	Minimum breaking strength of a new component
S_t	Strouhal number
t	Total number of wires
T_{C-mean}	Characteristic mean line tension, due to pretension and mean environmental actions in the environmental state
T_{C-dyn}	Characteristic dynamic line tension induced by low-frequency and wave-frequency loads in the environmental state
T_D	Design life time of mooring line component in seconds
$T_{Design-L}$	Total design tension calculated in the operational limiting environment
$T_{Design-100}$	Total design tension in an environmental condition with a return period of 100 year
T_i	Duration of the environmental state
T_X	Thrust component in surge
T_Y	Thrust component in sway
T_p	Peak wave period
T_z	Zero up-crossing wave period
T_{WF-max}	Maximum wave frequency tension
$T_{QS}(\cdot)$	Quasi-static line tension function
$U_{1\text{ hour}, 10m}$	Mean wind speed over a 1 hour period 10 m above sea level
V	Current speed
V_C	Surface current speed
$V_{C_{Wind}}$	Wind generated current speed
V_r	Reduced velocity
X_{LF-sig}	Horizontal significant low frequency motion
X_{LF-max}	Maximum horizontal low frequency motion
X_{mean}	Horizontal excursion caused by the mean environmental loads relative to the still water location of the unit
X_V	The horizontal distance between the unit and an installation
X_{WF-sig}	Horizontal significant wave frequency motion
X_{WF-max}	Maximum horizontal wave frequency motion

202 Greek characters

δ_s	The coefficient of variation of the breaking strength of the component
δ_w	Bandwidth parameter
ΔT_{growth}	Marine growth surface thickness
γ	Arc of support of a steel wire rope in a fairlead
γ_p	Peak shape parameter
γ_F	Fatigue safety factor
γ_L	Additional safety factor for operational states
γ_{mean}	Partial safety factor on mean tension
γ_{dyn}	Partial safety factor on dynamic tension
λ_L, λ_W	Normalised variances of the low and wave frequency stress process
κ	Correction for 3-D effects
μ	Factor used to calculate marine growth. 2.0 for chain, 1.0 for wire rope

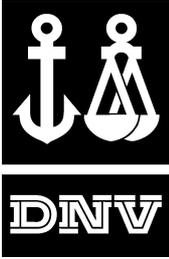
μ_s	The mean value of breaking strength of the component
ν_i	The mean up-crossing rate (hertz) of the stress process in environmental state i
ν_{yi}	The mean-up-crossing rate (hertz) for the combined stress process in environmental state i
σ_b	Specified minimum tensile strength of the material
σ_e	Nominal equivalent stress
σ_f	Specified minimum upper yield strength of the material
ρ_{growth}	Density of marine growth
ρ_i	Correction factor based on the two frequency bands that are present in the tension process
ρ_{seawater}	Density of seawater
σ_{Li}	Standard deviation of low frequency stress range in one environmental state
σ_{Si}	Standard deviation of the stress process
σ_{X-LF}	The standard deviation of horizontal, low frequency motion of the upper terminal point in the mean mooring line direction
σ_{X-WF}	The standard deviation of horizontal, wave frequency motion of the upper terminal point in the mean mooring line direction
σ_{T-WF}	The standard deviation of the wave-frequency component of line tension
σ_{yi}	Standard deviation of the stress process including both wave and low frequency components
σ_{Wi}	Standard deviation of wave frequency stress range in one environmental state
ω	wave frequency

F. Documentation

F 100 General

101 When preparing documentation in accordance with this standard a design brief document shall be prepared and used as basis for the design documentation, stating all project specification, standards and functional requirements.

102 The design documentation shall include drawings and calculations for the limit states. Documentation requirements shall be in accordance with the NPS DocReq (DNV Nauticus Production System for documentation requirements) and DNV-RP-A201. Details are found in Appendix A.



CHAPTER 2

TECHNICAL PROVISIONS

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Sec. 4 Mooring Equipment	66
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SECTION 1 ENVIRONMENTAL CONDITIONS AND LOADS

A. General

A 100 Objective

101 This section describes the environmental data to be used in the mooring system analyses.

A 200 Application

201 The following environmental effects shall be taken into account, as appropriate for the location of the mooring:

- waves
- wind
- current
- marine growth
- tide and storm surge
- earthquake
- temperature
- snow and ice.

Other effects may conceivably be relevant in special locations

202 Detailed metocean criteria should be developed for long term moorings. Less detailed criteria may be acceptable for mobile moorings that are expected to be in consequence class 1 during extreme environmental conditions. The documentation of the metocean criteria shall be made available for information during the assessment of mooring designs.

203 10 000-year wave will be considered for the restoring force to be taken by the turret or STP/STL-buoy and transformed in the ALS condition.

204 The environmental effects to be applied in mooring line response calculations for the ULS and the ALS shall include the most unfavourable combination of wind, wave and current with a return period of no less than 100 years for the combination. Unfavourable conditions are those conditions leading to higher mooring loads. Both the intensities and the directions of the environmental effects are significant. Conservative conditions shall be applied when detailed information is lacking. Note that the absence of a minor effect may sometimes lead to higher line tensions than a moderate intensity of that effect; e.g. through a reduction in damping of platform motions.

205 In Norwegian waters and some other extra-tropical locations, a combination employing both wind and waves with 100-year return periods together with current with a 10-year return period is usually acceptable. This combination becomes less acceptable as load-effects arising from current become more important.

206 In locations with more complex combinations of environmental effects, it is advantageous to consider a few likely candidates for the dominant effect. A 100-year return period is applied to each candidate in turn and fairly realistic, unfavourable levels are applied to the other effects that act simultaneously; e.g.

- a) Dominant squall winds with a 100-year return, with wind seas arising from the squall, in association with;
(i) other effects with 1-year return periods, (ii) in the absence of some or all other effects.
- b) Dominant current with a 100-year return period, in association with; (i) other effects with a 5% probability of exceedance, (ii) other effects with 95% probability of exceedance.

It should be demonstrated that the range of potentially critical cases has been covered, usually by a combination of reasoning, calculation and relevant experience.

207 Reliability analysis can be applied as a more precise alternative, if sufficient environmental data is available to develop joint probability distributions for the environmental loads.

208 For the fatigue analysis of long term moorings, a set of environmental states shall be specified, to cover the range of conditions that are encountered and allow the calculation of fatigue damage with adequate accuracy.

B. Environmental Conditions

B 100 General

101 The load effects are based on the predicted tensions in the mooring lines, normally obtained by calculations. The analysis of the line tensions shall take into account the motion of the floating unit induced by

environmental loads, and the response of the mooring lines to these motions. The characteristic load effects are obtained for stationary, environmental states. Each stationary environmental state may be specified in terms of:

- significant wave height (H_s)
- peak wave period (T_p)
- wave spectrum (JONSWAP or double-peaked).

In the North Sea and North Atlantic the Torsethaugen double peak spectrum can be applied. This spectrum has been developed based on measured spectra for Norwegian waters (Haltenbanken and Staffjord), ref. DNV-RP-C205.

For other locations the Ochi-Hubble spectrum is an alternative. The Ochi-Hubble spectrum is a sum of two Gamma distributions, each with three parameters for each wave system with respect to significant wave height, peak period and a shape factors. The parameters should be determined numerically to best fit the observed spectra, ref. DNV-RP-C205 and ISO 19901-1.

In e.g. West Africa and other areas where wind-waves and swell waves are not collinear the use of double peaked spectrum shall not be applied.

- wave energy spreading function (long crested waves or a cosine to the power of 4)
- main wave direction
- mean wind speed, over a 1 hour averaging period 10 m above sea level ($U_{1 \text{ hour}, 10 \text{ m}}$)
- wind spectrum function
- wind direction
- surface current speed (V_C)
- current profile over depth
- current direction.

The same environmental conditions should be considered for the ULS and ALS, while a wider range of environmental conditions must be considered for the FLS.

B 200 Waves

201 Sea states with return periods of 100 years shall normally be used, see A200. The wave conditions shall include a set of combinations of significant wave height and peak period along the 100-year contour, as defined by inverse FORM technique, /1/. The joint probability distribution of significant wave height and peak wave periods at the mooring system site is necessary to establish the contour line.

202 If this joint distribution is not available, then the range of combinations may be based on a contour line for the North Atlantic, see 204.

203 It is important to perform calculations for several sea states along the 100-year contour line to make sure that the mooring system is properly designed. Ship-shaped units are sensitive to low frequency motion, and consequently a sea state with a short peak period can be critical. How to choose sea states along the contour line is indicated in Fig.1. The same values for wind and current shall be applied together with all the sea states chosen along the 100-year contour.

204 If it is not possible to develop a contour line due to limited environmental data for a location a sensitivity analysis with respect to the peak period for the 100 year sea state shall be carried out. The range of wave steepness criteria defined in DNV-RP-C205 can be applied to indicate a suitable range of peak wave periods to be considered in the sensitivity analysis.

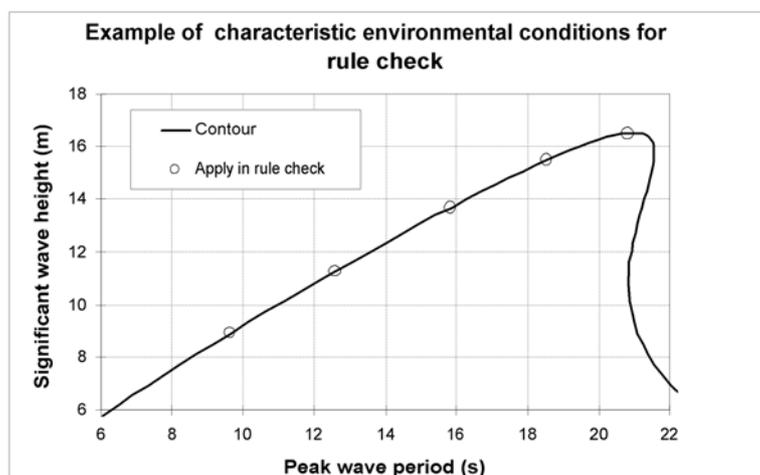
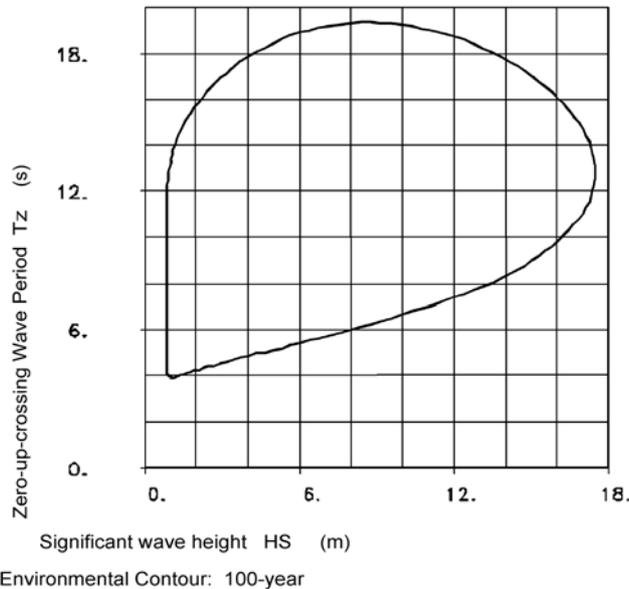


Figure 1
Selections of sea states along a 100-year contour line

205 For mobile offshore units intended for world wide operations a 100-year contour line for the North Atlantic may be applied in the design of the mooring system. This wave data should represent reasonable conservative wave conditions compared with locations elsewhere. The contour line is given in the Guidance Note below. The contour line is based on the scatter diagram for the North Atlantic given in DNV-RP-C205. Typical sea states with a 100-year return period for different locations around the world is also given in the Guidance Note applicable for preliminary designs when detailed metocean data is not available.

Guidance note:



Typical sea states at different locations with a return period of 100 years are given below. Each sea state (3-hour duration) is characterised by maximum significant wave height and wave period (T_p or T_z):

Norwegian Sea (Haltenbanken)	H_s	=	16.5 m
	T_p	=	17.0 -19.0 s
Northern North Sea (Troll field)	H_s	=	15.0 m
	T_p	=	15.5 –17.5 s
North Sea (Greater Ekofisk area)	H_s	=	14.0 m
	T_p	=	15.0 – 17.0 s
<i>Mediterranean</i>			
- Libya (shallow water)	H_s	=	8.5 m
	T_p	=	14.0 s
- Egypt	H_s	=	12.1 m
	T_p	=	14.4 s
<i>Gulf of Mexico</i>			
Hurricane	H_s	=	15.8 m
	T_p	=	13.9 - 16.9 s
Winter storm	H_s	=	7.3 m
	T_p	=	10.8 -12.8 s
<i>West Africa</i>			
- Nigeria (swell)	H_s	=	3.6 m
	T_p	=	15.9 s
- Nigeria (squalls)	H_s	=	2.7 m
	T_p	=	7.6 s
- Gabon (wind generated)	H_s	=	2.0 m
	T_p	=	7.0 s
- Gabon (swell)	H_s	=	3.7 m
	T_p	=	15.5 s
- Ivory Coast (swell):	H_s	=	6.0 m

	T_p	=	13.0 s
- Angola (swell, shallow water)	H_s	=	4.1 m
	T_p	=	16.0 s
<i>South America</i>			
- Brazil (Campos Basin)	H_s	=	8.0 m
	T_p	=	13.0 s
<i>Timor Sea</i>			
- Non typhoon	H_s	=	4.8 m
	T_p	=	11.5 s
	T_z	=	8.3 s
- Typhoon	H_s	=	5.5 m
	T_p	=	10.1 s
	T_z	=	7.4 s
<i>South China Sea</i>			
- Non typhoon	H_s	=	7.3 m
	T_p	=	11.1 s
- Typhoon	H_s	=	13.6 m
	T_p	=	15.1 s

Additional information can be found in ISO19901-1 and API RP 95F.

The zero up crossing wave period T_z and the mean wave period T_1 may be related to the peak period by the following approximate relations ($1 \leq \gamma < 7$), applicable to the JONSWAP spectrum.

$$\frac{T_z}{T_p} = 0.6673 + 0.05037\gamma_p - 0.006230\gamma_p^2 + 0.0003341\gamma_p^3$$

$$\frac{T_1}{T_p} = 0.7303 + 0.04936\gamma_p - 0.006556\gamma_p^2 + 0.0003610\gamma_p^3$$

For $\gamma_p = 3.3$; $T_p = 1.2859 T_z$ and $T_1 = 1.0734 T_z$

For $\gamma_p = 1.0$ (PM spectrum); $T_p = 1.4049 T_z$ and $T_1 = 1.0867 T_z$

If no particular peakedness parameter γ_p , the following value may be applied:

$$\gamma_p = 5 \text{ for } \frac{T_p}{\sqrt{H_s}} \leq 3.6$$

$$\gamma_p = e^{5.75 - 1.15 \frac{T_p}{\sqrt{H_s}}} \text{ for } 3.6 \leq \frac{T_p}{\sqrt{H_s}} < 5$$

$$\gamma_p = 1.0 \text{ for } 5 \leq \frac{T_p}{\sqrt{H_s}}$$

where T_p is in seconds and H_s in metres.

See also DNV-RP-C205, Ch.3.5.5.

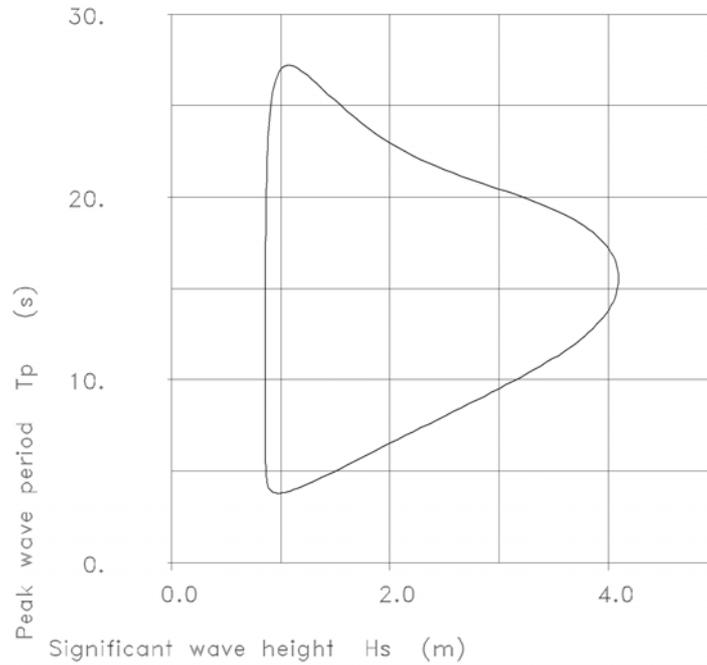
If better data is not available the following can be applied:

- North Sea or North Atlantic: $\gamma_p = 3.3$
- West Africa: $\gamma_p = 1.5 \pm 0.5$
- Gulf of Mexico: $\gamma_p = 1$ for $H_s \leq 6.5$ m
 $\gamma_p = 2$ for $H_s > 6.5$ m.

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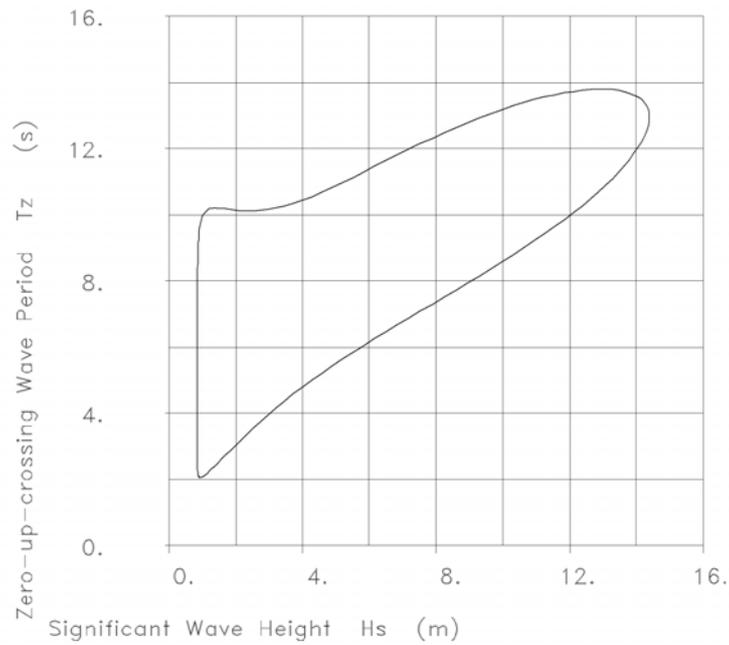
206 Examples of contour lines for different areas are given in the guidance note below.

Guidance note:



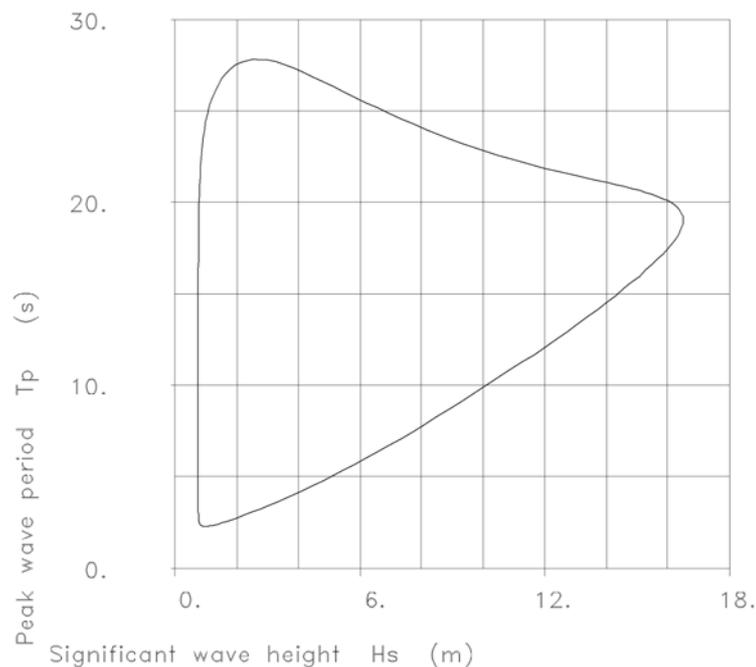
Environmental Contour: 100-year
Data from ANGOLA at 35 m depth, 1980–84

100-year contour line – Angola (swell)



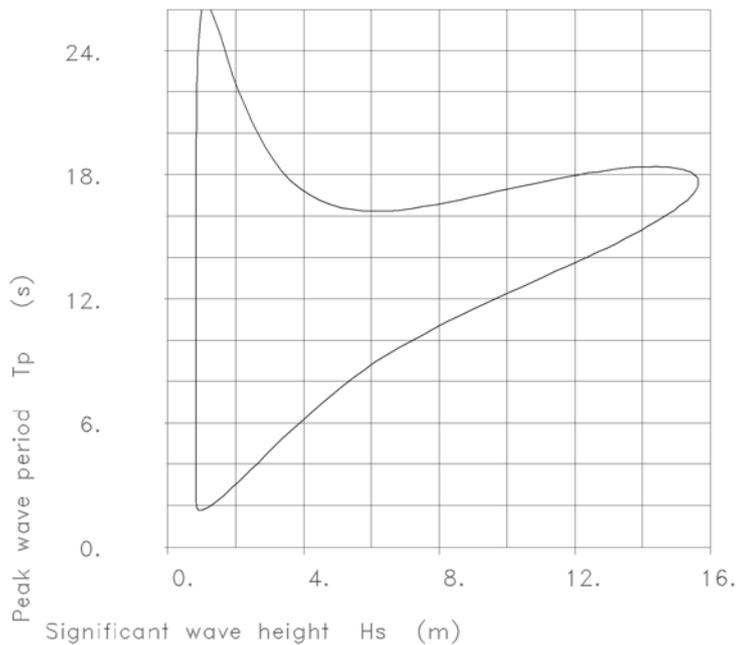
Environmental Contour: 100-year
Data from EKOFISK 1980–96

100-year contour – Ekofisk (North Sea)



Environmental Contour: 100-year
 Buoy data from Haltenbanken 1980–85

100-year contour – Haltenbanken (North Atlantic)



Environmental Contour: 100-year
 VORING Plateau 1989–91, buoy & hindcast

100-year contour – Vøring (North Atlantic)

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B 300 Wind

301 A mean wind speed 10 m above the water surface with a 100-year return period should normally be used, see A200, and be based on the marginal distribution of wind speeds at the specific locations.

302 Wind load shall be treated as a steady component in combination with a time varying component known as the gust, which generates low frequency motion. The time varying wind is described by a wind gust spectrum.

303 The NPD/ISO wind spectrum shall be applied for all locations. The formulation is given in NORSOK N-003 and in ISO 19901-1.

Guidance note:

The NPD/ISO wind spectrum as published in ISO 19901-1 is valid for $0.00167 \text{ Hz} < f < 0.5 \text{ Hz}$, i.e. $600 \text{ s} > 1/f > 2 \text{ s}$. However, in DNV-RP-C205 it is stated that this spectrum is valid up to 2400 s rather than 600 s. It should be noted that the NPD/ISO wind spectrum is uncertain for very long periods (> 600 to 2400 s).

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304 The steady component of the wind speed is represented by a 1-hour average mean wind 10 m above sea level.

Guidance note:

Some typical 1 hour mean wind speeds with a return period of 100 years at different locations:

Norwegian Sea (Haltenbanken)	37.0 m/s
North Sea (Troll field)	40.5 m/s
North Sea (Greater Ekofisk area)	34.0 m/s
<i>Mediterranean</i>	
- Libya	25.3 m/s
- Egypt	25.1 m/s
<i>Gulf of Mexico</i>	
Hurricane	48.0 m/s
Winter storm	23.9 m/s
<i>West Africa</i>	
- Nigeria (combined with swell)	16.0 m/s
- Gabon (combined with swell)	16.6 m/s
- Gabon (squall)	24.1 m/s
- Ivory Coast (combined with swell)	16.0 m/s
- Ivory Coast (squall)	29.5 m/s
- Angola (squall)	21.8 m/s
<i>South America</i>	
- Brazil (Campos Basin)	35.0 m/s
<i>Timor Sea</i>	
- Non typhoon	16.6 m/s
- Typhoon	23.2 m/s
<i>South China Sea</i>	
- Non typhoon	28.6 m/s
- Typhoon	56.3 m/s

Additional information can be found in ISO19901-1 and API RP 95F.

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305 The definition of wind speed as a function of time and height above sea level is given in DNV-RP-C205.

306 The Squall events should normally be analysed in the time domain using the time histories of squalls. The time series shall include variation in both wind speed and direction. The duration of squalls is approximately one hour. The squall wind speed shall be scaled to represent a return period of 100 year. Scaling of the time axis to preserve the rate of increase wind speed may be considered. The squall shall be assumed to approach from any direction if it is not documented that squall always approach from specified directions. The extreme value of the mooring line tension and offset shall be taken as the maximum value for the time series of the actual responses. The 100 year squall wind speed shall be combined with waves and current according to A205. An example of a squall time series with respect to wind speed and direction is given in the guidance note. The squalls directions may vary more than the Fig.3 in the guidance note indicate. Site specific data shall always be applied.

Guidance note:

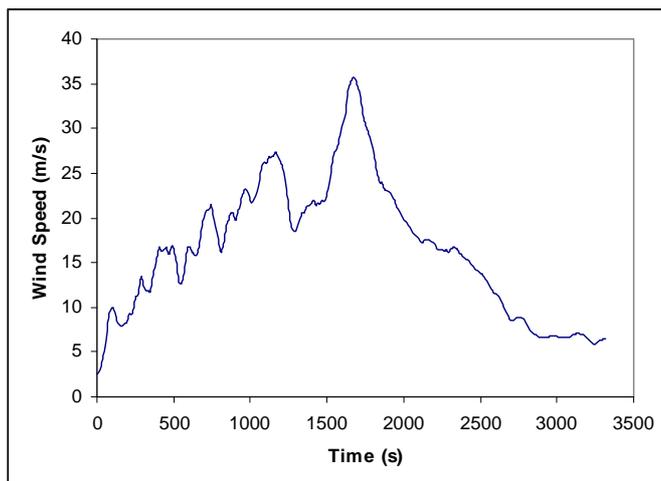


Figure 2
Squall time series with respect to wind speed

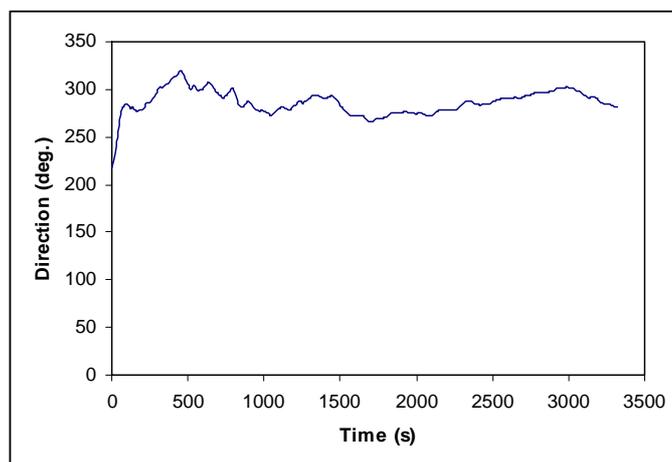


Figure 3
Squall time series with respect to direction

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307 If squall time series are not available the squall can be represented by a one minute average constant wind speed with a return period of 100 year. Wind Spectrum shall not be applied.

B 400 Current

401 A surface current speed with a 10-year return period should normally be used, see A200, and be based on the marginal distribution of current speeds at the location.

402 The most common categories are:

- tidal currents (associated with astronomical tides)
- circulatory currents (associated with oceanic circulation patterns)
- wind generated currents
- loop and eddy currents
- soliton currents.

The vector sum of these currents is the total current, and the speed and direction of the current at specified depths are represented by a current profile. In certain geographical areas, current loads can be the governing design loads.

403 In areas where the current speed is high, and the sea states are represented with small wave heights e.g. West Africa, it is important to have detailed metocean data in order to establish conservative design condition, see A200.

404 In open areas wind generated current velocities at the still water level may be taken as follows, if statistical data is not available:

$$V_{C_{Wind}} = 0.015 \cdot U_{1hour, 10m}$$

Guidance note:

Some typical surface current speeds with a return period of 10 years at different location:

Norwegian Sea (Haltenbanken)	0.90 m/s
North Sea (Troll)	1.50 m/s
North Sea (Greater Ekofisk area)	0.55 m/s
<i>Mediterranean</i>	
- Libya	1.00 m/s
- Egypt	0.78 m/s
<i>Gulf of Mexico</i>	
Hurricane	1.8 m/s
Winter storm	1.08 m/s
Loop current - 100 year	2.37 m/s
<i>West Africa</i>	
- Nigeria	1.1 m/s
- Gabon	0.91 m/s
- Ivory Coast	0.90 m/s ¹⁾
- Angola	1.85 m/s ²⁾
<i>South America</i>	
- Brazil (Campos Basin)	1.60 m/s
<i>Timor Sea</i>	
- Non typhoon	1.10 m/s
- Typhoon	1.90 m/s
<i>South China Sea</i>	
- Non typhoon	0.85 m/s
- Typhoon	2.05 m/s
1) Ocean current going to east	
2) Ocean current going to 347.5° approximately parallel to the coast	

Additional information can be found in ISO19901-1 and API RP 95F.

---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

405 The current's influence on the wave drift forces shall be taken into account.

B 500 Direction of wind, waves and current relative to the unit

501 For column-stabilised units and ships, which are directionally fixed, the loads from wind, waves and current are assumed acting in the same direction.

502 For units with symmetrical anchor pattern, at least head, quartering and beam load directions should be analysed in addition to the case where wind, current and waves are acting in the direction of an anchoring line.

503 A directional distribution of wind, waves and current may be applied if available.

504 For offset calculation use the direction that is intermediate to two neighbour lines in addition to the directions specified in 501.

505 For units with non-symmetrical anchor pattern all directions from 0° to 360° with a maximum spacing of 30° should be investigated. At least one case where the wind, current and waves are acting in the direction of an anchoring line shall be included. A directional distribution of wind, waves and current may be applied if available.

506 For weather-vaneing units such as turret moored production or storage vessels dependant on heading control, site specific data regarding the direction spread of wind, waves and current shall be applied.

507 If site specific data is not available the following two combinations of wind, wave and current shall be applied:

Collinear environment:

— wind, waves and current acting in the same direction. The direction shall be 15° relative to the unit's bow.

Non-Collinear environment:

- wave towards the unit's bow (0°)
- wind 30° relative to the waves
- current 45° relative to the waves.

Wind and current shall approach the unit from the same side, see Fig.4.

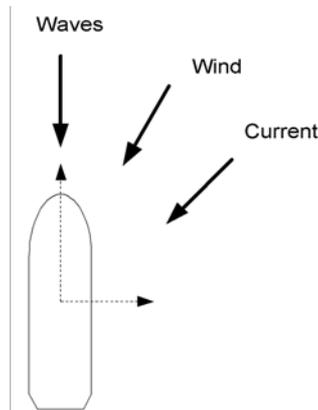


Figure 4
Non-collinear – Directions of wind, waves and current

508 The environmental directions in 507 are also applicable for freely weather-vaneing units, which will rotate to an equilibrium position where the environmental directions have changed relative to the bow.

509 Directional distribution of wind wave and current may be applied if available.

510 The directionality shall be considered for units in regions where the directions of wind, waves and current are not correlated. Typical directionality for West Africa (offshore Nigeria) is shown in Fig.5.

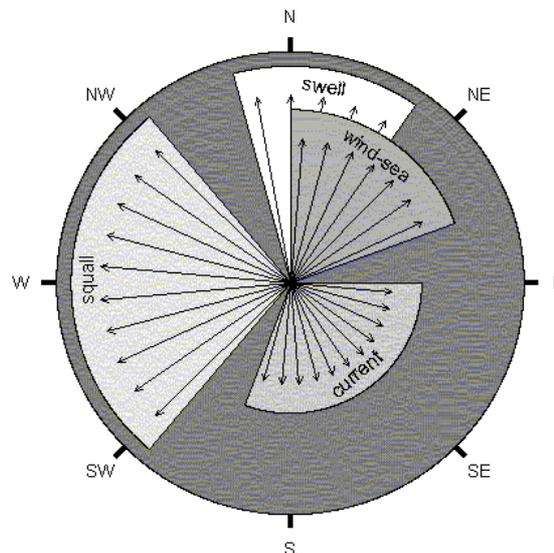


Figure 5
The directional sectors of swell, sea, current and squalls offshore Nigeria

B 600 Soil condition

601 For long term mooring, sea bed soil conditions shall be determined for the intended site to provide data for the anchor design. Soil data should be based on soil borings at location to a depth representative of anchor penetration.

B 700 Drag coefficients for mooring components without marine growth

701 The drag force per unit length applied to D can be written as

$$f = \frac{1}{2} \rho C_D D \cdot v \cdot |v|$$

where C_D is the drag coefficient according to the table below. D is the nominal diameter of the chain or wire rope and v is the corresponding velocity component, either transverse or longitudinal.

	Transverse	Longitudinal
Stud chain	2.6	1.4
Stud less chain	2.4	1.15
Stranded rope	1.8	*
Spiral rope without plastic sheathing	1.6	*
Spiral rope with plastic sheathing	1.2	*
Fibre rope	1.6	*

(*) Longitudinal forces can often be neglected in these cases or the expressions from DNV-RP-C205 can be applied.

702 Other drag coefficients can be accepted provided they are properly documented.

B 800 Marine growth

801 Marine growth on the mooring lines shall be included in the analysis of long term mooring systems for production and storage vessels. The thickness of the marine growth shall be in accordance with the specification for the actual location. The marine growth is accounted for by increasing the weight of the line segments, and increasing the drag coefficients.

Guidance note:

Marine growth is dependent on the location. If no data is available the following data from NORSOK N-003 shall be used:

	56 -59 °N	59 - 72 °N
Water depth (m)	Thickness (mm)	Thickness (mm)
+2 to -40	100	60
below -40	50	30

The density of marine growth may be set to 1325 kg/m³

Mass of marine growth:

$$M_{\text{growth}} = \frac{\pi}{4} \left[(D_{\text{nom}} + 2\Delta T_{\text{growth}})^2 - D_{\text{nom}}^2 \right] \rho_{\text{growth}} \cdot \mu \quad (\text{kg/m})$$

Submerged weight of marine growth:

$$W_{\text{growth}} = M_{\text{growth}} \left[1 - \frac{\rho_{\text{seawater}}}{\rho_{\text{growth}}} \right] \frac{9.81}{1000} \quad (\text{kN/m})$$

ρ_{growth}	=	density of marine growth
ρ_{seawater}	=	density of sea water
D_{nom}	=	nominal chain or wire rope diameter
ΔT_{growth}	=	marine growth surface thickness
μ	=	2.0 for chain, 1.0 for wire rope.

Increasing the drag coefficient due to marine growth:

$$C_{D\text{growth}} = C_D \left[\frac{D_{\text{nom}} + 2 \cdot \Delta T_{\text{growth}}}{D_{\text{nom}}} \right]$$

C_D	=	stud chain: 2.6 studless chain: 2.4 with respect to chain diameter
C_D	=	stranded rope: 1.8 spiral rope without sheathing: 1.6 spiral rope with sheathing: 1.2.

Other methods for determining the increased drag coefficients due to marine growth may be accepted.

---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

C. Environmental Loads

C 100 Wind loads

101 The wind load may be determined by using wind tunnel tests, model basin tests or calculations according to recognised standards, such as:

- DNV-RP-C205 Section 5
- OCIMF Prediction of Wind and Current Loads on VLCCs, 2nd Edition 1994
- API RP 2SK.

102 Mean wind force may be calculated using a drag force formulation, with drag coefficients from model tests, or numerical flow analysis.

103 Mean wind forces described with a wind profile, and oscillatory wind forces due to wind gusts shall both be included. Wind profile according to DNV-RP-C205 and ISO19901-1 shall be applied.

104 Model test data may be used to predict wind loads for mooring system analyses provided that a representative model of the unit is tested. The condition of the model in the tests, such as draught and deck arrangement should closely match the expected conditions that the unit will see in service. Care should also be taken to ensure that the character of the flow in the model tests is the same as the character of the flow for the full scale unit.

105 Documentation of the load analysis method shall be available. The accuracy of numerical models should be quantified by comparison with full scale or model tests. The accuracy of model test results applied in the design shall also be quantified.

C 200 Current loads

201 The current load may be determined from wind tunnel tests, model basin tests or calculations according to recognised theories, such as:

- DNV-RP-C205 Section 6
- OCIMF Prediction of Wind and Current Loads on VLCCs, 2nd Edition 1994.

202 Mean current force may be calculated using a drag force formulation, with drag coefficients from model tests, or numerical flow analysis.

203 If the water depth is less than three times the draught of a ship, the current drag coefficients will increase. Current coefficients for ships given in the OCIMF guideline referred above include shallow water effects.

204 Current profiles shall be used. The current profile described in DNV-RP-C205 can be applied.

205 Site specific current profiles have to be developed for regions where loop or soliton current is dominant.

206 The current loads on multiple riser systems have to be included. Current load is normally neglected for a riser system consisting of a single drilling riser.

207 Current loads on mooring lines are normally neglected. However, in regions where current is dominating (see A202 and B403) current loads on the anchor lines have to be included.

208 Model test data may be used to predict current loads for mooring system analyses provided that a representative model of the under water hull of the unit is tested. The draughts of the model in the tests have to match the expected conditions that the unit will see in service.

209 Documentation of the load analysis method shall be available. The accuracy of numerical models should be quantified by comparison with full scale or model tests. The accuracy of model test results applied in the design shall also be quantified.

C 300 Wave loads

301 Interaction between waves and a floating unit results in loads of three categories:

- a) Steady component of the second order loads known as mean wave drift loads.
- b) First order wave loads inducing first order motions known as wave frequency motions.
- c) Second order wave loads that act together with oscillatory wind loads to induce low frequency motions.

302 Documentation of the load analysis method shall be available. The accuracy of numerical models should be quantified by comparison with full scale or model tests. The accuracy of model test results applied in the design shall also be quantified.

C 400 Wave drift forces

401 The mean wave drift load is induced by the steady component of the second order wave loads. The determination of mean drift load requires motion analysis e.g. radiation or diffraction theory or model testing results.

402 The wave drift force coefficients calculated by potential theory do not include viscous forces. Effects from wave/current interaction have to be included together with viscous effects if relevant.

C 500 Wave frequency motions

501 Wave frequency motions shall be calculated according to recognised theory or based on model testing. The following calculation methods are recommended:

- a) Wave frequency motions of large volume structures shall be calculated by diffraction theory. For slender structures, strip theory may be applied.
- b) Wave diffraction solutions do not include viscous effects. When body members are relatively slender or have sharp edges, viscous effects may be important and viscous effects should be added to the diffraction forces. For slender bodies such as ships viscous damping in roll has to be included.
- c) Wave frequency motions of column-stabilised units, which consist of large volume parts and slender members should be calculated by using a combination of wave diffraction theory and Morison's equation.

502 The JONSWAP spectrum shall normally be used to describe wind induced extreme sea states. The formulation of the JONSWAP spectrum is given in DNV-RP-C205. If no particular peakedness parameter is given, the relation between the significant wave height, peak period and the peakedness parameter given in Sec.1 B204 should be applied.

503 Extreme wind generated waves may be considered to be long crested or the short crestedness may be described by cosine to the power of 4.

504 Consideration of swell should be included if relevant. Sea states comprising collinear wind generated waves and swell may be represented by a recognised doubled-peaked spectrum according to B101. The formulation of both Torsethaugen and Ochi-Hubble doubled peak spectra can be found in DNV-RP-C205. Swell shall be considered long crested.

505 The most probable largest wave frequency motion amplitude may be calculated assuming that the maxima of the motion response fit a Rayleigh distribution according to Sec.2 B405.

506 When anchoring takes place in shallow water, the following shall be included in the calculation of wave frequency motion:

- a) The effect on wave frequency motion caused by restoring forces due to the mooring system and risers shall be investigated when the water depth is below 70 m. The effect shall be taken into account if the wave frequency motions are significantly affected.
- b) When the water depth is less than 100 m, the finite depth effect shall be included in the wave frequency motions (RAOs). Calculations shall be carried out for the actual water depth at the location according to C501. RAOs calculated for a water depth within a deviation of ± 10 m will be accepted.

507 For taut leg mooring systems the stiffness of the mooring system and risers shall be included in the calculation of wave frequency motions regardless of water depth if the wave frequency motions are significantly affected.

C 600 Low frequency motions

601 Environmental actions due to wind, waves and current shall be taken into account in the analysis of the mean and low frequency motion response of the vessel. Only horizontal modes of motion (surge, sway, yaw) are usually considered for ships and semisubmersibles, while vertical modes need to be included for deep draught floaters /4/.

602 Mean wind and current forces may be calculated using a drag force formulation, with drag coefficients from model tests, or numerical flow analysis. The drag coefficients are dependent on the angular orientation of the vessel relative to the incoming fluid flow direction.

603 Mean wave forces may contain components due to both potential and viscous effects. Potential effects may be based on the results of a prior first-order analysis, which provides mean drift force coefficients for each mode of motion, as a function of wave frequency, current speed, and angular orientation of the vessel. Linear superposition may be applied to obtain the mean forces in irregular, long-crested waves, by combination of the mean drift force coefficients with a wave spectrum. Viscous effects on the mean force due to waves are usually omitted in practice.

604 The mean position of the vessel in an environmental state is computed by finding the position where equilibrium is established between the mean environmental loads and the restoring forces from the positioning system. The nonlinear characteristic of a catenary mooring should be taken accurately into account in establishing the mean offset. If the vessel is free to rotate, then the effect of any rotation should be taken into account in computing the magnitude of the mean environmental forces. A stable equilibrium position should be sought.

605 Low-frequency wind forces may be based on a drag force formulation, with wind speed as the sum of the mean wind speed and an unsteady wind speed, from a wind spectrum. Expansion of the quadratic term in

wind speed yields:

- the mean force, already considered above
- a force proportional to the unsteady wind spectrum, scaled by the mean speed
- a quadratic term in the unsteady speed, which is neglected.

606 The low-frequency wave forces may contain components due to both potential and viscous effects. In this case, it may be necessary to take the viscous effects into account for column-stabilised units, but they may be neglected for ships. Potential effects may still be based on first-order analysis, using the mean drift force coefficients, mentioned above. The spectral density of exciting forces in irregular waves may then be obtained as described in /5/.

607 It is more difficult to incorporate viscous contributions to the low-frequency excitation in a frequency domain analysis. Hence a time domain analysis may be needed for semisubmersibles.

608 Low-frequency motion response to the exciting forces may be calculated in the frequency domain or the time domain. Linearisation of the restoring forces from the mooring system is necessary in frequency domain analysis. The linearisation should be applied around the mean vessel offset for the environmental state being considered, using stochastic linearisation, or assuming a realistic response amplitude.

609 Low frequency wave induced motion may be based on model testing in stead of, or in addition to numerical calculations.

610 The test or simulation duration time shall be sufficient to provide adequate statistics, and shall not be taken less than three hours.

611 The most probable largest low frequency motion amplitude may be calculated assuming that the maxima of the motion response fit a Rayleigh distribution. See Sec.2 B405.

612 The effect of the current velocity on the low frequency damping shall be considered. Comparison with relevant model test data is recommended.

Guidance note:

Low frequency motion of a moored unit is dominated by the resonance at the natural frequency of the moored unit. The motion amplitude is highly dependent on the stiffness of the mooring system, and on the system damping. A good estimate of damping is critical in computing low frequency motions. There are four main sources of damping:

- viscous damping of the unit
- wave drift damping
- mooring and riser system damping
- thruster damping (only applicable for thruster assisted mooring)

The wave drift damping and the mooring or riser system damping are often the most important contributors to the total damping.

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D. Vortex Induced Motion (VIM)

D 100 General

101 Moored platforms constructed from large circular cylinders, such as Spars and some other deep draught floaters, may experience vortex-induced motions (VIM) when exposed to a steady current. VIM should be considered in the design of mooring systems for such floaters, because it may induce additional loads on the mooring system.

102 Vortex-induced motions occur transversely to the current direction, and in line with the current. These motions contribute to the offset away from the still water position. The occurrence of VIM also increases the mean drag force in the current direction, making a further contribution to offset. Increased offset implies increased mooring line tensions, to be checked against the line strength in the ULS and ALS. VIM also causes oscillations in the line tension, which may contribute to fatigue damage, to be checked in the FLS.

103 The present guidance is largely based on general principles, and will need to be refined when more full scale experience with VIM of moored platforms has been accumulated.

D 200 Conditions for VIM to occur

201 Significant VIM is only expected to occur if a natural frequency of the moored system lies in the vicinity of the vortex shedding frequency of a major cylindrical component of the platform. Natural frequencies for rigid body modes transverse to the current direction (e.g. sway and roll) should be considered. They may be compared to the vortex shedding frequency given by

$$f_s = S_t \frac{V}{D}$$

where V is the current speed, D is the cylinder diameter, and St is the Strouhal number. The Strouhal number is dependent on Reynolds number. The Reynolds number tends to be $> 10^7$ for the large cylinder diameters used in these platforms. Hence, it should be appropriate to consider a Strouhal number $S_t \approx 0.22$ in such cases.

Only the maximum current speed needs to be considered when checking for occurrence of VIM i.e. the current speed with 100-years return period. If the natural frequencies are appreciably greater than the vortex shedding frequency for this current speed, then VIM is not expected to occur. Otherwise, VIM may occur at this speed or at lower speeds.

202 It is most convenient if significant VIM can be ruled out. In some cases, it may be possible to increase the stiffness of the mooring system, such that the natural frequencies lie above the vortex shedding range. However, an increase in the stiffness of the mooring system usually implies higher mooring line tensions, increased wear in the lines and increased mooring loads on the platform. A highly nonlinear restoring force from the mooring system will also tend to suppress VIM.

D 300 VIM analysis

301 VIM should be analysed when it cannot be ruled out. This can require considerable effort, and is likely to depend on careful model testing. DNV-RP-C205 provides further guidance and some data that can be used in a preliminary, rough assessment of VIM response. The objective of the VIM analysis is primarily to obtain:

- a) the amplitude of the transverse VIM, under varying current speeds
- b) the magnitude of the mean drag coefficient, dependent on the amplitude of VIM
- c) the amplitude of the variation in the drag force, at twice the vortex shedding frequency.

302 It is usually convenient to present results in a non-dimensional form, giving the ratio of transverse VIM amplitude to cylinder diameter A/D as a function of the reduced velocity

$$V_r = \frac{V}{Df_n}$$

where f_n is the natural frequency of the transverse rigid body mode. Some random variation of the VIM amplitude will normally be found in test results for a given velocity. The mean amplitude is appropriate for use in the FLS, while the USL should take account of the random variation.

303 It should be acceptable to assume that the oscillation frequency is equal to the natural frequency of the transverse oscillation mode, for lightly damped systems, although there is some tendency for the oscillation frequency to increase with V_r . The drag coefficient is given as a function of the amplitude ratio A/D . The following functional form is sometimes used:

$$C_D = \kappa C_{D0} \left(1 + k_1 \frac{A}{D} \right)$$

where κ is a correction for 3-D effects, C_{D0} is the initial hull drag coefficient, including strakes, but without VIM, and k_1 is an amplification factor for transverse VIM.

It should be noted that these results are dependent on:

- mass (or inertia) ratio of the cylinder to the displaced fluid
- any system damping in addition to direct fluid effects on the cylinder
- Reynold's number
- surface roughness of the cylinder
- turbulence or shear in the incoming velocity field
- any VIM suppression devices, such as strakes.

304 Hence, scale effects should be considered carefully when utilising model test results. When Froude scaling is applied and the viscosity is about the same at both scales, then the Reynolds number falls by the scale factor raised to the power $3/2$ in the model tests. It is important to check the effect of this change on VIM. A roughened model can be useful to compensate for a low Reynolds number; i.e. to provide the correct flow regime in the model tests.

Additional considerations for model tests include:

- accurate representation of the actual underwater hull with cut-outs, terminations, etc.
- sufficient heading angles are tested to cover all aspects of asymmetry in the hull
- sufficient simulation/towing length in the basin such that vortex shedding can be fully developed
- an adequate range of reduced velocity is covered.

305 Platform VIM response may include both translational and rotational modes (e.g. sway and roll), especially when these two modes have fairly similar natural frequencies. However, it is more convenient to only consider a single translational mode of freedom in VIM model tests. Care should be exercised when applying such model test results to evaluate the actual platform response. The frequency extent of lock-in, and

the magnitude of the forces are known to be dependent on the motion amplitude; i.e. they may vary over the length of a cylinder vibrating in a rotational mode. Hence, a strip method, that takes account of amplitude variation over the cylinder length, might possibly be useful in some cases.

306 VIM analysis concentrates on the effect of current. The frequencies of incoming waves are unlikely to cause vortex shedding loads in the vicinity of the low natural frequencies for sway and roll. If wind and waves are present at the same time as currents causing VIM, then they will certainly affect the system response. It seems plausible that the wave-induced fluid velocities will tend to disorganise the combined velocity field, as compared to a pure current field, and be more likely to reduce the mean amplitude of the lift force due to vortex shedding, than to increase it. Hence, it should be conservative to superimpose the forces calculated separately due to waves and vortex shedding. The nonlinearity of the mooring system stiffness normally needs to be taken into account in the response analysis; i.e. it is not generally acceptable to calculate separately the line tensions due to coincident wind, waves and current, and then superimpose these results. However, this may be acceptable for a nearly linear system stiffness, as might be the case with a taut mooring system.

D 400 ULS and ALS

401 Appropriate combinations of wind, wave, and current-induced load-effects need to be considered, such that these environmental combinations each have a joint annual probability of exceedence of 10^{-2} ; i.e. a 100-year return period. Relevant directions of the separate environmental effects also have to be considered. The usual combination of 100-year return period for wind and waves with 10-year return period for current, from A205, is not necessarily adequate in cases with significant VIM.

402 A time domain mooring system analysis is advisable to include the effects of VIM on mooring line tensions. The drag coefficient should be adjusted for the effect of VIM in this analysis. This may be achieved by initially assuming a VIM amplitude, and subsequently iterating on that amplitude. Mean environmental loads are then applied to determine the mean platform offset. The natural frequencies of sway and roll are determined for that mean position. The VIM amplitude is extracted from the VIM analysis, and a sinusoidal force (or force and moment) is found which will result in the same amplitude of transverse platform displacement relative to the mean position. This transverse sinusoidal force and an in-line drag force variation at twice the frequency are then imposed, together with the other wind, wave and current loads. The vortex shedding loads should be modelled as independent of the oscillatory wind and wave loads. The resulting time histories of mooring line tensions are analysed in the usual way to obtain the characteristic line tensions. The VIM effects contribute primarily to the mean and low-frequency components of line tension. Care should be taken to ensure that the length of the realisations is adequate to avoid significant statistical uncertainty.

403 A strip model for variation of vortex shedding loads along the cylinder length would introduce more complexity into this mooring system analysis, and possibly require additional model test results for vortex shedding forces on a cylinder undergoing forced vibrations.

404 The distribution of the maxima of the low-frequency tension component should be checked to ensure that it does not seriously deviate from the usual distribution type (between exponential and Rayleigh distributions), not in a conservative direction.

405 It is assumed that the safety factors already defined for the ULS and ALS may be applied in cases when VIM contributes significantly to the dynamic line tension. To ensure that this assumption is permissible, the following should be observed:

- a) bias in the analysis of VIM effects should be avoided, and any unavoidable bias should be conservative with respect to line tension
- b) VIM effects should imply a coefficient of variation less than 10% for the estimation of the standard deviation of low-frequency tension, under specified environmental conditions
- c) model uncertainty in the estimation of VIM effects should imply a coefficient of variation less than 5% for the estimation of the mean tension, under specified environmental conditions.

Additional conservatism should be applied to compensate, if conditions (b) and (c) are not fulfilled.

D 500 FLS

501 VIM may contribute appreciably to the accumulation of fatigue damage if sufficiently severe VIM events are expected to occur, with an appreciable duration. If this appears to be the case, then detailed analysis of VIM is required for the FLS. The joint environment must be made discrete in enough detail to allow a reasonably accurate estimate of the total fatigue damage. This can require consideration of an extensive set of environmental states. If VIM events coincide with line tension due to wind and/or wave effects, then it is essential to consider the effects together, because of the nonlinear nature of the Miner-Palmgren hypothesis for fatigue damage accumulation.

502 The same analysis technique as described for the ULS and ALS may be applied to determine the tension time history in an environmental state. It seems likely that the VIM effects will contribute to the low-frequency tension, without significantly increasing the bandwidth of this tension component. Hence, combined spectrum or dual narrow-banded approaches described in Sec.2 F300 may be applicable to calculation of the fatigue

damage. It may be advisable to check a few cases by rainflow counting. If VIM events occur in the absence of wind and waves, then the fatigue damage calculation may possibly be simplified, by assuming constant amplitude for the tension oscillations.

The accuracy and computational expense of time domain analysis may be somewhat excessive for the fatigue analysis. Somewhat more uncertainty is normally tolerable for an individual environmental state, since the total fatigue damage is the sum of damages from many states. Hence, it may well be possible to develop an acceptable frequency domain analysis for this purpose.

503 It is assumed that the safety factors already defined for the FLS be applied in cases when VIM contributes significantly to the fatigue damage, provided the bounds on the model uncertainty are observed.

E. References

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SECTION 2 MOORING SYSTEM ANALYSIS

A. General

A 100 Objective

101 This section provides a structural design procedure for the mooring lines and soft yoke systems of floating offshore units, in a partial safety factor format.

102 Single point mooring system includes a “soft yoke” for mooring a ship directly to a fixed tower. A turntable is fastened on the tower with a bearing to allow the vessel to freely weather-vane about the tower. A yoke arm is connected to the turntable with pitch and roll joints to allow the vessel to pitch and to roll. The yoke includes a large ballast tank to provide the necessary restoring force to minimize vessel motions. The yoke arm is connected to the offloading vessel via a pendulum or chain/rope system. Product is transferred from the tower across swivels located on the turntable and through hoses from the turntable to the vessel.

A 200 Application

201 The design criteria are formulated in terms of three limit states ULS, ALS and FLS. Definitions are given in B101.

202 The safety factors for the limit states have been calibrated against more detailed calculations using the methods of structural reliability analysis. Turret moored ships and semi- submersibles in water depths from 70 m to 2000 m, and environmental conditions for the Norwegian continental shelf and for the Gulf of Mexico were included in the calibration.

203 The safety factors are also applicable to deep draught platforms (such as SPAR), provided that additional attention is applied to current loads and current directions. Possible effects of low frequency excitation on vertical plane motions shall be considered.

204 The design procedure is intended to be applicable for floating units with position mooring systems consisting of chain links, steel wire ropes, synthetic fibre ropes and a combination of these mooring line components. The design procedure is also applicable for soft yoke system with respect to establishing the loads caused by the floating unit into the yoke's mooring arms.

205 The design procedure should be applicable to other geographical locations where the environmental conditions are more or less severe than considered in the calibration.

206 The design procedure is intended to be equally applicable to mobile drilling units, floating production units, loading buoys and floating accommodation units. Distinction between the possible consequences of a mooring system failure for different types of units is included in the ULS and ALS.

B. Method

B 100 General

101 The mooring system shall be analysed according to design criteria formulated in terms of three limit state equations:

- An ultimate limit state (ULS) to ensure that the individual mooring lines have adequate strength to withstand the load effects imposed by extreme environmental actions.
- An accidental limit state (ALS) to ensure that the mooring system has adequate capacity to withstand the failure of one mooring line, failure of one thruster or one failure in the thrusters' control or power systems for unknown reasons. A single failure in the control or power systems may cause that several thrusters are not working.
- A fatigue limit state (FLS) to ensure that the individual mooring lines have adequate capacity to withstand cyclic loading.

102 FLS is mainly of concern for steel components where fatigue endurance may be limiting the design. For fibre-rope segments, the time-dependent strength may be limiting the design, thus stress rupture or creep failure should be incorporated in the checks for ULS and ALS as appropriate.

Guidance note:

Elevated tension and stress rupture

The ability of a polymeric fibre to sustain prolonged, elevated tension depends on the magnitude of tension and the preceding time under elevated tension. Failure under sustained, elevated tension is referred to as stress rupture. This is measured in time-to-rupture tests, and the results are plotted with tension on the y-axis and log time on the x-axis.

This way, a design curve for stress rupture under constant tension can be established analogue to what is used for fatigue under cyclic tension.

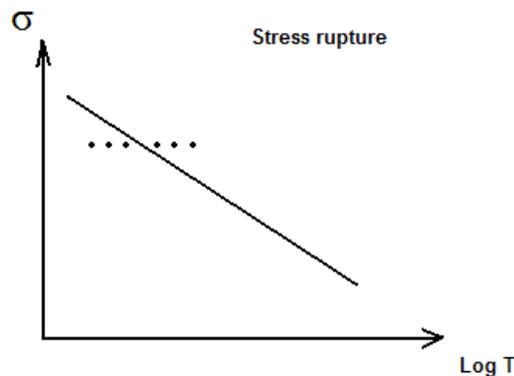


Figure 1
 Typical stress rupture curve

Creep and Creep Failure

In polyester and para-aramid fibres the rate of creep (i.e. length increase under sustained tension) decreases logarithmically over time. For HMPE fibre the rate of stage-II creep is constant under sustained tension.

Creep takes place in three phases, where the transition between phases II and III is referred to as creep failure. At this point, the creep accelerates and the remaining time to break is short. In a creep test the changes in strain (i.e. creep) is measured as a function of time under constant tension. The results are plotted with strain on the y-axis and time on the x-axis. A typical curve for HMPE is given in Fig.1.

Although HMPE fibres exhibit more creep than polyester and para-aramid, the rate and extent of creep is predictable. These will depend on the particular HMPE yarn, temperature, tension level and duration. The time-based safety margin against creep failure of HMPE-based ropes should be taken as 3 for mobile moorings.

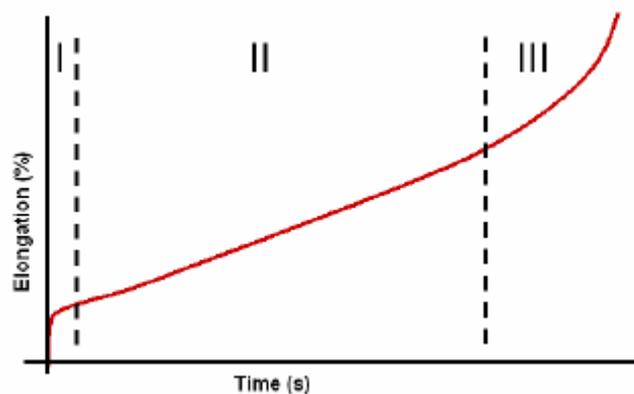


Figure 2
 Typical HMPE creep curve. /9/

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103 If a mooring line in a material that exhibits stress rupture needs to be subjected to tensions exceeding 70% SC - for example due to strong loop-current events with another line damaged - then the safety margin towards stress rupture should be established for that particular loading scenario and mooring line.

104 For long-term moorings the design should accommodate expected loop-current events for the design life. For mobile moorings, the design may be based on a single event, after which the mooring system should be replaced. The time-based safety margin against stress rupture in polyester, polyamide, para-aramid or LCAP ropes should be taken between 5 - 8 for long-term moorings and 3 for mobile moorings.

105 If a mooring rope has been replaced due to prolonged, elevated tension then it should be recertified, with a potentially reduced SC. Alternatively, it should be discarded.

106 Each limit state is formulated as a design equation or inequality in the form:

$$Design\ capacity \text{ --- } Design\ load\ effect \geq 0$$

Where typically:

$$\text{Design capacity} = \frac{\text{Characteristic capacity}}{\text{Partial safety factor on capacity}}$$

Design load-effect = *Characteristic load-effect* · *Partial safety factor on load-effect*.

The characteristic values are computed according to a recipe in the procedure. The anchor line design for long term mooring must satisfy all the limit states.

107 The environmental condition and loads shall be in accordance with Sec.1.

108 Unless otherwise documented a friction coefficient of 1.0 between the mooring line (chain) and the sea bottom can be applied. For steel wire rope a friction coefficients of 0.5 can be applied. Further guidance regarding friction coefficients for mooring lines resting on clay bottom are provided in DNV-RP-E301 and DNV-RP-E302.

109 The stiffness characteristics of the mooring system shall be determined from recognised theory taking account of both line elasticity and weight.

110 The effective elastic modulus shall be obtained from the manufacturer of the mooring line component.

Guidance note:

For preliminary design the effective elastic modulus applied in the mooring analysis may be taken as:

- Stud chain R3/R4/R5: Not less than $5.6 \cdot 10^{10} \text{ N/m}^2$
- Studless chain R3: $(5.40-0.0040 \cdot d) \cdot 10^{10} \text{ N/m}^2$
- Studless chain R4: $(5.45-0.0025 \cdot d) \cdot 10^{10} \text{ N/m}^2$
- Studless chain R5: $(6.00-0.0033 \cdot d) \cdot 10^{10} \text{ N/m}^2$

Where d is the chain diameter in mm. Vicinay has provided the elastic modulus for studless chain.

- Stranded rope:
 $7.0 \cdot 10^{10} \text{ N/m}^2$ corresponding to nominal diameter of the steel wire rope.
- Spiral rope:
 $1.13 \cdot 10^{11} \text{ N/m}^2$ corresponding to nominal diameter of the steel wire rope.

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111 Synthetic fibre ropes are made of visco-elastic materials, so their stiffness characteristics are not constant and vary with the duration of load application, the load magnitude and number of cycles. In general, synthetic mooring lines become stiffer after a long service time. The following stiffness models should be applied in the analysis:

- a) An exhaustive non-linear force elongation model, which fully represents the change-in-length behaviour of the fibre rope.
If such exhaustive model for the complete change-in-length performance is not available, then the procedure in b), c) and d) should be applied.
- b) To establish the unit's excursion and demonstrate that it does not exceed the excursion capability of risers or other offset constraints. This analysis is carried out using the post-installation stiffness in ULS and ALS.
- c) To establish characteristic line tension in ULS and ALS the dynamic stiffness should be applied. Alternatively, a model consisting of two parts can be applied: (i) the static stiffness for calculation of characteristic tension due to mean loads and low frequency motions, and (ii) a dynamic stiffness for the characteristic tension due to wave frequency motions.

Guidance note:

In order to avoid potential over conservatism for tensions it is advisable to apply the pristine force vs. elongation curve for new fibre rope.

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- d) The fatigue (FLS) shall be performed using the same procedure as for ULS and ALS in c).
- e) The intended operations of the mooring system shall be verified to be within the operational boundary demonstrated for the yarn.

112 The change-in-length behaviour of synthetic fibre ropes has to be verified by testing in connection with certification of the fibre-rope assemblies.

113 In order to ensure against excessive offset in high tension and sea bed contact in low tension and during hook up of mooring system with fibre rope segments, the following should be calculated based on test results from the actual mooring system:

- The total length of the mooring line as result of ULS tension with associated duration.
- The total length of the mooring line as a result of the installation tensions, with associated duration.

Guidance note:

For ULS tension the associated duration shall be taken as wave period or loop current duration as appropriate.

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114 The maximum allowable azimuth deviation between the design and “as laid” anchor pattern for long term pre laid mooring system is $\pm 1.5^\circ$ for each anchor line. The maximum allowable deviation is $\pm 5^\circ$ for mobile units, typically drilling units and accommodation units.

115 In the design of long term mooring systems the anchor positions shall be given with tolerances. Typical radial tolerance for suction and pile anchors is ± 5 m. After the installation has been completed the as laid mooring system shall be documented.

B 200 General system response analysis

201 Mooring analyses can be performed by applying a frequency domain or a time domain method.

202 The frequency domain method is well suited for systems exposed to stationary random loads, since the response spectrum can be computed directly from the transfer function and the wave spectrum in the following way:

$$S_R(\omega) = |H(\omega)|^2 S(\omega)$$

ω = Wave frequency ($= 2\pi / T$)

$H(\omega)$ = Transfer function of the response in question (e.g. platform heave motion)

$S(\omega)$ = Wave spectrum

$S_R(\omega)$ = Response spectrum (resulting platform motions due to environmental loads)

Method limitations:

- requires linear equations of motion
- Linearity implies some inaccuracy in effects like drag loads, time varying geometry, variable surface elevation and horizontal restoring forces. However, in many cases these non-linearities can be satisfactorily linearised.

Frequency domain analysis is used extensively for analysis of floating units, including analysis of both motions and forces. It is usually applied in fatigue analyses, and analyses of more moderate environmental conditions where linearised analysis gives satisfactory results.

203 In the time domain analysis the equations of motion are solved by direct numerical integration.

Due to the direct integration approach effects may be included involving non-linear functions of the wave and motion variables. Typical effects are:

- drag forces
- finite motion amplitude effects
- finite wave amplitude effects
- non-linear positioning or mooring systems.

204 The following apply for time domain simulations of mooring line tension:

- The basis for extreme value statistics is: the maximum response between two successive mean-up-crossings is termed a global maximum (see Fig.3)
- Global maxima are assumed to be independent stochastic variables.

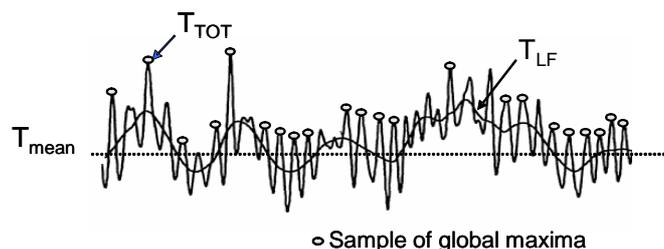


Figure 3
Time series of mooring line tension

Guidance note:

A 3 parameter Weibull distribution is commonly adopted as a model for the global maxima.

The Weibull distribution of global maxima may be written

$$F(x) = 1 - \exp\left\{-\left(\frac{x-\gamma}{\alpha}\right)^\beta\right\}$$

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205 The duration of an environmental state is normally taken as 3 hours.

In time domain analyses the required simulation length shall be sufficient to provide adequate statistics (e.g. 3 hour extreme value). The required simulation length is governed by the number of maxima per unit time of the combined WF/LF process. Please note that when WF tension variations are significantly dependent of the LF offsets this will increase the required simulation length.

206 The required extreme value shall be estimated as the MPM value of the extreme value distribution for the line tension.

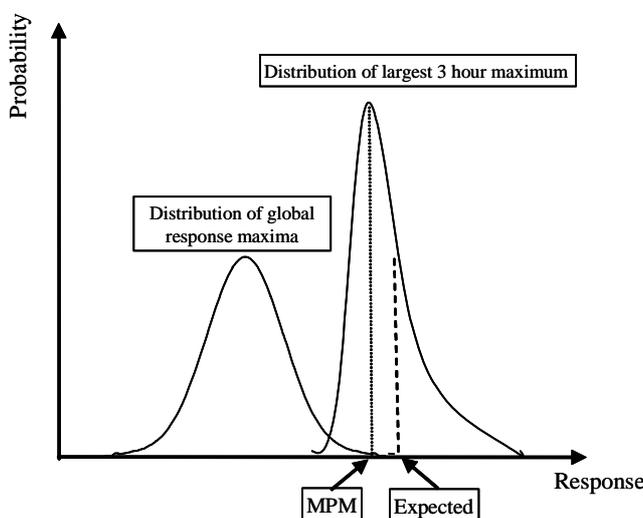


Figure 4
Statistical distributions

Guidance note:

The extreme value distribution will for increasing number of maxima approach a Gumbel distribution. The MPM value of the Gumbel distributions corresponds to the 37% percentile (i.e. 63% probability of exceedance).

According to DNV's current understanding API RP-2SK applies the expected 3-hour extreme for time domain analysis. This corresponds to the 57% percentile (43% probability of exceedance) while ISO 19901-7 apply the MPM value.

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207 For time domain analyses an alternative to one long simulation, to which an extreme value distribution can be fitted, could be to:

- simulate several (10-20) realisations of duration 3 hours
- establish extreme sample as maximum from each simulation
- establish an extreme value distribution to the extreme sample.

Guidance note:

As an alternative to establish an extreme value distribution, the mean of the individual extremes from the set of simulation can be applied. This will be conservative since this mean value will correspond to the expected maximum in the extreme value distribution.

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208 The analysis of the mooring system behaviour may be based on quasi-static or dynamic approaches. For water depth exceeding 100 m a dynamic analysis according to B507 and B508 has to be carried out (see also B300).

Guidance note:

Catenary moorings without buoyancy elements or clump weights will have a quasi static behaviour in shallow water (water depths < 100 m).

Simplified line dynamic models should be used with care in shallow water since such models may give erroneous results. The applicability of these simplified methods may also be questionable for lines equipped with buoyancy elements or clump weights regardless of water depth.

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209 For floating production, storage units and CALM buoys analysis including effect from anchor line dynamics shall be carried out regardless of water depth.

210 For weather-vaning units such as turret mooring, soft yoke systems and tanker connected to buoys with hawsers time domain analysis shall always be carried out.

211 The floater motions in shallow water are to a large extent excited and damped by fluid forces on the floater itself. As the water depth increases the interaction/coupling between the slender structures and the large volume floater becomes more important. In this case, a coupled analysis is required to capture the interaction between the two in order to accurately predict the individual responses of floater, risers and mooring. Coupled analysis is now being used by the industry in the design of deepwater floating systems.

Detailed information is given in DNV-RP-F205.

212 In a coupled analysis the complete system of equations accounting for the rigid body model of the floater as well as the slender body model for the risers and mooring lines are solved simultaneously using a non-linear time domain approach for dynamic analyses. Dynamic equilibrium is obtained at each time step ensuring consistent treatment of the floater/slender structure coupling effects. The coupling effects are automatically included in the analysis scheme.

213 The coupling effects from slender structure restoring, damping and inertia forces are governed by the following force contributions:

Restoring:

- 1) Static restoring force from the mooring and riser system as a function of floater offset
- 2) Current loading and its effects on the restoring force of the mooring and riser system
- 3) Seafloor friction (if mooring lines and/or risers have bottom contact)

Damping:

- 4) Damping from mooring and riser system due to dynamics, current, etc.
- 5) Friction forces due to hull/riser contact.

Inertia:

- 6) Additional inertia forces due to the mooring and riser system.

In a traditional mooring analysis, item 1) can be accurately accounted for. Items 2), 4) and 6) may be approximated. Generally, items 3) and 5) cannot be accounted for. A coupled analysis can include consistent treatment of all these effects.

B 300 Floating platform response analysis

301 The response of the floating platform in a stationary, short-term, environmental state may conveniently be split into four components:

- 1) Mean displacement due to mean environmental loads.
- 2) Low frequency displacements, in the frequency range of the natural periods of the moored platform in surge, sway and yaw modes of motion, due to low-frequency wind loads and second-order wave loads. (Low frequency response for other modes such as pitch and roll can be important for some platform types, such as deep draught floating platforms).
- 3) Oscillations in the frequency range of the incoming waves, due to first-order wave loads.
- 4) Vortex induced motion shall be considered for deep draught floating platforms.

302 The analysis must take due account of all these elements of excitation and response. Forces due to the mooring lines and risers must also be taken into account, but some simplification is usually appropriate with mooring lines in a catenary configuration:

- 1) The restoring forces due to the mooring lines must be taken into account in the mean displacement. The non-linear restoring force function due to the mooring system should be applied directly.
- 2) The restoring force and damping effect due to mooring lines must be taken into account in the low-frequency response. The effects may be linearised, but the linearisation should be centred on the mean position applicable in the environmental state.

- 3) The effects of mooring lines on the wave-frequency response can be neglected when the displacement of the floater is large compared to the weight of the mooring system, see Sec.1 C506.
- 4) The effects of a single riser are usually negligible in comparison with the effects of the mooring lines, but the effects of multiple risers may need to be included. Risers may cause restoring forces, damping and excitation forces, which have to be taken into account.

303 The damping of the low-frequency motions is a critical parameter, which may be difficult to quantify. It is dependent on water depth, the number of mooring lines and risers in addition to the actual sea state and current profile. If model tests are available, then they can provide a basis to quantify the damping. The basis for the damping should always be clearly documented by relevant model tests for units designed for production and/or storage of hydrocarbons. If an adequate basis is lacking, then a conservative estimate should be made.

Guidance note:

Some examples of total damping levels for mooring systems:

For a ship in 150 m water depth, with 12 mooring lines and no risers:

- the surge damping coefficient was 5 to 10% of critical damping
- the sway damping coefficient was 15 to 20% of critical damping.

For a twin-pontoon drilling semi-submersible in 450 m water depth, with 8 mooring lines and no risers:

- the surge damping was 10% of critical damping
- the sway damping was 15% of critical damping.

These values must be used with care taking into consideration:

- The damping force for a given system is strongly dependent on sea state (wave frequency motion) and on mean line tension
- The relative damping, for a given damping force, depends on natural period of the LF motion (water depth, mean force).

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304 Critical damping is given by

$$2\sqrt{k \cdot M}$$

Where k is the restoring coefficient at the mean platform position and M is the platform mass including added mass.

305 Documentation of the unit's response analysis methods must be available. The accuracy of computer programs for response analysis must be quantified by comparison with relevant model test results. The accuracy of model test results applied in the design must be quantified.

B 400 Mooring line response analysis

401 Quasi-static analysis is usually appropriate to determine the mooring line response to mean and low-frequency platform displacements, while dynamic mooring line analysis is usually appropriate for mooring line response to wave-frequency displacements of the platform. The quasi-static mooring line response analysis must take account of:

- the displacement of the upper terminal point of the mooring line or yoke arms due to the unit's motions
- the weight and buoyancy of the mooring line components
- the elasticity of the mooring line components
- reaction and friction forces from the seabed.

402 In addition, dynamic mooring line response analysis must also take account of:

- hydrodynamic drag forces acting on the mooring line components
- inertia forces acting on the mooring line components, including any buoyancy elements.

403 The dynamic analysis may be linearised, but the linearisation point should take account of the line configuration at the instantaneous platform position in the environmental state, due to mean displacement and low-frequency motion.

404 The anchor position is assumed fixed in the mooring line analysis. Hydrodynamic excitation forces on mooring line components are normally negligible in comparison with the other forces, but may need consideration for buoyancy modules. The bending stiffness of the mooring line is normally negligible.

405 Documentation of the method applied in anchor line response analysis shall be available. The accuracy of computer programs for mooring line response must be checked by comparison with other methods, for instance model tests.

406 The relevant pretension shall be applied for the operating state that is considered. It is not allowed to take into account in the mooring analysis adjustment of pretension in the various lines by running the winches.

407 Adjustment of line tension caused by change of position or draught and shift of consequence class should

be taken into account:

- a) An accommodation unit with gangway connection to another installation, which is lifting the gangway and is running the winches to move to a standby position due to bad weather.
- b) Units operating with continuously changing position e.g. pipe laying units.
- c) A production unit, which is running the winches to increase the distance to a well head platform due to bad weather.
- d) Shift from consequence class 2 to consequence class 1, prior to severe weather by e.g. changing to survival draught.

B 500 Characteristic line tension for the ULS

501 All mooring lines in the system are considered to be intact in the analysis of the ULS. Two components of characteristic line tension are considered:

- a) T_{C_mean} the characteristic mean line tension, due to pretension and mean environmental loads. The mean environmental loads are caused by static wind, current and mean wave drift forces.
- b) T_{C_dyn} the characteristic dynamic line tension induced by low-frequency and wave-frequency motions.

502 The following response statistics are determined in each environmental state considered:

- X_{mean} is the mean horizontal distance of the upper terminal point of the mooring line from the anchor
- σ_{X-LF} is the standard deviation of horizontal, low-frequency motion of the upper terminal point in the mean mooring line direction.

For dynamic analysis of wave-frequency tension:

- $\sigma_{T-WF}[X]$ is the standard deviation of the wave-frequency component of line tension, which is dependent on the mean excursion X applied in the analysis, computed for one location, with excursion $X = X_C - X_{WF-max}$, where X_C , X_{WF-max} are defined in 505 and 506.

For quasi-static analysis of wave frequency tension:

- σ_{X-WF} is the standard deviation of horizontal, wave-frequency motion of the upper terminal point in the mean mooring line direction.

503 If all lines are identical, then the statistics are only needed for the most heavily loaded line. If the lines are different, then the statistics are needed for each line. The line tension results are primarily needed at the most heavily loaded location along the line, usually close to the top, or to a buoyancy module. If different strengths of mooring line components are applied along the length of the line, then the line tension results can be applied for the most heavily loaded location of each component type.

504 Quasi-static mooring line response analysis provides the line tension T at a point in the line as a function of the horizontal distance between lower and upper terminal points of the line X , as can be represented by the function:

$T_{QS}[X]$ Quasi static tension calculated with the upper terminal point in position X

Thus, the characteristic mean tension is given by

$T_{C-mean} = T_{QS}[X_{mean}]$ Quasi static tension calculated with the upper terminal point in position X_{mean}

Note that this mean tension includes the pretension of the line, which would occur at the mooring system equilibrium position, in the absence of environmental effects.

505 A Gaussian process model is applied in the development of the characteristic tension from the statistics listed in 502. This Gaussian model is adopted as a compromise between simplicity and accuracy in this design procedure. The inaccuracy of the Gaussian process model has been taken into account in the calibration of the design procedure. On this basis, significant and maximum low-frequency excursion are defined as

$$X_{LF-sig} = 2\sigma_{X-LF}$$

$$X_{LF-max} = \sigma_{X-LF} \cdot \sqrt{2 \ln N_{LF}}$$

Where N_{LF} is the number of low-frequency platform oscillations during the duration of the environmental state, which is normally taken as 3 hours. Similarly, significant and maximum wave-frequency excursion are defined as

$$X_{WF-sig} = 2\sigma_{X-WF}$$

$$X_{WF-max} = \sigma_{X-WF} \cdot \sqrt{2 \ln N_{WF}}$$

Where N_{WF} is the number of wave-frequency platform oscillations during the duration of the environmental state.

506 The characteristic offset X_C is taken as the larger of:

$$X_{C1} = X_{\text{mean}} + X_{\text{LF-max}} + X_{\text{WF-sig}}$$

$$X_{C2} = X_{\text{mean}} + X_{\text{LF-sig}} + X_{\text{WF-max}}$$

507 When dynamic mooring line analysis is applied, the maximum wave frequency tension is defined by:

$$T_{\text{WF-max}} = \sigma_{\text{T-WF}} [X_C - X_{\text{WF-max}}] \sqrt{2 \ln N_{\text{WF}}}$$

where the notation is intended to provide a reminder that the standard deviation of wave frequency tension is a function of the excursion about which wave frequency motion takes place.

508 When dynamic mooring line analysis is applied, the characteristic dynamic tension $T_{\text{C-dyn}}$ is defined by:

$$T_{\text{C-dyn}} = T_{\text{QS}} [X_C - X_{\text{WF-max}}] - T_{\text{C-mean}} + T_{\text{WF-max}}$$

$T_{\text{QS}} [X_C - X_{\text{WF-max}}]$ = Quasi static tension calculated with the upper terminal point in position $X_C - X_{\text{WF-max}}$.

509 When the quasi-static mooring line analysis is applied, then the characteristic dynamic tension $T_{\text{C-dyn}}$ is defined by

$$T_{\text{C-dyn}} = T_{\text{QS}} [X_C] - T_{\text{C-mean}}$$

$T_{\text{QS}} [X_C]$ = Quasi static tension calculated with the upper terminal point in position X_C .

510 For time domain analyses the following apply:

$T_{\text{C-mean}}$ = mean tension of the time series

$T_{\text{C-dyn}}$ = $T_{\text{MPM}} - T_{\text{C-mean}}$

T_{MPM} = most probable max of the time series, see B206

It should be noted that the mean tension ($T_{\text{C-mean}}$) from frequency domain analysis and time domain analysis can be different if the dynamics in the time series are non-symmetrical. However, it is assumed that the discrepancy in $T_{\text{C-mean}}$ caused by this effect is minor, and that the design equation format (see D200) can also be applied for time domain analyses.

511 The relationship between the tension components and excursion positions needed in order to calculate the design equation can be illustrated by Fig.5 (the 1st case from 506 is shown):

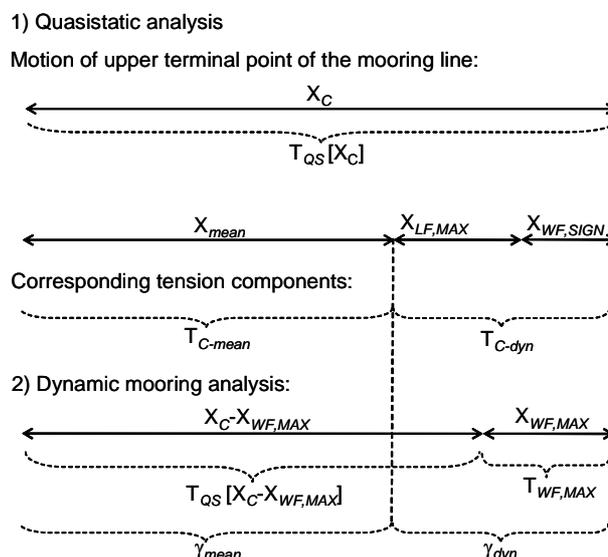


Figure 5
Illustration of relationship between different excursion and tension components needed in the design equation.

B 600 Characteristic line tension for the ALS

601 One mooring line is assumed to have failed, and is removed in the analysis of the ALS.

- When all mooring lines are identical, several lines shall be removed one at a time in order to identify the line failure leading to the largest tension in an adjacent line.
- If the mooring lines are not identical, then it may be necessary to consider a number of cases with different missing lines, to check the highest resulting tension in each type of mooring line.
- If the mooring lines are equipped with buoyancy elements (MLBE) or clump weights the loss of a buoy or a clump weight due to failure of the connection to the mooring line shall be included as single failure event.

If the MLBE is dived into compartments the consequence of one compartment damage should be checked.

602 The ALS addresses the situation where the initial line failure occurs in severe weather, and considers the stationary mooring system response to the same environmental conditions. Hence, no adjustment of line pretension after the initial line failure shall be considered in the analysis. For convenience, the same environmental conditions are applied as for the ULS, and the calibration of the safety factors has taken account of the low probability of occurrence of so severe weather together with a random initial failure.

603 The transient response immediately after the initial failure might be expected to lead to higher line tensions. This has been found to be very unlikely in the presence of severe environmental conditions, with considerable oscillatory excitation forces. If unusually high line tensions are required for some special operations in relatively calm weather, then it is advisable to also consider the transient case, but this is not covered here.

604 The platform response and mooring line response analysis is carried out exactly as for the ULS, but with one line missing. The characteristic tension components are computed as for the ULS.

C. Characteristic Capacity

C 100 Characteristic capacity for the ULS and ALS

101 The mooring line components should be manufactured with a high standard of quality control, according to recognised standards, such as, DNV-OS-E302, DNV-OS-E303 and DNV-OS-E304.

102 Careful control of all aspects of handling, transport, storage, installation, and retrieval of the mooring lines is also imperative to ensure that the capacity of the mooring lines is not reduced. The characteristic capacity is defined on this basis.

C 200 Main body of mooring line

201 A mooring line is usually assembled from a large number of identical components of a few types, together with a few connecting links, line terminations, etc. A chain line obviously contains a large number of chain links. A long steel wire rope or a synthetic fibre rope may also be conceptually treated as a large number of wire rope segments. It is well known that the strength of a long line is expected to be less than the average strength of the components that make up the line. This effect is taken into account in the present definition of the characteristic capacity.

202 The following statistics are required for the strength of the components that make up the main body of the mooring line:

- μ_s the mean value of the breaking strength of the component
- δ_s the coefficient of variation of the breaking strength of the component.

Then the characteristic strength of the body of the mooring line constructed from this component is defined by:

$$S_c = \mu_s [1 - \delta_s (3 - 6\delta_s)], \quad \delta_s < 0.10$$

This formulation is applicable for components consisting of chain, steel wire ropes and synthetic fibre rope.

203 When statistics of the breaking strength of a component are not available, then the characteristic strength may be obtained from the minimum breaking strength S_{mbs} of new components, as

$$S_c = 0.95 S_{mbs}$$

204 The statistical basis for the characteristic strength can also be applied to used components if breaking strength statistics are obtained for the used components by carrying out break load tests. However, the alternative basis using the minimum breaking strength should not be applied to used components without changing the reduction factor.

Guidance note:

To avoid a reduction in minimum breaking strength of 5%, the breaking tests of the mooring line segments can be performed to a load 5% higher than the specified minimum breaking strength. Number of tests shall be as required in DNV-OS-E302, DNV-OS-E303 and DNV-OS-E304.

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205 When the strength distribution is based on test statistics, the statistical uncertainty in the results depends on the number of tests performed. The uncertainty in the characteristic line strength has been simulated for different test sizes and for different coefficients of variation of the individual line component strength. Simplified reliability analyses, using a typical load distribution, have then been performed in order to quantify a reduction in the characteristic strength that is necessary in order to maintain the target reliability. A simple

expression has been fitted to these results, and the reduced characteristic strength S^*_c can be expressed as:

$$S^*_c = S_c \left[1 - 2.0 \left(\frac{\delta_s}{n} \right) \right]$$

- δ_s is the coefficient of variation of the breaking strength of the component
- n is the number of tests, not less than 5.

C 300 Connecting links and terminations

301 Other components in the mooring line such as connecting links and terminations should be designed to have strength exceeding the characteristic strength of the main body of the mooring line, with a very high level of confidence.

C 400 Soft yoke connection arms

401 The yoke arm is connected to the offloading vessel via pendulums, which may consist of a combination of chains and steel structure or steel beams/pipes instead of chains. The loads from the response analysis multiplied with the safety factors in D200 are the design load which shall be applied in dimension the yoke system.

D. Partial Safety Factors and Premises

D 100 Consequence classes

101 Two consequence classes are introduced in the ULS and ALS, defined as:

Class 1, where mooring system failure is unlikely to lead to unacceptable consequences such as loss of life, collision with an adjacent platform, uncontrolled outflow of oil or gas, capsizing or sinking.

Class 2, where mooring system failure may well lead to unacceptable consequences of these types.

102 The partial safety factors given in 200 and 300 are applicable to chain, steel wire ropes and synthetic fibre ropes.

D 200 Partial safety factors for the ULS

201 The design equation for the ULS is given by

$$S_C - T_{C-mean} \gamma_{mean} - T_{C-dyn} \gamma_{dyn} \geq 0$$

where the characteristic quantities are defined above, a partial safety factor of unity on the capacity is implicit, and the remaining partial safety factors are given in Table D1.

<i>Consequence Class</i>	<i>Type of analysis of wave frequency tension</i>	<i>Partial Safety factor on mean tension</i> γ_{mean}	<i>Partial Safety factor on dynamic tension</i> γ_{dyn}
1	Dynamic	1.10	1.50
2	Dynamic	1.40	2.10
1	Quasi-static	1.70	
2	Quasi-static	2.50	

202 If the characteristic mean tension exceeds 2/3 of the characteristic dynamic tension, when applying a dynamic analysis in consequence class 1, then a common value of 1.3 shall be applied instead of the separate static and dynamic safety factors given in Table D1. This is intended to ensure adequate safety in cases dominated by the mean tension component.

203 For several types of single point mooring systems the system is designed without redundancy and consequently ALS is not an applicable design condition. These systems may be accepted provided that the safety factors given in Table D1 are increased by a factor of 1.2 and further that the loss of the mooring system will not result in a major pollution or major damage to the unit. Emergency disconnection systems for risers and mooring will be required. Further, the main propulsion of the unit shall be in operation.

D 300 Partial safety factors for the ALS

301 The design equation for the ALS is identical to the ULS, but the partial safety factors are given in Table

D2.

Consequence Class	Type of analysis of wave frequency tension	Partial Safety factor on mean tension	Partial Safety factor on dynamic tension
		γ_{mean}	γ_{dyn}
1	Dynamic	1.00	1.10
2	Dynamic	1.00	1.25
1	Quasi-static	1.10	
2	Quasi-static	1.35	

302 The combination of an accidental line failure with characteristic loads based on a 100-year return period is, in itself, relatively conservative. Hence, the partial safety factors in table D2 are relatively small; i.e. close to unity. These factors should be adequate even when the loading is dominated by the mean tension, provided that 100-year environmental conditions give rise to a significant portion of the mean tension.

D 400 Partial safety factors for the connection between buoyancy element and mooring line

401 For mooring calculations where mooring line buoyancy elements (MLBE) are modelled completely with buoyancy, inertia and drag forces (e.g. in a FEM program) the safety factor for the load in the connection between mooring line and buoyancy element shall be 1.5.

For programs with less accurate modelling possibilities the MBL of the connection shall as a minimum equal 5 times the buoyancy force of the buoyancy element.

D 500 Typical operations covered by consequence class 1

501 Safety factors for consequence class 1 are applicable for the operations in 502 to 505:

502 Column-stabilised drilling units with the riser disconnected, when the unit is located at least a distance X_V (m) from other units or installations defined as follows:

$$\begin{aligned} X_V &= 300\text{m} & h &\leq 300\text{m} \\ X_V &= 1.5(h - 300) + 300 \text{ (m)} & h &> 300\text{m} \end{aligned}$$

h = water depth in meter

For ship-shaped units the distance (X_V) shall be as follows:

$$\begin{aligned} X_V &= 2L_{oa} \text{ (m)} & h &\leq 300 \text{ m} \\ X_V &= 2.0(h - 300) + 2L_{oa} \text{ (m)} & h &> 300 \text{ m} \end{aligned}$$

L_{oa} = overall length

See Fig.6.

503 Column stabilised accommodation units positioned 300 m away from another unit or fixed installation. However, column stabilised accommodation units in stand by position at least 150 m away from a fixed installation can be designed according to Consequence Class 1 provided it is documented that loss of all lines at one column will not cause collision with the fixed installation and the safety factor in the remaining lines is not less than 1.0.

504 Units designed for production and/or storage and/or injection of oil, water or gas through a system of flexible risers and an associated well control umbilicals. The unit shall be located at least a distance X_V away from another structure and the production shall be terminated. An emergency disconnection system of risers and umbilicals must be available. The environmental condition in terms of return period shall be established for termination of the production. Watch circles with respect to offset and/or line tension shall be available in order to prepare for disconnection.

Guidance note:

Production is to be terminated when the consequence class 2 limits for the environmental conditions are exceeded.

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505 Offshore loading buoys with no tanker moored.

506 Drilling units with drilling riser disconnected.

D 600 Typical operations covered by consequence class 2

601 Drilling units with the riser connected.

602 Drilling, support and accommodation units operating at a distance less than 50 m from other units or installations. See Fig.7.

603 Units designed for production and/or storage and/or injection of oil, water and or gas through a system of flexible, steel catenary or rigid risers, and associated umbilicals shall be designed according to consequence class 2, when the unit is not designed for emergency disconnection.

604 When a column stabilised accommodation unit is positioned a distance between 50 m and X_v m from another unit or installation, the mooring lines pointing away from the installation have to be designed according to consequence class 2, while the mooring lines pointing towards the installation may be designed according to consequence class 1. See Fig.8.

605 Offshore loading buoys with a tanker moored. The buoy's distance from another installation shall be large enough to give sufficient space for manoeuvring of a tanker.

606 Production of hydrocarbons may take place after a line failure or a failure in thruster assisted systems provided the design equation for ULS and ALS given in 201 meets the requirements for consequence class 2 for all the remaining anchor lines. The limiting environmental condition for termination of the production has to be established.

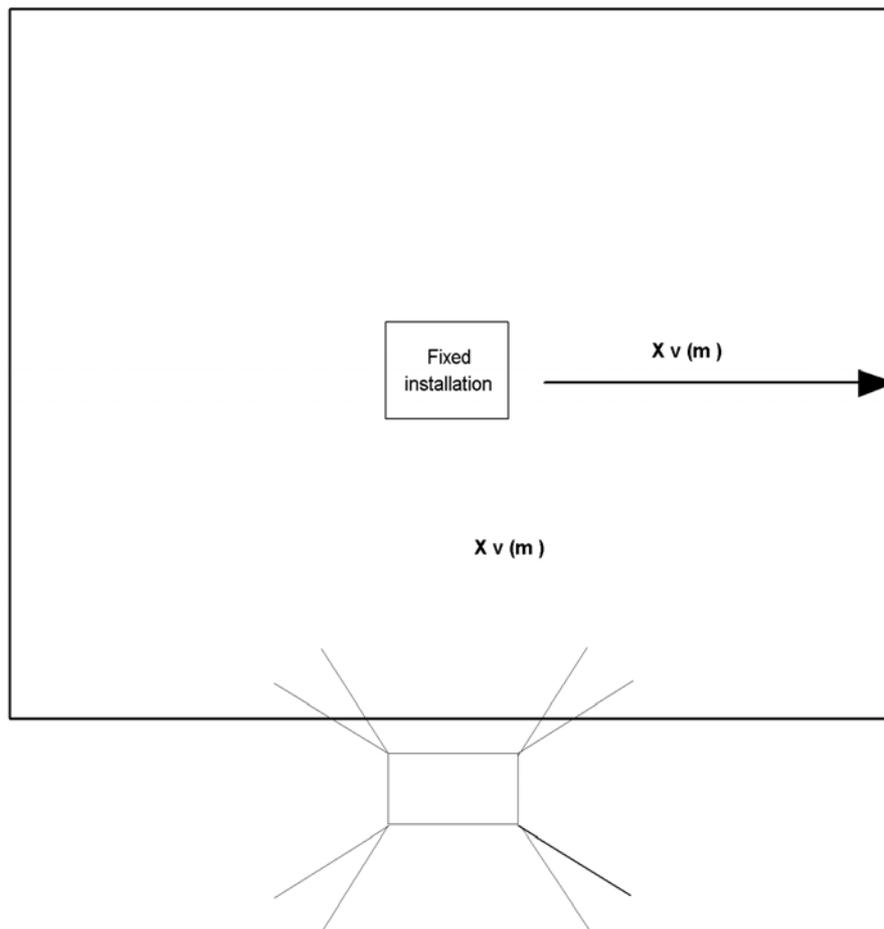


Figure 6
The position of a unit at least a distance X_v away from an installation

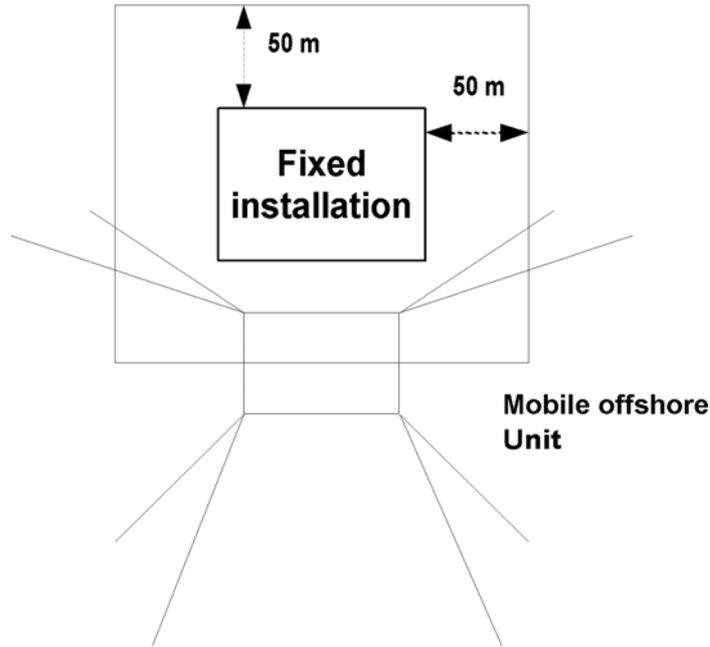


Figure 7
The position of a unit within 50 m of another installation

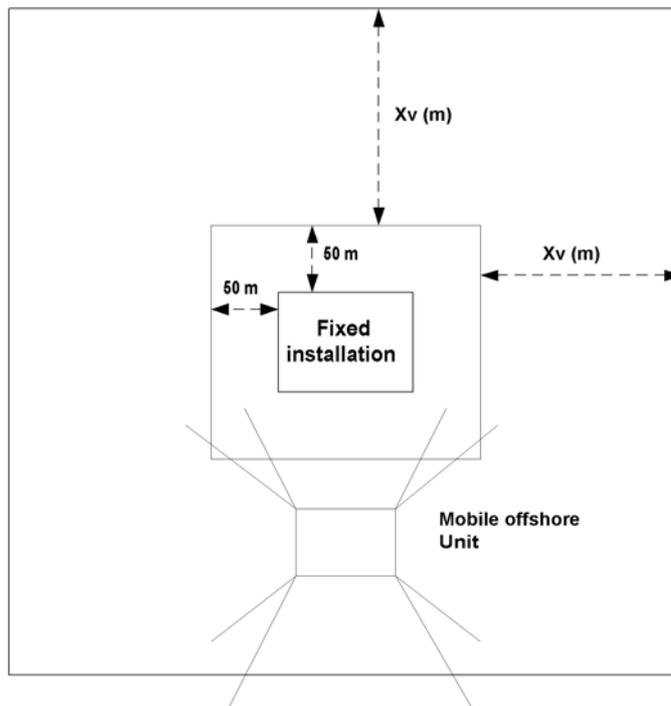


Figure 8
The position of a unit between 50 m and a distance X_v away from an installation

D 700 Permissible horizontal offset

701 The horizontal offset from a given reference point shall be within the operational service limitation, including offsets:

- for the intact mooring system
- after any single failure of a line or in the thruster system.

702 When the unit is connected to a rigid or vertical riser (e.g. drilling riser), the maximum horizontal offset is limited by the maximum allowable riser angle at the BOP flex joint. A safety margin of 2.5% of the water

depth shall be included.

703 Maximum horizontal offset of flexible and steel catenary risers shall not exceed the manufacture specification.

704 Maximum environmental conditions for drilling operation are also to take the heave compensating capacity into consideration.

705 When the unit is connected by a gangway to another structure, the positioning system and the gangway structure shall meet the following criteria:

- a) The distance between the unit and the installations shall not be less than 10 m at any point.
- b) During normal operation an excursion reserve of 1.5 m of the specified maximum excursion of the gangway shall be included.
- c) The gangway shall be equipped with alarm in the control room, which shall be activated when the maximum excursion is exceeded.
- d) The gangway shall be positioned so that it will not collide with any other structure after a single failure.

D 800 Permissible line length

801 For anchors not designed to take uplift forces, the following applies:

- the mooring lines shall have enough length to avoid uplift at anchors for all relevant design conditions in the ULS
- vertical forces on the anchors can be accepted in the ALS, if it is documented that these vertical forces will not significantly reduce the characteristic resistance of the anchors.

802 Anchors designed to withstand vertical forces will be accepted in both ULS and ALS conditions, see Sec.4.

803 Unrealistic line lengths to meet the requirements in 801 shall not be used in the mooring analyses.

Guidance note:

The maximum deployed line length allowed to be taken into account in the calculations is limited to the suspended length at a line tension equal to the breaking strength of the line plus 500 m.

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D 900 Clearance

901 Sufficient clearance shall be ensured at all times between the unit and adjacent structures, between anchor lines during cross anchoring and between anchor lines and fixed structures or other floating units. Environmental conditions, motions and consequence of breakage of one anchor line during the operation shall be considered in order to establish sufficient clearance. Detailed information is given in DNV Rules for Planning and Execution of Marine Operations Pt.2 Ch.7 4.3, Table 4.1.

902 Contact between a fibre rope mooring line and sub-sea equipment can be accepted if contact will not cause damage to the fibre rope and the equipment.

E. Additional Requirements for Long Term Mooring

E 100 General

101 These requirements are applicable to all type of floating units equipped with a mooring system, which are positioned at the same location for 5 years or more.

102 Fatigue calculations shall be carried out for mooring lines and connection elements by using site specific environmental data.

103 It is recommended that fatigue calculations are carried out for units positioned at a location for less than 5 years, when the in service experience has shown anchor line fatigue damage.

104 Fatigue calculation of long term mooring (LTM) D-shackles dimension according to ISO 1704 may be omitted. These shackles are oversized compared to the common chain links, therefore the fatigue life of a LTM shackle is higher than the fatigue life of the chain.

E 200 Corrosion allowance

201 Corrosion allowance for chain, including wear and tear of chain and connection elements to be included in design. The minimum corrosion allowance given in Table E1 shall be used if corrosion allowance data is not available for the actual location.

Table E1 Corrosion allowance for chain			
<i>Part of mooring line</i>	<i>Corrosion allowance referred to the chain diameter</i>		
	<i>Regular inspection ¹⁾ (mm/year)</i>	<i>Regular inspection ²⁾ (mm/year)</i>	<i>Requirements for the Norwegian continental shelf</i>
Splash zone ⁴⁾	0.4	0.2	0.8 ³⁾
Catenary ⁵⁾	0.3	0.2	0.2
Bottom ⁶⁾	0.4	0.3	0.2 ⁷⁾

1) Recommended minimum corrosion allowance when the regular inspection is carried out by ROV according to DNV-OSS-102 Ch.3 Sec.6 B800 or according to operators own inspection program approved by the National Authorities if necessary. The mooring lines have to be replaced when the diameter of the chain with the allowable breaking strength used in design of the mooring system, taking into account corrosion allowance, is reduced by 2%.

2) Recommended minimum corrosion allowance when the regular inspection is carried out according to DNV-OSS-102 Ch.3 Sec.6 B700 or according to operators own inspection program approved by the National Authorities if necessary. The mooring lines have to be replaced when the diameter of the chain with the allowable breaking strength used in design of the mooring system is reduced by 2%.

3) The increased corrosion allowance in the splash zone is required by NORSOK M-001 and is required for compliance with PSA, see DNV-OSS-201.

4) Splash Zone is defined as 5 m above the still water level and 4 m below the still water level.

5) Suspended length of the mooring line below the splash zone and always above the touch down point.

6) The corrosion allowance given in the table is given as guidance, significant larger corrosion allowance should be considered if bacterial corrosion is suspected.

7) Investigation of the soil condition shall be carried out in order to document that bacterial corrosion is not taking place.

202 The characteristic capacity of the anchor lines which forms the basis for the mooring calculations shall be adjusted for the reduction in capacity due to corrosion, wear and tear according to the corrosion allowance given in Table E1.

203 The lifetime of a steel wire rope is dependent on the construction and degree of protection. Guidance for choice of steel wire rope construction depending on the wanted design is given in Table E2.

Table E2 Choice of steel wire rope construction		
<i>Field design life (years)</i>	<i>Possibilities for replacement of wire rope segments</i>	
	Yes	No
< 8	A/B/C	A/B/C
8 – 15	A/B/C	A/B
> 15	A/B	A

A) Half locked coil/full locked coil/spiral rope with plastic sheathing.
B) Half locked coil/full locked coil/spiral rope without plastic sheathing.
C) Stranded rope.

204 Buoy pennant lines, clump weights and their fasteners attached to mooring lines shall be dimensioned with corrosion allowance according to Table E1 if no detailed data for the location is available.

F. Fatigue Limit State (FLS)

F 100 Accumulated fatigue damage

101 The characteristic fatigue damage, accumulated in a mooring line component as a result of cyclic loading, is summed up from the fatigue damage arising in a set of environmental states chosen to discretise the long term environment that the mooring system is subject to:

$$d_c = \sum_{i=1}^{i=n} d_i$$

where d_i is the fatigue damage to the component arising in state i and the discretisation into $i=1, \dots, n$ states is sufficiently detailed to avoid any significant error in the total. Each environmental state is defined in terms of the heading angles, wind, wave and current parameters required to compute the stationary mooring system response in that state. The probability of occurrence P_i is required for each environmental state.

102 When the effects of mean tension can be neglected, the fatigue damage accumulated in an individual state

may be computed as:

$$d_i = n_i \int_0^{\infty} \frac{f_{S_i}(s)}{n_c(s)} ds$$

where n_i is the number of stress cycles encountered in state i during the design life of the mooring line component, $f_{S_i}(s)$ is the probability density of the nominal magnitudes (peak-to-trough) of the stress cycles applied to the component in state i , and $n_c(s)$ is the number of stress cycles of magnitude s that would lead to failure of the component. The nominal magnitudes of the stress cycles are computed by dividing the magnitudes of the corresponding tension cycles by the nominal cross-sectional area of the component; i.e.

$\frac{2\pi d^2}{4}$ for chain, and $\frac{\pi d^2}{4}$ for steel wire rope, where d is the

component diameter.

103 The number of stress cycles in each state can usually be determined as:

$$n_i = v_i \cdot P_i \cdot T_D$$

where v_i is the mean-up-crossing rate (frequency in hertz) of the stress process (i.e. the mean up-crossing rate through the mean stress level) in state i , P_i indicates the probability of occurrence of state i , and T_D is the design lifetime of the mooring line component in seconds. In practice the integral in 102 is usually replaced by the cycle counting algorithm in 300.

F 200 Fatigue properties

201 The following equation can be used for the component capacity against tension fatigue:

$$n_c(s) = a_D s^{-m}$$

This equation can be linearised by taking logarithms to give:

$$\log(n_c(s)) = \log(a_D) - m \cdot \log(s)$$

$n_c(s)$	=	the number of stress ranges (number of cycles)
s	=	the stress range (double amplitude) in MPa
a_D	=	the intercept parameter of the S-N curve
m	=	the slope of the S-N curve

The parameters a_D and m are given in Table F1 and the S-N curves are shown in Fig.6.

Table F1 S-N Fatigue Curve Parameters		
	a_D	m
Stud chain	$1.2 \cdot 10^{11}$	3.0
Studless chain (open link)	$6.0 \cdot 10^{10}$	3.0
Stranded rope	$3.4 \cdot 10^{14}$	4.0
Spiral rope	$1.7 \cdot 10^{17}$	4.8

202 The fatigue life of long term mooring (LTM) shackles can be calculated using the B1 curve parameter according to DNV-RP-C203 and appropriate stress concentration factors (SCF) obtained by a finite element method. S-N curves for kenter shackles are not included since these shackles shall not be used in long term mooring systems. Other type of connection elements shall not be used in long term mooring if not the fatigue life is properly documented, ref. 204.

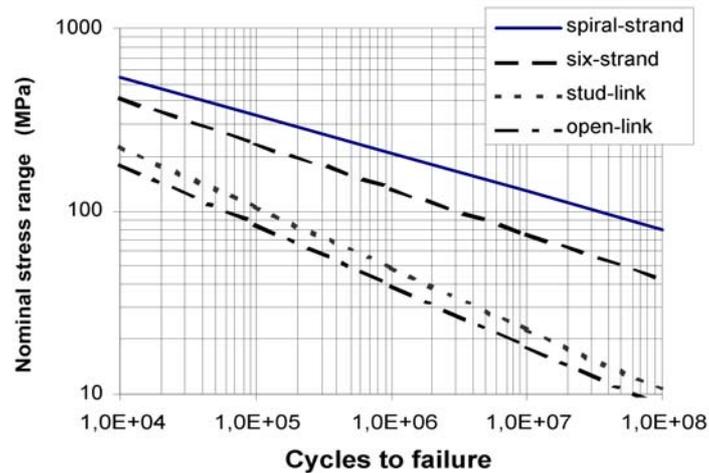


Figure 9
Design S-N curves

203 The S-N curves for chain given Table F1 and Fig.9 are intended to be applicable in sea water, while the S-N curves for steel wire ropes assume that the rope is protected from the corrosive effect of sea water.

204 It is permissible to use test data for a specific type of mooring line component in design. A linear regression analysis shall then be used to establish the S-N curve with the design curve located a little more than two standard deviations below the mean line, with the use of the procedure given in F500. In the case of chain tests in air, the effect of sea water shall be accounted for by a reduction of the fatigue life by 2 for stud-link chain, and by a factor of 5 for studless chain.

205 It should be noted that the recommended reduction factor for stud chain is only applicable when the stud is perfectly fitted in the chain link. The fatigue life of a stud chain link is highly sensitive to variations depending on the tightening of the stud. When the stud gets loose, the scenario of stress distribution changes totally and this may lead to a significant reduction in fatigue life. These problems are avoided by using studless chain.

206 The S-N curves presented in Table F1 and Fig.9 include only tension-tension fatigue. In addition fatigue caused by out of plane bending (OPB) shall be considered. Tension fatigue is due to cyclic range of tension variations loading the chain. OPB fatigue is due to range of interlink rotation under a certain tension and occurs predominantly in the first link after a link that is constrained against free rotational movement. OPB shall be considered in connection with the following conditions:

- chain links that are frequently located on a chain wheel (fairlead) with 7 pockets will have a SCF of 1.15 due to out of plane bending /8/
- wire rope that is passed over sheaths, pulleys or fairleads.
- Chain passing over bending shoes and chain link constraint provided by chain hawse or chain stopper.

207 The contribution to fatigue due to OPB can be established by theoretical calculations or testing. In connection with chain hawse, chain pipe and connecting rod it is important to establish the friction in the bearings, which will have significant impact on the OPB.

F 300 Fatigue analysis

301 The long term environment can be represented by a number of discrete conditions. Each condition consists of a reference direction and a reference sea state characterised by a significant wave height, peak period, current velocity and wind velocity. The probability of occurrence of these conditions must be specified. In general 8 to 12 reference directions provide a good representation of the directional distribution of a long-term environment. The required number of reference sea states can be in the range of 10 to 50. Fatigue damage prediction can be sensitive to the number of sea states, and sensitivity studies can be necessary.

302 In the fatigue analysis 50% of the chain's corrosion allowance can be taken into account.

303 Provided the equation given in 201 is applicable to the fatigue properties, the fatigue damage in environmental state i can be computed as:

$$d_i = \frac{n_i}{a_D} E[S_i^m]$$

Where $E[S_i^m]$ is the expected value of the nominal stress ranges raised to the power m in state i . The nominal stress ranges should be computed taking into account the effects of pretension and the effects of the

environmental loads due to wind, waves and current, as described for the ULS. Although the cumulative effect of the stress cycles is required in the FLS, rather than the extreme tension required in the ULS, it is still necessary to take care to compute the dynamic response of the mooring line to wave-frequency loads at a representative offset for each environmental state. The method given in the guidance note can be used.

Guidance note:

Determine all loads and motions (low and wave frequency) as described for ULS, see B500.

Compute mooring system responses under mean loading using quasi-static analysis. Then impose wave frequency motions and calculate the standard deviation of the wave frequency tension from dynamic analysis.

Add the standard deviation of the low frequency motion to the mean position and calculate the corresponding tension. The standard deviation of the low frequency tension is the calculated tension minus the tension in the mean position.

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304 The computed tension range divided by the nominal cross-sectional area of the chain link or the wire rope component gives the nominal stress range, The cross sectional areas are defined in 102.

305 If the low-frequency content of the stress process is negligible, then a narrow-banded assumption may be applied to give:

$$d_{NBi} = \frac{v_{0i} T_i}{a_D} (2\sqrt{2} \sigma_{Si})^m \Gamma\left(\frac{m}{2} + 1\right)$$

where σ_{Si} is the standard deviation of the stress process and $\Gamma(\cdot)$ is the gamma function. In this case, the number of tension cycles is computed from the mean-up-crossing rate in hertz of the tension process v_{0i} and the duration of the environmental state $T_i = P_i \cdot T_D$.

306 If there are both significant wave-frequency and low-frequency components in the tension process, then the expression for a narrow-banded process is no longer appropriate. There is fairly general consensus that the rain-flow counting technique provides the most accurate estimate for the probability density of the tension ranges, but this requires relatively time-consuming analysis. Therefore the following alternatives are recommended:

- combined spectrum approach
- dual narrow-band approach.

307 The combined spectrum approach provides a simple, conservative approach, which may be used in computing the characteristic damage. The fatigue damage for one sea state is denoted by d_{CSi} :

$$d_{CSi} = \frac{v_{yi} T_i}{a_D} (2\sqrt{2} \sigma_{Yi})^m \Gamma\left(\frac{m}{2} + 1\right)$$

The standard deviation of the stress process is including both wave-frequency σ_{Wi} and low-frequency components σ_{Li} .

$$\sigma_{Yi} = \sqrt{\sigma_{Li}^2 + \sigma_{Wi}^2}$$

The mean-up-crossing rate v_{yi} in hertz for one sea state is computed from the moments of the combined spectrum:

$$v_{yi} = \sqrt{\lambda_{Li} v_{Li}^2 + \lambda_{Wi} v_{Wi}^2}$$

λ and λ_w are defined in 310.

308 The number cycles in the combined spectrum, per sea state in the lifetime is:

$$n_i = v_{yi} T_i = v_{yi} \cdot P_i \cdot T_D$$

309 The dual narrow-banded approach takes the result of the combined spectrum approach and multiplies it by a correction factor ρ , based on the two frequency bands that are present in the tension process.

$$d_{DNBi} = \rho_i \cdot d_{CSi}$$

The correction factor is given by

Where subscript Y refers to the combined stress process, subscript P refers to the envelope of the combined stress process, subscript L refers to the low-frequency part of the stress process, and subscript W refers to the wave-frequency part of the stress process.

$$\rho = \frac{v_P}{v_Y} \left[(\lambda_L)^{\frac{m}{2}+2} \left(1 - \sqrt{\frac{\lambda_W}{\lambda_L}} \right) + \sqrt{\pi \lambda_L \lambda_W} \frac{m \Gamma\left(\frac{1+m}{2}\right)}{\Gamma\left(\frac{2+m}{2}\right)} \right] + \frac{v_W}{v_Y} \cdot (\lambda_W)^{m/2}$$

310 The symbol λ represents the normalised variance of the corresponding stress component

$$\lambda_L = \frac{\sigma_L^2}{\sigma_L^2 + \sigma_W^2}, \quad \lambda_W = \frac{\sigma_W^2}{\sigma_L^2 + \sigma_W^2}$$

Where σ_L is the standard deviation of the low-frequency part of the stress process, and σ_W is the standard deviation of the wave-frequency part of the stress process. The symbol v represents the up-crossing rate through the mean value, as computed from the second and zero order moments of the corresponding part of the stress spectrum, for subscripts Y, L, and W. For the envelope of the stress process, the mean-up-crossing rate is given by

$$v_P = \sqrt{\lambda_L^2 v_L^2 + \lambda_L \lambda_W v_W^2 \delta_W^2}$$

Where δ_W is the bandwidth parameter for the wave-frequency part of the stress process, but is here set equal to 0.1.

311 A subscript i could have been attached to all the short-term statistics in equations in 310 to indicate dependency on the environmental state, but it has been omitted for clarity.

312 Values of the gamma function to be used in the equations given in 307 and 308 for different values of m are given in Table F2

Table F2 Gamma Functions			
m	3.0	4.0	4.8
$\Gamma\left[\frac{m}{2} + 1\right]$	1.3293	2.0000	2.9812
$\Gamma\left[\frac{1+m}{2}\right]$	1.0000	1.3293	1.8274

313 Results from other approaches may be accepted provided they are conservative in comparison to the dual narrow-banded approach, or to the rainfall counting approach, for the mooring system under consideration.

F 400 Design equation format

401 The fatigue limit state is intended to ensure that each type of component in an individual mooring line has a suitable resistance to fatigue failure. The design equation for FLS is:

$$1 - d_c \cdot \gamma_F \geq 0$$

d_c = the characteristic fatigue damage accumulated as a result of cyclic loading during the design life time. The combined spectrum approach or the dual narrow band shall be applied as the cycle counting algorithms. See 307 and 308.

γ_F = the single safety factor for the fatigue limit state.

402 The fatigue safety factor γ_F shall cover a range of uncertainties in the fatigue analysis. The following values shall be used for mooring lines which are not regularly inspected ashore:

$$\gamma_F = 5 \quad \text{when } d_F \leq 0.8$$

$$\gamma_F = 5 + 3 \left(\frac{d_F - 0.8}{0.2} \right) \quad \text{when } d_F > 0.8$$

Where d_F is the adjacent fatigue damage ratio, which is the ratio between the characteristic fatigue damage d_c in two adjacent lines taken as the lesser damage divided by the greater damage. d_F cannot be larger than one.

403 A single line failure in fatigue is taken to be “without substantial consequences,” while near-

simultaneous fatigue failure of two or more lines is taken to have “substantial consequences.” Analysis has shown that nominally identical mooring lines will have very nearly the same fatigue capacity, and that the recent practice of grouping mooring lines leads to very nearly the same loads in lines within a group. Hence, this practice may lead to an increase in the occurrence of multiple fatigue failures. The safety factors defined above are intended to allow the use of grouped lines while retaining a suitable level of safety.

404 If the mooring line is regularly inspected ashore, which is common for mobile offshore units such as drilling units, then a safety factor of 3 should be applicable.

405 For long term mooring systems stress concentration factors (SCF) due to bending of the chain links in the fairleads, bending shoes, guide tubes and chocks shall all be considered in the fatigue analysis.

F 500 Effect of number of fatigue tests on design curve

501 It is usual practice to offset the design value of the a -parameter of the S-N curve by two standard deviations relative to the mean value

$$\log(a_D) = \log(a) - 2\sigma$$

502 With a normal distribution assumption, this implies that the realised value of the a -parameter for a mooring line component is likely to exceed the design value with probability:

$$P[A > a_D] = 0.9772$$

503 This holds true when the underlying distribution values of a, σ are applied, but not when estimates of these parameters are applied. It may be expected that this probability is very nearly achieved from estimates based on a large number of fatigue tests, and deviates more when the number of tests is small. The effect of the number of test data may be included by introducing a correction factor $k_p(l)$ into the expression for the design value of the a -parameter

$$\log(\hat{a}_D) = \log(\hat{a}) - (2 + k_p(l))\hat{\sigma}$$

The value of the correction factor $k_p(l)$ can be evaluated for any test set size l , by making a large number of simulations of A and a_D , and iterating the value of the correction factor until the relative frequency of 0.9772 is obtained for realisations of A exceeding realisations of \hat{a}_D . Naturally, the normal distribution assumption has to be retained to make these simulations feasible.

504 Such simulations have been carried out for a range of values of test set size l . A million realisations were found sufficient to make the variability in the results for the correction factor negligible, and were applied in the simulations. A simple algebraic function has also been fitted to these results, and is given by

$$k_p(l) = \frac{3.3}{l} + \frac{11.2}{l^2}, \quad 6 < l < 200$$

It is suggested that this correction factor should be applied when establishing fatigue design curves for mooring line components from relatively small numbers of fatigue tests.

F 600 Fatigue limit state (FLS) for fibre ropes

601 Tension - tension fatigue life of fibre ropes can be calculated according to the procedure given in F. However, the fatigue capacity is related to the relative tension R rather than the stress. The fatigue should be calculated using the R-N curve given in 201.

602 Tension - compression fatigue is not considered a problem for polyester. However, for other fibres sensitive to compression such as Aramid, the tension - compression fatigue life shall be documented by testing.

603 The manufacturer shall propose the procedure for tension – compression testing and the company responsible for the certification shall approve the procedure.

604 The fatigue curve shown in Fig.7 is developed for polyester ropes /7/.

605 The following equation described in F201 can be used for the component capacity against tension fatigue:

$$\log(n_c(R)) = \log(a_D) - m \cdot \log(R)$$

Where R is the ratio of tension range to characteristic strength defined in C202.

The parameters a_D and m are given in Table F3.

Table F3 T-N Fatigue Curve Parameters		
	a_D	m
Polyester rope	0.259	13.46

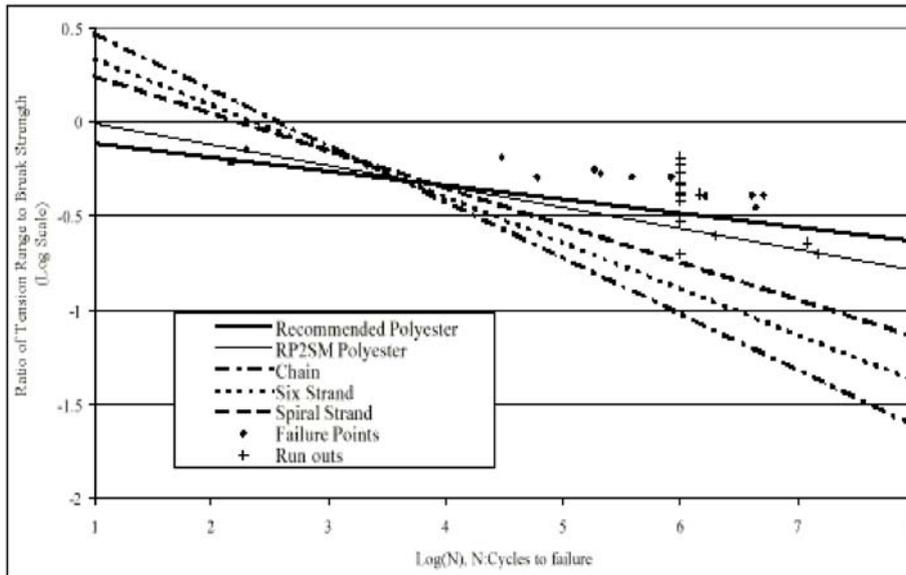


Figure 10
Polyester rope fatigue data and design curve

F 700 Design equation format for fibre ropes

701 The fatigue limit state is intended to ensure that each type of component in an individual mooring line has a suitable resistance to fatigue failure. The design equation for FLS is:

$$1 - d_c \gamma_F \geq 0$$

d_c = is the characteristic fatigue damage accumulated as a result of cyclic loading during the design life time. The combined spectrum approach or the dual narrow band shall be applied as the cycle counting algorithms. See F307 and F309.

γ_F = is the single safety factor for the fatigue limit state.

702 The fatigue safety factor γ_F is 60 for polyester ropes and shall cover a range of uncertainties in the fatigue analysis.

Guidance note:

The fatigue safety factor specified for polyester rope is unusually large compared to values in the range from 1 to 10 typically applicable to steel components. This is partly due to the larger variability in the fatigue test result around the fitted R–N curve. Secondly, it is a consequence of the large exponent $m = 13.46$ of the polyester R–N curve, compared to $m = 3$ to 4 for typical steel components. The safety factor of 60 on the fatigue lifetime together with $m = 13.46$ correspond to a safety factor of 1.36 on the line tension. The same safety factor on the line tension would also correspond to a safety factor of 2.5 on the design lifetime if the exponent were $m = 3$.

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703 Alternatively the fatigue life can be qualified against the design curve for spiral rope. For long term mooring the ratio between calculated fatigue life and design life shall be 5 - 8 (ref. F400), when replacement of the fibre rope segments is not included as a possibility in the operation and inspection plans. If the fibre rope segment will be replaced a fatigue life factor of 3 can be accepted.

F 800 Vortex Induced Motions (VIM)

801 Semi-taut and taut mooring systems with steel wire rope or fibre rope segments can be exposed to VIM which can contribute to the fatigue damage. VIM is caused by vortices shed alternatively from upper and lower side of a cylinder giving rise to oscillatory forces in the transverse direction to the incoming flow as well as in the in-line direction.

802 The main effect of VIM on the mooring line forces is an increase in the effective drag coefficient C_D . For a VIM amplitude on the order of the diameter, the effective C_D can be increased by a factor 2 (ref. DNV-RP-C205). This increase in C_D will have an effect on the wave induced dynamic tension in the mooring line, not on the static (mean) tension. It is assumed that chain is not affected by VIM.

803 The possibility of VIM should be checked and the effect on the dynamic tension shall be included in the fatigue evaluation.

G. Reliability Analysis

G 100 Target annual probabilities

101 A mooring system may be designed by direct application of structural reliability analysis, as an alternative to the simplified design calculation presented in B, C, D and G.

102 Such an analysis should be at least as refined as the reliability analysis used to calibrate the present design procedure /4/, /5/, /6/, and must be checked against the results of the calibration, for at least one relevant test case.

103 The probability levels given in Table H1 have been applied in the calibration, and should also be applicable in a comparable reliability analysis:

Limit state	Consequence class ¹⁾	Target annual probability of failure
ULS	1	10 ⁻⁴
	2	10 ⁻⁵
ALS	1	10 ⁻⁴
	2	10 ⁻⁵
FLS	Single line	10 ⁻³
	Multiple lines	10 ⁻⁵

1) Consequence Classes are not considered for FLS

H. References

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SECTION 3 THRUSTER ASSISTED MOORING

A. General

A 100 Objective

101 This section provides recommendations and methods for the design of thruster assisted moorings.

A 200 Application

201 For units equipped with thrusters, a part of or full net thrust effect may be taken into account in all design conditions.

202 The effect of thruster assistance may be included in the computation of the characteristic tension for the ULS.

203 The ALS analysis shall be carried out for:

- loss of one mooring line
- loss of thruster assistance defined as loss of a single thruster or a single failure in the power or control system causing the most severe loss of thrusters. Detailed description of control systems and failure scenarios are given in DNV Rules for Classification of Ships Pt.6 Ch.7 Sec.3.

204 If the thruster system includes redundant power systems, the reliability and availability of the system shall be documented by a failure mode and effect analysis.

205 The effect of thruster assistance is depending on the layout of the thrust control system and the design conditions. The permissible use of thrusters and the effects are given in Table A1.

206 Thrusters may be used to assist the mooring system by reducing the mean environmental forces, heading control and damping of low frequency motions or a combination of these functions.

207 The net thrust referred to in Table A1 shall be based on the following conditions:

- fixed propellers can be considered only if thrust produced contributes to the force or moment balance
- azimuthing thrusters can be considered to provide thrust in all direction, unless specific restrictions are defined
- thruster induced moment shall be taken into account when thruster assistance is analysed.

208 When thrusters are used, failures leading to stop of thrusters shall be considered equivalent to line failure as defined in Sec.2 B101, and the corresponding safety factors will apply. See Sec.2 D.

<i>Consequence class</i>	<i>Limit state</i>	<i>Manual remote control</i>	<i>Automatic remote control</i>
1	ULS	70% of net thrust effect from all thrusters	100% of net thrust effect from all thrusters
	ALS	70% of net thrust effect from all thrusters ¹⁾	100% of net thrust effect from all thrusters ¹⁾
2	ULS	70% of net thrust effect from all thrusters	100% of net thrust effect from all thrusters
	ALS	70% of net thrust effect from all thrusters ¹⁾	100% of net thrust effect from all thrusters ¹⁾

1) A failure leading to stop of thrusters shall be considered equivalent to a line failure. Redundancy in the thruster systems is not required if blackout is considered as a single failure, and the design equation given in Sec.2 D201 fulfilled.

Guidance note:

Based on experience from DNV surveyors it is not common practice to utilize 100% of the power capacity.

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209 The maximum effect of single failure shall not cause a design load effect higher than the characteristic capacity. See Sec.2 A202 and D202.

210 Blackout is one typical maximum effect of a single failure. If blackout leads to that the sum of line tensions multiplied with the relevant safety factors is higher than the characteristic capacity than permitted in ALS (see Sec.2 D300), the power and control systems have to be arranged with redundancy.

211 Manual thruster control is intended only for limited time periods, and the arrangement assumes continuous attention of an operator.

212 Turret moored units, which are not naturally weather-vaneing, and hence dependent on heading control shall be equipped with an automatic remote control system. Blackout has to be considered as a single failure if an emergency shut down is causing stop of all thrusters.

A 300 Definitions

301 The thruster assisted mooring system which is dependent on a manual remote thruster system, signifies a system comprising:

- thruster system
- power system
- control system
- reference system.

302 The remote thrust control system is a semi-automatic control system, which enables the operator to give a defined thrust (force and direction) and/or a turning moment to the unit.

303 The thruster assisted mooring system, which is dependent on an automatic remote thruster control system, signifies a system similar to a manual remote system with the addition of an automatic control mode.

304 The thruster system comprises the thruster units, included gear drives and control hardware for control of thruster speed/pitch and azimuth.

B. Available Thrust

B 100 Determination of available thrust capacity

101 The available thrust (net thrust) shall be documented by the manufacturer and verified by sea trials. In an early design stage the net thrust capacity may be estimated by calculation.

Guidance note:

To determine the available thrust capacity the propeller thrust at bollard pull has to be calculated first by using the following conversion factor for nozzle propellers:

0.158 kN/kW.

For open propellers the following factor shall be used:

0.105 kN/kW.

This thrust has to be corrected by applying thrust reduction factors. These factors are depending on the following:

- propeller/thruster installation geometry and arrangement
- inflow velocity into the propeller
- propeller sense of rotation (ahead or reverse).

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102 Determination of reduction factors can be carried out according to ISO/TR 13637 or API RP 2SK. These standards contain guidelines which apply to the following:

- open and nozzled propellers installed in the stern of a ship-shaped unit i.e. conventional main propulsion arrangement
- azimuthing or direction fixed nozzled thrusters installed under the bottom of a hull
- tunnel thrusters installed in a transverse tunnel in the hull.

C. Method

C 100 Mean load reduction

101 This is a simplified approach where the thrusters are assumed to counteract only the mean environmental actions in surge, sway and yaw direction. Available thrust from thrusters shall be evaluated according to Table A1. The mooring lines are assumed to counteract the remaining mean loads; i.e. the total mean loads minus the thruster forces.

102 For spread mooring systems where the yaw moment has insignificant effect on the mooring (column-stabilised units), the force balance in the yaw direction can be neglected. In this case the surge and sway components of the allowable thrust can be subtracted from the mean surge and sway environmental loads.

103 For vessels equipped with a single point mooring system where the vessels heading is controlled by thrusters, the balance of yaw moment about the turret must be taken into consideration. A procedure to determine the mean load reduction is given in the guidance note below.

Guidance note:

- 1) Determine the mean environmental yaw moment as a function of the unit's heading, typically in the range of -90° to $+90^\circ$, and locate the equilibrium heading at which the yaw moment is zero.
- 2) Determine a target heading, which is the desired heading to maintain based on operation requirements and the consideration of minimising the unit's loads and motions. For collinear environments, the target heading is

normally 0° to the environment. For non-collinear environments the target heading could be the wave direction.

- 3) Search for the maximum yaw moment (M_E) between the target and the equilibrium heading.
- 4) Determine the maximum yaw moment that can be generated by the thrusters (M_T) under the damaged condition.
- 5) If M_T is less than M_E , thruster assist should be neglected, and the mooring system should be analysed without thruster assistance. If M_T is equal or greater than M_E go to step 6.
- 6) Determine the mean environmental loads in surge (F_X), sway (F_Y) and yaw (M_Z) at the target heading plus or minus an angle α , whichever is more critical where $\alpha = 10^\circ$ for collinear environment and 15° for non-collinear environment.
- 7) Determine the surge (T_X) and sway (T_Y) thrust components from the thruster system that can be used to counteract the environmental load. T_X and T_Y can be determined as follows:
 - Thrust from the whole system is the vector sum of the thrust from each thruster.
 - Output from each thruster shall satisfy the available thrust according to the thruster control system.
 - The moment generated by T_X and T_Y shall balance M_Z .
 - The thrust generated by an individual thruster shall not exceed the allowable thrust.
- 8) Combine T_X and T_Y with F_X and F_Y to obtain reduced mean surge and sway loads.
- 9) Perform analysis to obtain mooring system response under reduced mean load.

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C 200 System dynamic analysis

201 A system dynamic analysis is normally performed using a three-axis (surge, sway and yaw) time domain simulator. This simulator generates the mean offset and low frequency vessel motions and thruster responses corresponding to specific environmental force during time records. In this analysis, constant wind, current, mean wave drift forces and low frequency wind and wave forces are included. Wave frequency forces, which are not countered by the thruster system, can be excluded in the simulation.

D. System Requirements

D 100 Thruster systems

101 The thruster configuration may consist of both fixed and rotating thrusters. Variable pitch and variable speed can e.g. control thrust output. The thruster configuration has to be evaluated on the basis of the mooring system.

D 200 Power system

201 An automatic power management system shall be provided which will ensure adequate running generator capacity relative to power demand, i.e. available power reserve.

202 The automatic power management system shall be able to execute immediate limitations in power consumption to prevent blackout due to overload caused by sudden shortage of available power.

203 The capacity of the power system shall be evaluated on the principle that a single failure in the power system shall be considered equivalent to an anchor line failure. The limiting requirements for tensions and motions for the type of operation shall be applied.

204 Detailed requirements to power systems are given in the Rules for Classification of Ships Pt.6 Ch.7 Sec.5.

205 If the design capacity is dependent on certain thrusters to remain intact after failure as in 203, the power system shall be designed with redundancy to ensure operation of these thrusters.

Guidance note:

The following can be used as guidance:

The Rules for Classification of Ships Pt.6 Ch.7 shall be used as reference.

NMD: Regulations of 4 September 1987 No. 857 concerning anchoring/positioning systems on mobile offshore units and Guideline No. 28 to the NMD regulations and Appendix B to Guideline No. 28.

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206 The definition of design capacity is given in Sec.2 B102.

D 300 Control systems

301 Manual remote thrust control system shall include:

- manual control of each thruster
- remote thrust control, joystick system.

302 Automatic remote thrust control system shall include:

- manual control of each thruster
- automatic control of all thrusters.

303 A mode selector shall be arranged in the thruster assistance control area to enable switching between remote thrust control, or automatic control and manual control.

304 Detailed requirements for control systems are given in the Rules for Classification of Ships Pt.6 Ch.7 Sec.3.

D 400 Manual thruster control

401 Manual operation of each thruster, start, stop, azimuth and pitch or speed controls shall be arranged. Displays shall be provided for all information necessary for safe and practical operation.

402 Individual stop (emergency stop) of each thruster shall be possible from thruster assistance control area.

403 The location of the thruster assistance control stand shall be chosen with consideration of the operation. Units operating at a safe distance from other stationary structures can have the control stand in a control room with no direct view of the unit's surroundings. Units operating in the vicinity of other structures, see Sec.2 D500 and D600 shall have a control stand from where there is a good view of the unit's surroundings.

404 The thruster assistance control stand shall be equipped with displays for line tensions and line length measurements.

D 500 Remote thrust control, joystick system

501 The remote thrust control system shall be located in the control area together with the manual thruster controls and with the same access to thruster and mooring displays.

502 The remote thrust control system shall be a joystick system with integrated control of all thrusters. Automatic heading control shall be included.

503 At least one gyrocompass shall be interfaced to the joystick system.

D 600 Automatic thruster control

601 The automatic control mode shall include the following main functions:

- 1) *Automatic control* for optimal use of available thrust in co-operation with the mooring system forces, and automatic compensation of the effects of anchor line failure, thruster failure and thruster power failure. Detailed requirements are given in 700.
- 2) *Monitoring* of position and mooring line tension and alarms for excursion limits. Detailed requirements are given in 800.
- 3) *Consequence analysis* consisting of prediction of line tensions and the unit's position in the event of a single anchor line failure or thruster failure under the prevailing environmental conditions. Detailed requirements are given in 900.
- 4) *Simulation* of motions and anchor line tensions during manoeuvres, changing of anchor patterns, effect of changing weather conditions, and failures in thrusters and anchor lines. Detailed requirements are given in 1000.
- 5) *Logging* of relevant parameters for display or hard copy on operator's request. Detailed requirements are given in 1100.
- 6) *Self-diagnostics* with alarms for faults within the automatic control system or in data received from interfaced equipment. Detailed requirements are given in 1200.
- 7) *System response to major failures*. Information is given in E.

602 The automatic control system shall be powered from a non-interruptible power source, UPS. The battery power reserve in the UPS shall be sufficient for 15 minutes operation.

603 Redundant automatic thruster control is required when the mooring analysis is based on thruster assistance to the required design capacity in ALS.

D 700 Automatic control

701 The thrusters automatic control system shall be designed to cover one or combination of the following functions:

- heading control
- counteracting the static environmental forces
- reducing the low frequency motions.

Turret moored units, which are not freely weather-vaneing have to be designed with an automatic heading

control system.

702 When the thruster shall be controlled to produce thrust to counteract the static environmental forces, the thrust shall be proportionate to the magnitude of anchor line tension and position offset. Thrusters can be deactivated when anchor line tension and position offset are within acceptable limits.

703 The thrusters shall be controlled to produce thrust to compensate for the effect of anchor line failure if necessary.

704 The thruster control system shall be able to reallocate thrust when failure of a thruster is detected, or the operator deselects a thruster.

705 When the power demand for use of thrusters exceeds available power, the control system shall use the available power in an optimal manner and introduce thrust limitations to avoid overloads and blackout situations. The method of thrust limitation shall be quick enough to avoid blackout due to a sudden overload caused by stop of one or more generators.

D 800 Monitoring

801 Continuous monitoring shall be provided of all important parameters, which at least shall include:

- position
- heading
- anchor line tension, see Sec.4 Q
- available electrical power.

802 Deviations from the specified position and heading shall be compared with at least two adjustable limits. An alarm shall be released when passing both limits. When passing the first limit, the alarm can be considered as a warning and shall be distinguishable from the other alarms realised at a more severe limit.

803 Anchor line tensions shall be monitored and compared to both high and low limits.

804 Low anchor line tension alarms can be interpreted as an anchor line failure if the anchor line tension measurement system has self check facilities, and these have not detected a measurement failure. Otherwise, the low tension alarm shall not be interpreted as anchor line failure and used for thruster control unless one more parameter e.g. position or heading indicates anchor line failure.

805 Monitoring of position shall be based on position measurements from at least one position reference system. If redundancy is required at least two independent position reference systems are required. Typical position reference systems are:

- hydro acoustic
- taut wire
- microwave (ARTEMIS, MINIRANGER)
- radio wave (SYLEDIS)
- riser angle sensors
- satellite (DGPS)
- gangway sensor.

806 The position being calculated from mooring system data can be used to check the direct position measurement, and can be used in the event of failure of the position reference systems.

807 The position measurements shall have an accuracy of 2% of the water depth, obtained either directly by one source of reference, or by pooling the results of several.

808 The position reference systems shall provide new position data with a refresh rate and accuracy suitable for the intended operation.

Guidance note:

The accuracy of the position reference data is generally to be within a radius of 2% of water depth for bottom-based systems, and within a radius of 3 m for surface-based systems.

For satellite based systems, interface and necessary equipment for receiving differential correction signals is required installed.

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809 The position measurements shall be transformed to represent the position of any critical point on the unit as determined by its application.

810 The automatic remote thrust control panel shall be equipped with alarm display for thrusters, which can be relayed from the thruster alarm panel or general alarm system.

811 There shall be alarm displays for failure of external devices interfaced to the automatic remote thrust control system, e.g. gyrocompass, wind sensor and UPS.

812 All alarms shall be acknowledged by the operator at the automatic remote thrust control panel. For alarms relayed from general alarm systems or other common source, the acknowledgement shall have only local effect.

D 900 Consequence analysis – Failure mode and effect analysis (FMEA)

901 Concurrent with control and monitoring, there shall be performed an analysis of the consequences of certain defined failures under prevailing operation conditions. The consequences are defined as anchor line tensions and position deviations in excess of accepted limits.

902 The failures to be considered shall include failure of any anchor line, failure of any single thruster, or stop of thrusters which will occur in the event of the most serious failure in the power system. If there is no redundancy in power supply or control systems, the most serious event is blackout.

903 The consequence analysis shall check the consequence criteria against all defined faults in sequence, and the repetition rate shall not be less than once per 5 minutes.

904 All computed consequences shall release an alarm or a warning. The consequence and reason shall be suitably identified. The warning or alarm shall be acknowledged.

905 The software or hardware used for preparing the consequence analysis is exempted from the redundancy requirements for automatic control system, see 603.

906 If the consequence analysis function is carried out by non-redundant equipment, failure of this shall cause alarm.

Guidance note:

Some additional information regarding the FMEA analysis is given in DNV Rules for Classification of Ships Pt.6 Ch.7 Sec.1 D700.

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D 1000 Simulation

1001 The simulation function can be executed in an off-line computer system with access to process data. If the control system is used for simulation, the priority shall be next to control, monitoring and consequence analysis.

1002 The simulation facility can use the display system of the control system, but shall not obstruct the presentation of alarms.

1003 The simulation facility should at least provide for:

- mooring conditions on input of proposed anchor pattern and anchor line tensions
- effects of changing weather conditions
- anchor line tensions, low frequency motions, wave frequency motions and final position caused by anchor line failure. The effects shall be displayed in true time scale
- relevant functions both with and without thruster assistance.

D 1100 Logging

1101 Automatic logging shall be carried out of important parameters. This will at least include all anchor lines' tensions, position and heading deviations, power consumption, thrust resultant in magnitude and direction, wind speed and direction.

1102 The data shall be recorded with a sampling interval of 1 s and stored on a hard disk.

1103 The data shall be presented in graphical form covering at least 24 hours back in time.

D 1200 Self-monitoring

1201 There shall be automatic self-monitoring of automatic control system, which shall detect computer stop, software hang-ups, power failures, and false operation of interfaced equipment as far as this can be determined from the central system.

E. System Response to Major Failures

E 100 Line failure

101 For both manual and automatic thruster systems there shall be no need to consider the use of thrusters to compensate for line failure at the time of failure or immediately after. Any compensation should be the results of considering the new mooring pattern i.e. with one line missing, and making adjustments to the required heading and position as appropriate.

102 Line failure during offtake operations should be considered and the effect on the shuttle tanker shown to be without serious consequences.

E 200 Blackout prevention

201 In situations where thruster assist is not essential a blackout prevent system or a system whereby thrusters have power priority is also not essential provided it can be shown that the sudden loss of thrusters or control

system cannot cause an unmanageable problem. This includes times when a shuttle tanker is engaged in loading.

202 Both systems to give thrusters priority for power and a blackout prevention system shall be installed on units where heading control is essential and where heading control and mooring load reduction by thrusters are required.

E 300 Thruster to full power

301 Thruster faults should not result in unwanted power being applied, or power applied in the wrong direction.

302 If this fault is possible then the duration of the unwanted thrust should be so short that it does not risk a heading excursion larger than 15° or a line tension to increase greater than accepted from the worst failure case. This means that these faults shall be detected and alarmed so that the thruster can be correctly stopped either by the operator or automatically.

E 400 Gyro compass drift

401 If the drift of one gyro compass can cause a change of heading there shall be a method of fault detection and alarm that enables the system and the operator to reject the gyro data and restore the correct heading before an excursion of 15° is reached. Alternatively there shall be adequate redundancy of heading references.

E 500 Position reference fault

501 If the drift or jump of one position reference or two references of the same type can cause unnecessary thrust then the detection and rejection of false data shall be fast enough to prevent an increase in mooring line tensions greater than what will occur from a single line failure. Alternatively there must be adequate redundancy of position references.

E 600 Other major failures

601 The major faults described shall illustrate the principles involved and are not an exhaustive list of major failure modes that have to be considered by designers and operators.

F. Thrusters

F 100 General

101 Thrusters shall comply with DNV-OS-D101 Marine and Machinery System Equipment.

SECTION 4 MOORING EQUIPMENT

A. General

A 100 Objective

101 This section contains requirements regarding equipment and installation for temporary mooring, position mooring and towing.

A 200 Anchor types

201 The anchors are normally to be of fluke, plate, pile, suction or gravity type. Other anchor types can be accepted on a case to case basis.

202 For mobile offshore units (drilling, accommodation etc.) the anchors of embedment type shall be designed in such a way that additional anchors can be attached (piggyback).

B. Structural Design and Materials for Anchors

B 100 Structural strength

101 The structural strength of anchors for long term mooring is to be designed for a design load equal to the characteristic breaking strength of the anchor line. The nominal equivalent linearised primary membrane and bending stress σ_e shall not exceed $0.9 \sigma_f$, e.g. local peak stresses may exceed yield ref. DNV-OS-C101 Sec.5 A400.

102 Alternatively the anchor may be design based on the characteristic loads calculated according to Sec.2 and principles given in DNV-OS-C101 with a material factor of 1.1.

103 Structural strength of fluke anchors for mobile mooring e.g. drilling and accommodation units may be designed according to Ch.3 Sec.2 C.

104 Strength may also be documented by non-linear analysis using recognised programmes and procedures. Material factor of 1.1 to be taken into account in the analysis. Max allowable plastic strain is not to exceed 5%.

B 200 Materials for fluke anchors

201 For fluke anchors and drag-in plate anchors the connection point to the anchor shackle is denoted the anchor head.

202 Anchor heads may be cast, forged or fabricated from plate materials. Shank or shackles may be cast or forged.

203 Cast or forged material for anchor heads, shank, flukes and shackles are to be manufactured and tested in accordance with relevant requirements of DNV-OS-B101 Ch.2 Sec.4 Steel Castings and Ch.2 Sec.3 Steel Forgings.

204 Plate material used for fabricated anchor heads and flukes is to comply with relevant requirements of DNV-OS-B101 Ch.2 Sec.1 Rolled Steel for Structural Applications.

The structural category shall be primary, see DNV-OS-C101 Sec.4 'Structural categorisation, material selection and inspection principles'.

205 Fabrication and inspection of anchor heads, shanks and flukes shall be in accordance with DNV-OS-C401.

B 300 Design of anchor pad eye

301 For other types of anchors than fluke anchors and plate anchors the connection point to the anchor shackle is denoted the anchor pad eye.

302 The mooring connection is to be designed for a design load equal the characteristic breaking strength of the anchor line. The nominal equivalent linearised primary membrane and bending stress σ_e in the pad eye and the supporting structure is not to exceed $0,9 \sigma_f$, e.g. local stresses may exceed yield. Ref. DNV-OS-C101 Sec.5 A400.

303 Alternatively the pad eye and the supporting structure may be design based on the design loads calculated according to Sec.2 and principles given in DNV-OS-C101 with a material factor of 1.1.

304 Installation tolerances are to be accounted for.

B 400 Anchor shackle

401 The diameter of the shackle leg is normally not to be less than:

$$d_s = 1.4 \cdot D_{nom}$$

D_{nom} is the applied chain diameter with tensile strength equal to the shackle material. For long term mooring the material of the anchor shackle shall be R3, R3S, R4, R4S or R5. For mobile mooring systems the tensile strength for the shackle may differ from the chain material, and consequently D_{nom} has to be corrected correspondingly, see guidance note below.

Guidance note:

For shackle material with minimum tensile strength different from that of the steel grades R3, R3S, R4, R4S and R5, linear interpolation between table values of D_{nom} will normally be accepted, see DNV-OS-E302 Sec.2.

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402 The diameter of the shackle pin is normally not to be less than the greater of:

$$d_p = 1.5 \cdot D_{nom}$$

$$d_p = 0.7 \cdot l_p$$

D_{nom} is given in Ch.3 Sec.2 A100 unless the design is documented otherwise.

l_p = free length of pin. It is assumed that materials of the same tensile strength are used in shackle body and pin. For different materials d_p will be specially considered.

403 Anchor shackles to be applied in long term mooring system shall be of quality R3, R3S, R4, R4S or R5 and they shall be manufactured and tested according to DNV-OS-E302.

404 Anchor shackles to be applied in mobile mooring systems and which are not according to DNV-OS-E302 shall be proof load tested with the anchor, see Ch.3 Sec.2 C500.

B 500 Pile, gravity and suction anchors

501 The load bearing part of the anchors shall be primary structural category, while the pad eye and the part of the structure distributing the load to the load bearing part shall be special structural category, see DNV-OS-C101 Sec.4.

502 The material shall be according to the requirements given in DNV-OS-B101, and fabrication and testing shall be in accordance with DNV-OS-C401.

C. Fluke Anchors

C 100 General

Conventional fluke anchors are also known as drag embedment anchors. A further development of this anchor type is the so-called drag-in plate anchor, which is installed as a fluke anchor, but functions as an embedded plate anchor in its operational mode. Plate anchors are treated in D.

Further information about design and installation of fluke anchors is found in DNV-RP-E301.

C 200 Fluke anchor components

201 The main components of a fluke anchor (see Fig.1) are:

- the shank
- the fluke
- the shackle
- the forerunner.

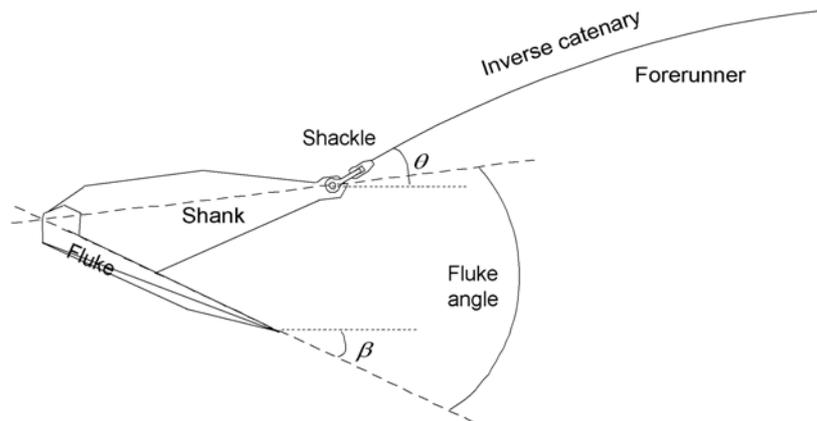


Figure 1
Fluke anchor

202 The fluke angle is the angle arbitrarily defined by the fluke plane and a line passing through the rear of the fluke and the anchor shackle. It is important to have a clear definition (although arbitrary) of how the fluke angle is being measured.

203 Normally the fluke angle is fixed within the range 30° to 50°, the lower angle used for sand and hard or stiff clay, the higher for soft normally consolidated clays. Intermediate angles may be more appropriate for certain soil conditions (layered soils, e.g. stiff clay above softer clay). The advantage of using the larger angle in soft normally consolidated clay is that the anchor penetrates deeper, where the soil strength and the normal component on the fluke is higher, giving an increased resistance.

204 The forerunner is the line segment attached to the anchor shackle, which will embed together with the anchor during installation. The anchor penetration path and the ultimate depth or resistance of the anchor are significantly affected by the type (wire or chain) and size of the forerunner, see Fig.1.

205 The inverse catenary of the anchor line is the curvature of the embedded part of the anchor line between the anchor padeye or shackle and the dip-down point at the seabed.

C 300 Definition of fluke anchor resistance

301 The characteristic resistance of a fluke anchor is the sum of the installation anchor resistance and the predicted post-installation effects of consolidation and cyclic loading. To this resistance in the dip-down point is added the possible seabed friction up to the line touch-down point.

302 The design anchor resistance at the line touchdown point, calculated according to the principles in DNV-RP-E301, shall be at least equal to the design line tension at the same point, calculated according to the principles laid down in this document.

303 The installation line tension applied shall account for any differences between the seabed line friction (length on the seabed) during installation and operation of the anchors. This tension shall be maintained during the specified holding time, normally 15 to 30 minutes.

C 400 Verification of anchor resistance - mobile mooring

401 For mobile moorings such as drilling units with drilling riser disconnected and accommodation units in standby condition, when the consequence of anchor dragging during extreme environmental conditions is not critical, the anchor resistance shall be verified by applying an anchor installation tension at the dip-down point not less than the maximum line tension caused by an environment load corresponding to the maximum operation condition, intact mooring. The consequence of anchor dragging during a 100 year storm shall be investigated and documented with respect to length of dragging and the line tensions in the adjacent lines.

402 When determining the required anchor installation tension at the dip-down point the friction between the mooring line and the sea bed and in the fairlead shall be considered

Guidance note:

If the friction in the fairlead can not be documented the friction can be assumed to be 10% of the tension. Before the important anchor installations the calibration of tension measuring system shall always be checked and when necessary recuperated, since the friction loss may sometimes be as great as 40% of the applied tension

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403 For mobile moorings where the consequence of anchor dragging during maximum characteristic environmental condition (100 year return period) is critical to adjacent installations, subsea structures, human life or the environment, the anchor resistance shall be verified by applying an anchor installation tension, which

satisfies the safety requirements for the governing limit state (ULS and ALS).

404 If the required installation tension according to 403 is not possible to achieve, the potential anchor drag during a 100 year storm shall be investigated. The additional drag distance can be predicted using e.g. the DNV software DIGIN and it shall be verified that this distance is tolerable for the actual environment and adjacent installations. For anchors in layered, hard or dense soil, when the penetration depth is small, the prediction of additional drag during a storm is subject to more uncertainties than in clay soil. In such soil conditions, when the consequences of anchor drag may be serious, the anchor installation tension may have to be set high enough to provide the required safety factor without anchor drag.

405 Design charts published e.g. by the anchor manufacturers and in API RP2SK shall be used with caution, particularly in layered, hard and dense soil when the anchor penetration is small, see also discussion in DNV-RP-E301.

406 If the specified anchor installation tension is too high to be achieved it may be required to pre-set the anchors to obtain the specified anchor installation resistance.

407 Acceptance of an uplift angle of the mooring line in the dip-down point can be given on a case to case basis, see DNV-RP-E301 for assessment of acceptable uplift angle.

C 500 Verification of fluke anchor resistance long term mooring

501 The required resistance of fluke anchors to be applied in long term mooring, shall be assessed and verified by theoretical calculations as described in DNV-RP-E301, which also provides the basis for assessment of the minimum anchor installation tension. For assessment of applicable consequence class reference is made to present document Sec.2 D500 and D600.

502 The anchor installation loads tension shall be equal to the extreme line tension based on an environment with a 100 year return period. Both ULS and ALS shall be considered. The installation load tension and required anchor resistance shall be according to DNV-RP-E301, which also provides general requirements to soil investigation for design and installation of fluke anchors.

503 The basis for assessment of the long-term anchor resistance and the required anchor installation tension shall be documented with reference to the recommendations given in DNV-RP-E301.

D. Plate Anchors

D 100 General

101 Plate anchors are anchors that are intended to resist the applied loads by orienting the plate approximately normal to the load after having been embedded. The embedment of the plate anchor may be by dragging (like a fluke anchor), by pushing, by driving or by use of suction.

102 For drag-in plate anchors a design and installation procedure has been developed, see DNV-RP-E302, which may be adopted as a tentative guidance for design also of other types of plate anchors. However, due consideration will have to be given to the differences in installation method and how this may affect the final pull-out resistance of the plate.

D 200 Drag-in plate anchors

201 Drag-in plate anchors are designed to take uplift or vertical loads in a taut mooring system. They are best described as a further development of the fluke anchor concept, with the added feature that the fluke (plate) after installation can be oriented normal to the applied load.

202 This triggering of the anchor leads to a significant (two-fold or more) increase of the anchor resistance expressed by the performance ratio, which gives the ratio between the pullout resistance and the installation resistance.

203 This principle is utilised also in the development of other plate anchor concepts.

204 According to the design procedure recommended by DNV the anchor pullout resistance is split into a static component and a cyclic component.

205 The design anchor resistance, which is obtained by multiplying the characteristic value of the respective component by a material coefficient, shall be at least equal to the design line tension at the dip-down point (seabed), as explained in more detail in DNV-RP-E302.

D 300 Other types of plate anchors

301 Results from instrumented tests in clay with different push-in types of plate anchors indicate that the principles outlined in DNV RP-E302 for calculation of the pullout resistance of drag-in plate anchors can be adopted also for other types of plate anchors.

302 In the design of other types of plate anchors, like push-in plate anchors, drive-in plate anchors and suction embedment plate anchors, consideration shall be given to the special characteristics of the respective anchor

type, particularly how the resistance of the plate in its operational mode is affected by the anchor installation.

303 In the assessment of the pullout resistance of plate anchors the extent and quality of the soil investigation shall be accounted for such that adequate conservatism is used in quantification of the governing design parameters.

D 400 Installation depth

401 The target installation depth and required long term anchor resistance shall be determined according to DNV-RP-E302, which also provides general requirements to soil investigation for design and installation of plate anchors.

E. Anchor Piles

E 100 General

101 Anchor piles shall account for pile bending stresses as well as ultimate lateral pile capacity. Pile embedment is also to be sufficient to develop the axial capacity to resist vertical loads with an appropriate factor of safety. The design shall be based on recognised codes and standards. Pile fatigue during installation shall be considered as relevant.

102 Design criteria for foundation of anchor piles may be taken according to DNV-OS-C101 Sec.11.

Guidance note:

An analysis method capable of determining the bending stresses shall model the pile as a beam column on an inelastic foundation. The inelastic foundation can be modelled using a soil resistance-deflection (p-y) curve, which is described for various soils in API RP 2A.

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F. Suction Anchors

F 100 General

101 The foundation of suction anchors shall be designed according to relevant requirements given in DNV-OS-C101 Sec.11.

102 An important load case for suction anchors is buckling during installation due to the difference between outside and inside pressure. Design to be performed according to DNV-OS-C101.

G. Gravity Anchors

G 100 General

101 The foundation of gravity anchors shall be designed according to relevant requirements given in DNV-OS-C101 Sec.11.

102 The capacity against uplift shall not be taken higher than the submerged weight. However, for anchors supplied with skirts, the contribution from friction along the skirts may be included.

103 In certain cases gravity anchors with skirts may be able to resist cyclic uplift loads by the development of temporary suction within their skirt compartments.

H. Mooring Chain and Accessories

H 100 General

101 The chain qualities K1, K2 and K3 intended for temporary mooring of ships shall not be used by offshore units for position mooring.

102 Typical examples of stud chain links, studless chain links and accessories are shown in Fig.2 and Fig.3, respectively. Deviations in accordance with ISO 1704 will normally be accepted for position mooring of mobile offshore units, which are changing location frequently, and when the mooring lines are subject to regular onshore inspection.

103 Requirements concerning materials, manufacture, testing, dimensions and tolerances, and other relevant requirements for anchor chain cables and accessories are given in DNV-OS-E302.

104 Typically connection elements such as kenter shackles, D-shackles, C-links and swivels are shown in Fig.2 and Fig.3. Kenter shackles, ordinary D-shackles, C-links and pear links are not permitted in long term

mooring systems due to their poor fatigue qualities. Fatigue life can not be calculated due to lack of fatigue data for these connection elements, with exception of Kenter shackles. API RP 2SK contains information sufficient for estimation of fatigue life for kenter shackles.

If non-conventional connectors are to be used in long term mooring systems these connectors are to be documented and qualified for the intended application.

105 In mobile mooring systems, connection elements such as pear links and C-links should not be used. Kenter shackles are accepted.

If non-conventional connectors are to be used in mobile mooring systems these connectors are to be documented and qualified for the intended application.

106 Recommended connection elements in long term mooring systems are purpose made elements such as triplates, see Fig.4, LTM D-shackles and H-shackles. New types of connection links may be accepted in long term mooring systems, provided their fatigue life is documented by testing and/or analysis.

107 Swivels are not permitted in long term mooring systems if they are not qualified with respect to functionality, structural strength and fatigue.

108 Twist of the chain links shall be avoided. Maximum allowable angle between each link is 5 degrees.

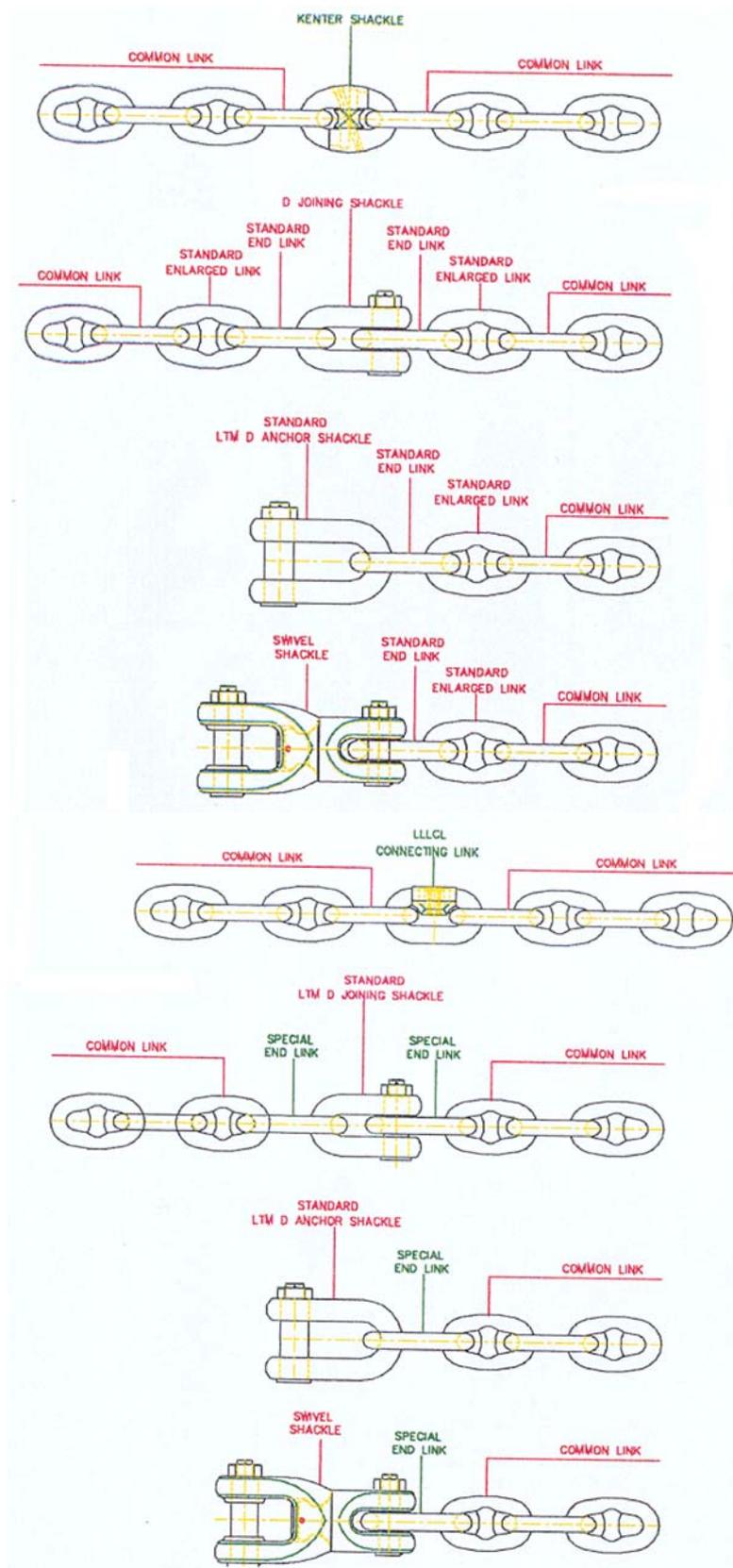


Figure 2
Standard stud link chain cable and accessories

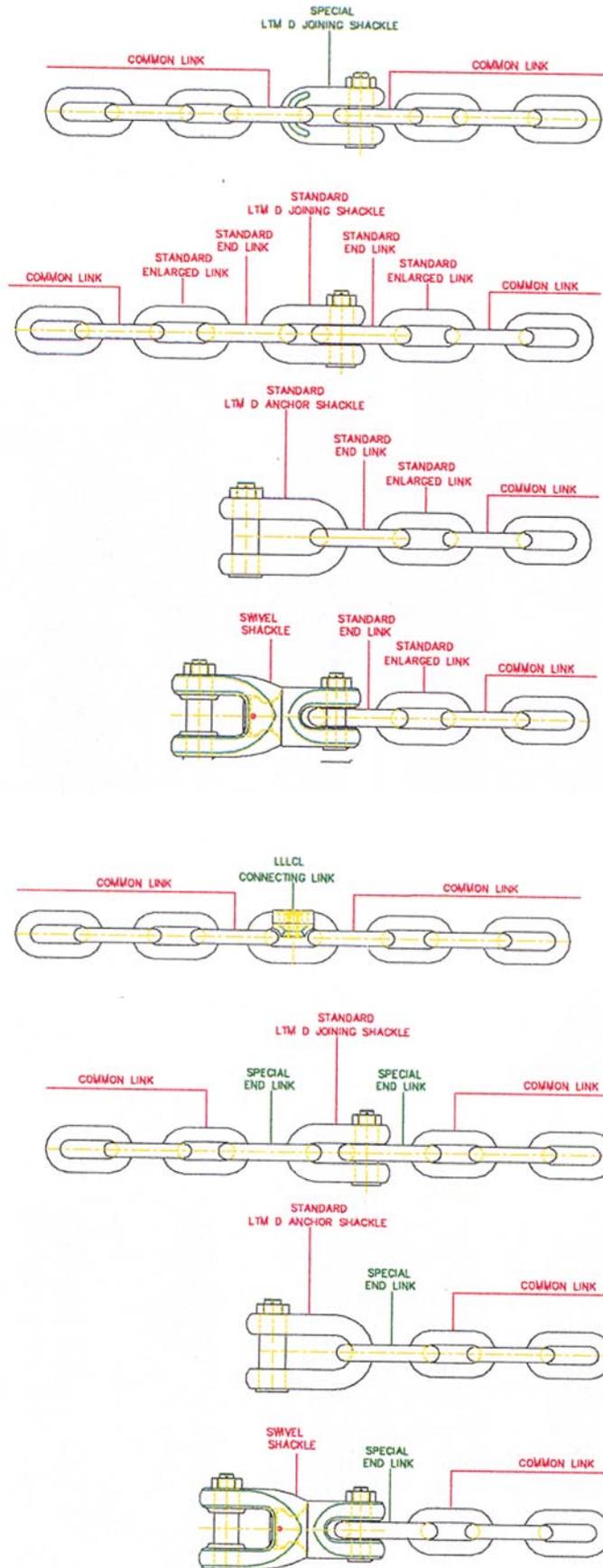


Figure 3
Standard studless link chain cable and accessories

- User specification.
- In-service condition assessment scheme.

202 The user specification shall contain all information about required strength capacity (MBS of the rope) characteristic line tension in operation, required torque and rotation characteristics, design range, design temperature, requirements to handling, length of segments etc. that is required for the rope manufacturer to make the right rope for the application.

203 In addition, the user specification for long-term moorings shall as a minimum include the following

- Requirements to length of fibre-rope assemblies as new and during the service life.
- Service requirements and operational boundaries for the finalised mooring system. (pretension and characteristic line tension for the installed mooring system, pre-stretching load and duration at installation)
- Design life.
- Highest and lowest occurring sea-water temperature
- Minimum bending diameter during transport and installation.

Guidance note:

Service requirements and operational boundaries comprise installation sequence, pretension, loading scenario including the maximal occurring cyclic loading.

Mixing torque-generating steel-wire rope with torque neutral fibre rope is mainly a concern for the fatigue life of the steel-wire rope. Consequently, the torque and rotation characteristics of the fibre ropes should match those of the connecting lines.

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204 The in-service condition assessment scheme shall completely describe the methods and techniques for assessing the condition of the fibre-rope assemblies during service. If applicable, examinations and tests to be performed on inserts shall be described, together with plan for retrieval and evaluation criteria. Instructions for ROV checking of the termination areas shall include dimensional verification of the eyes and splices, their seating and alignment on the termination hardware and checks for potential chafing.

205 The procedure for handling and installation shall contain the necessary instructions and limitations set to protect the integrity of the fibre-rope assemblies between manufacture and installed condition.

206 Restrictions with respect to sea-bed contact shall be conspicuously stated.

Guidance note:

Ingress of particles:

Strength loss in fibre ropes can be attributed to internal abrasion due to water-borne particles such as sand. The fibre rope assembly should not be used in areas of high content of particles in the water.

During deployment, fibre rope contact with the seabed is not permissible unless specifically qualified for such handling. Fibre rope assemblies can be designed for such handling, see DNV-OS-E303.

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K. Windlasses, Winches and Chain Stoppers

K 100 General

101 The windlass or winch shall normally have:

- one cable lifter or drum for each anchor
- coupling for release of each cable lifter or drum from the driving shaft
- static brakes for each cable lifter or drum
- dynamic braking device
- quick release system
- gear
- hydraulic or electrical motors.

K 200 Windlasses for Temporary Mooring

201 The anchors are normally to be operated by a specially designed windlass.

202 The windlass shall have one cable lifter for each stowed anchor. The cable lifter is normally to be connected to the driving shaft by release coupling and provided with brake. The number of pockets in the cable lifter shall not be less than 5. The pockets, including the groove width etc., shall be designed for the joining shackles with due attention to dimensional tolerances.

203 For each chain cable there is normally to be a chain stopper device, see 214.

204 Electrically driven windlasses shall have a torque-limiting device. Electric motors shall comply with the requirements of DNV-OS-D201.

205 The windlass with prime mover shall be able to exert the pull specified by Table K1 directly on the cable lifter. For double windlasses the requirements apply to one side at a time.

Table K1 Lifting power			
<i>Lifting force and speed</i>	<i>Grade of chain</i>		
	<i>R3/K3</i>	<i>R3S</i>	<i>R4/R5</i>
Normal lifting force for 30 minutes in N	46.6 D _{nom} ²	49.5 D _{nom} ²	52.8 D _{nom} ²
Mean hoisting speed for windlass dedicated to temporary mooring	> 9 m/minute		
Maximum lift force for 2 minutes (no speed requirement)	1.5 x normal lifting force		
D _{nom} = the diameter of chain (mm).			

206 Attention shall be paid to stress concentrations in keyways and other stress raisers and also to dynamic effects due to sudden starting or stopping of the prime mover or anchor chain.

207 The capacity of the windlass brake shall be sufficient for safe stopping of anchor and chain cable when paying out.

208 The windlass with brakes engaged and release coupling disengaged shall be able to withstand a static pull of 45% of the chain cable minimum breaking strength, without any permanent deformation of the stressed parts and without brake slip.

209 If a chain stopper is not fitted, the windlass shall be able to withstand a static pull equal to the 80% of the minimum breaking strength of the chain cable, without any permanent deformation of the stressed parts and without brake slip.

210 Calculations indicating compliance with the lifting power requirements in 205 and requirements for windlass brake capacity may be dispensed with when complete shop test verification is carried out.

211 The chain stoppers and their attachments shall be able to withstand the 80% of the minimum breaking strength of the chain cable, without any permanent deformation of the stressed parts. The chain stoppers shall be so designed that additional bending of the individual link does not occur and the links are evenly supported.

K 300 Winches for Temporary Mooring

301 When steel wire ropes are used as mooring lines winches are to be installed.

302 As far as practicable and suitable for the arrangement, drums are to be designed with a length sufficient to reel up the rope in not more than 7 layers. If the number of layers exceeds 7, special considerations and approval is required.

The ratio between winch drum diameter and wire diameter is normally to be in accordance with the recommendations of the wire manufacturer. However, the ratio should as a minimum satisfy the following requirement:

$$\frac{d_d}{d_w} \geq 16$$

d_d = winch drum diameter

d_w = nominal wire diameter

303 When all rope is reeled on the drum, the distance between top layer of the wire rope and the outer edge of the drum flange is to be at least 1.5 times the diameter of the wire rope. Except in the cases where wire rope guards are fitted to prevent overspilling of the wire.

Guidance note:

It is advised that the drums have grooves to accept the rope. Where a grooved rope drum is used the drum diameter is to be measured to the bottom of the rope groove. To avoid climbing of the rope on the grooves the fleet angle is not to exceed 4°.

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304 The strength of the drums is to be calculated, with the maximum rope tension acting in the most unfavourable position. The effects of support forces, overall bending, shear, torsion as well as hoop stresses in the barrel are to be considered.

305 The drum barrel is to be designed to withstand the surface pressure acting on it due to maximum number of windings, the rope is assumed to be spooled under maximum uniform rope tension.

K 400 Materials

401 Windlass and winch components shall be made from materials as stated in Table K2.

Table K2 Material requirements for windlasses and winches	
<i>Item</i>	<i>Material requirements</i>
Cable lifter and pawl wheel	Cast steel
Cable lifter shaft	Forged or rolled steel
Driving shaft	Forged or rolled steel
Gear wheels	Forged or rolled steel Cast steel Nodular cast iron
Couplings	Forged steel Cast steel
Wire drum, drum flanges	Cast steel Rolled steel
Drum shaft	Forged or rolled steel
Stopper, pawl stopper with shafts	Forged or rolled steel Cast steel
Brake components	Forged or rolled steel Cast steel

402 Windlasses, winches and chain stoppers may be cast or forged components or fabricated from plate materials. The material in the cast components shall be cast steel or nodular cast iron with elongation not less than 14%, and otherwise with material properties according to DNV-OS-B101 Ch.2 Sec.4. Steel grades with higher yield strength the given in DNV-OS-B101 are to comply with the requirements of DNV-OS-E302. Plate material in welded parts shall be in accordance with table D3 in DNV-OS-C101, Ch.1 Sec.4. The hardness of the material in the pockets of the cable lifter shall be less than the hardness of the chain.

403 Drums are either to be fabricated from steel plates or to be cast.

404 Components fabricated from plate material shall be manufactured in accordance with DNV-OS-C401. The components are categorised as primary structures according to DNV-OS-C101 Sec.4, while supporting structure is special structural category.

K 500 Capacity and system requirements applicable for windlasses and winches used in position mooring

501 The lifting force of the windlass or winch in stalling shall not be less than 40% of the minimum breaking strength of the relevant anchor line. The windlass or winch shall be able to maintain the stalling condition until the brakes are activated.

502 For windlasses or winches not fitted with stoppers, the braking system shall be separated into two independent systems, each able to hold a minimum static load corresponding to 50% of the minimum breaking strength of the anchor line. The brakes shall work directly on the wildcat drum.

503 For windlasses or winches not fitted with stoppers the brakes when engaged, shall not be affected by failure in the normal power supply. In event of failure in the power supply, a remainder braking force of minimum 50% of the windlass's or winch's braking force shall be instantly and automatically engaged. Means are also to be provided for regaining maximum braking capacity in event of power failure.

504 Windlasses or winches fitted with a stopper device, the capacity of the stopper device shall not be less than the minimum breaking strength of the anchor line. The windlasses or winches are also to be fitted with an independent brake, with static braking capacity of minimum 50% of the breaking strength of the anchor line. For winches the middle layer shall be used as reference.

505 The windlasses or winches are in addition to the static brakes also to be fitted with a dynamic brake. The characteristics of speed or load to which the dynamic brake system can be exposed during setting of the anchor without damaging overheating occurring, shall be documented and included in the operation manual. These characteristics are also to be reported to the relevant verifying authority and shall be clearly documented, e.g. in the Appendix to the classification certificate.

Unless otherwise documented the following capacity applies:

— The dynamic brake is to be designed to control 1200 m of anchor line at a max load of 60 MT at a max speed of 1.0 m/sec.

506 For preinstalled passive mooring system applicable for long term mooring, stalling capacity less than 40% of mooring line minimum breaking strength shall be considered on a case to case basis. Deviation with respect to the braking capacity and hoisting speed are acceptable, provided acceptance from the national authorities in question.

507 A manually operated back-up system for emergency lowering of the anchor line shall be provided in the vicinity of the winch or stopper.

508 If a riser disconnect system is fitted then it is not possible to release the anchor lines while risers are

connected to the unit. A special safety system preventing this shall be provided. Emergency release is nevertheless to be possible with risers connected after a manual cancellation of the above system.

509 It shall be possible to carry out a controlled lowering of the anchor lines in case of an emergency. The lowering shall be carried out individually or in convenient groups.

510 It shall be possible to release the brakes or stoppers from a protected area close to the winch itself, and from a manned control room or bridge. During the emergency release it shall be possible to apply the brakes once at a load of 100 tonnes at a speed of 2.5 m per second in order to halt the lowering and thereafter releasing them again.

511 No single error, including operator's error, shall lead to release of more than one anchor line.

512 An audible alarm system shall be fitted by each windlass or winch in order to warn that remote operation of the windlasses or winches shall take place.

513 At locations where remote operation of the windlasses or winches can be carried out, signboard shall state that the alarm system shall be engaged prior to remote operation of the windlasses or winches.

514 The hoisting speed for windlasses applied for position mooring to be decided based on the operational aspects.

515 For long term mooring with preinstalled passive mooring systems, deviations from the standard can be acceptable, provided acceptance from the national authorities in question.

516 Requirements to gears are given in L.

K 600 Stoppers

601 The chain stoppers may be of two different types:

- a) A stopper device fitted on the cable lifter or drum shaft preventing the cable lifter or drum to rotate (pawl stopper).
- b) A stopper preventing the anchor line to run out by direct contact between the stopper and the anchor line.

The latter type shall be of such design that the anchor line is not damaged at a load equivalent to the minimum breaking strength of the anchor line.

602 The material requirements are given in 400.

K 700 Strength and design load

701 For the structural part of windlass or winch and stopper, the strength requirements are given in Table K3.

Table K3 Design load and strength requirements for winches or windlasses		
<i>Case</i>	<i>Load in anchor line</i>	<i>Maximum equivalent stress, σ_e to be the smaller of the following values</i>
Stopper engaged	S_{mbs}	$0.73 \sigma_b$ or $0.9 \sigma_f$ in the stopper
Brakes engaged	$0.5 S_{mbs}$ for each brake	$0.73 \sigma_b$ or $0.9 \sigma_f$
Pulling	$0.4 S_{mbs}$	$0.5 \sigma_b$ or $0.6 \sigma_f$
$\sigma_e = \sqrt{\sigma_1^2 + \sigma_2^2 - \sigma_1 \cdot \sigma_2 + 3 \tau^2}$ <p>Where σ_1 and σ_2 are normal stresses perpendicular to each other, and τ is the shear stress in the plane of σ_1 and σ_2.</p> <p>σ_f is the specified minimum upper yield stress of the material.</p> <p>σ_b is the specified minimum tensile strength of the material.</p> <p>S_{mbs} is the minimum breaking strength of the anchor line.</p>		

702 Chain stoppers and their supporting on offshore loading buoys (CALM) may be designed according to K701 and DNV-RP-C103 Ch.2, or DNV-OS-C101 using the LRFD method.

K 800 Other type of winches

801 There are other types of winches available such as:

- chain jack
- linear winch
- traction winch.

802 These winches shall be designed according to requirements for windlasses and winches as far as applicable. Other design codes can be accepted.

L. Gear for windlass or winch

L 100 General

101 The windlass gear shall comply with DNV's classification note 41.2 "Calculation of gear rating for marine transmissions" May 2003 with safety factors as specified in the table below. Other codes may be accepted provided requirements according to classification note 41.2 are fulfilled.

L 200 Load Distribution

201 The gear life time shall as a minimum be 2400 hours (corresponding to a rig life time of 20 years, 5 rig moves per year and 24 hours per rig move).

202 The 2400 hours shall be distributed as follows:

- 480 hours at maximum load (corresponding to stalling load, 40% of chain MBL).
- 1920 hours at 70% of maximum load (corresponding to 28% of chain MBL).

L 300 Acceptance Criteria

301 The gear shall have safety factors as shown in Table L1

<i>Type of stress</i>	<i>Safety factor</i>
Tooth root stresses	1.4
Contact stresses	1.0
Scuffing	1.0

M. Fairleads

M 100 General design

101 Fairleads are normally of roller type.

102 Normally the chain cable shall be directly conveyed from the lower fairlead to the cable lifter, without interruption of an upper fairlead. An upper fairlead may be accepted only upon special consideration, taking into account the fairlead diameter, number of fairlead pockets and the distance between fairlead and cable lifter.

103 The lower fairlead is normally to be provided with a swivel arrangement. For a chain cable fairlead on mobile offshore units the number of pockets is normally not to be less than 5. The pockets shall be designed for the joining shackles with due attention to dimensional tolerances.

104 Sharp edges at interface structures with anchor chain or steel wire rope to be avoided.

105 Increasing number of pockets in fairleads above 5 will lead to lower stress and reduced wear. For units designed to stay at the same location for more than 5 years, it is recommended to have 9 pockets in the lower fairlead at least not less than 7 pockets. Other constructions provided with similar or better supporting for chain cable may be accepted.

106 For a steel cable fairlead the ratio between pitch diameter of fairlead wheel and nominal wire rope diameter shall not be less than 16. This applies to all sheaves including combined wire rope or chain arrangement of a mooring system. The groove in fairlead wheel is normally to satisfy the relations as indicated in Fig.5.

107 Fairleads for combined chain or wire anchor line will be considered in each case.

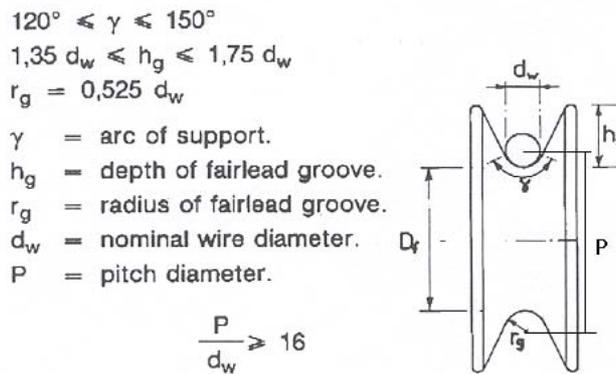


Figure 5
Fairlead for steel wire rope, diameter or groove

M 200 Materials

201 Generally the material in the fairlead wheel shall be of cast steel according to DNV-OS-B101 Ch.2 Sec.4. Steel grades with higher yield strength the given in DNV-OS-B101 are to comply with the requirements of DNV-OS-E302. The hardness of the material is normally to be compatible but not exceeding that of the chain or wire rope.

202 The selection of material grades for plates in the fairlead housing shall be based on the plate thickness and the design temperature according to DNV-OS-C101 Sec.4. The parts, which shall be welded to the column structure, shall be considered as special structure. Manufacturing shall be in accordance with DNV-OS-C401.

203 If the fairleads are not exposed to air in operation and survival conditions, a design temperature of 0° may be accepted on a case by case basis.

204 The material in the fairlead shafts shall be of forged or rolled steel, see DNV-OS-B101 Ch.2 Sec.3 or Sec.1.

Highly stressed elements of the fairleads and their supporting structure are special structural category, see DNV-OS-C101 Sec.4. The other parts of the fairleads and supporting structures are categorised as primary.

M 300 Strength and design load

301 In the structural part of the fairlead the nominal equivalent stress σ_e is normally not to exceed $0.9 \sigma_f$ when subjected to a load equal to the breaking strength of the anchor line. The strength analysis shall be made for the most unfavourable direction of the anchor line. The horizontal design working range (DWR) and the vertical design inlet angle (DIA) normally to be considered in the strength analysis are shown in Fig.6.

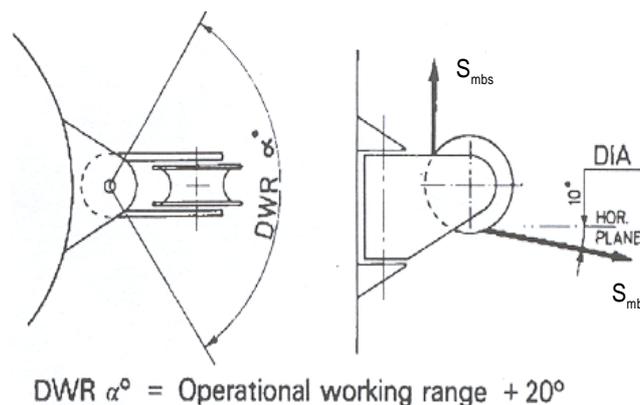


Figure 6
Horizontal DWR and vertical DIA

302 The skew load caused by bearing friction shall be included in the structural strength assessment.

303 Strength may also be documented by non-linear analysis using recognised programmes and procedures. Material factor of 1.1 to be taken into account in the analysis. Max allowable plastic strain is not to exceed 5%.

304 Calculation of the characteristic fatigue damage in fairlead and fairlead attachment shall be carried out. Load spectrum developed in accordance with Sec.2 F300 shall be applied. Stress concentration factors and S-N curves can be found in DNV-RP-C203. A DFF of 3 applies.

The design fatigue life for the structural components should be based on the specific service life of the structure, with service life minimum 20 years.

305 Fairlead support shall be calculated according to DNV-OS-C103.

N. Steel Wire Rope End Attachment

N 100 Structural strength

101 The strength of end connections and connecting links for combined chain, steel wire rope or fibre rope systems shall have a strength which is at least is the same as for the mooring line.

102 Steel wire rope end attachments of the open or closed socket type are normally to be used, see Fig.7 and Fig.8. Other end attachment types will be considered in each separate case.

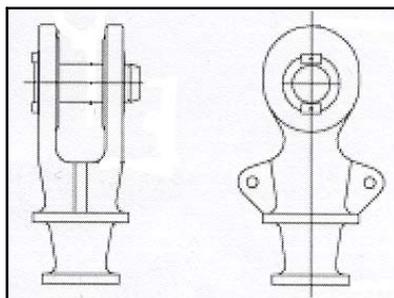


Figure 7
Open socket

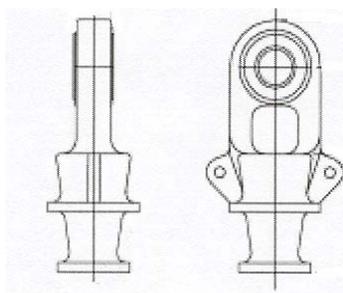


Figure 8
Closed socket

103 Requirements concerning materials, manufacture, testing, dimensions and tolerances, and other relevant requirements for the sockets are given in DNV-OS-E304.

O. Structural Arrangement for Mooring Equipment for Mobile Mooring

O 100 General

101 The anchors shall be effectively stowed and secured in transit to prevent movement of anchor and chain due to wave action. The arrangements shall provide an easy lead of the chain cable or wire rope from the windlass or winch to the anchors. Upon release of the brake, the anchor is immediately to start falling by its own weight.

102 If anchors are supported directly by the shell, the shell plating in way of the anchor stowage shall be increased in thickness and the framing reinforced as necessary to ensure an effective supporting of the anchor.

103 Anchors bolsters shall be efficiently supported to the main structure. However, if the anchor bolsters are damaged or torn off, the main structure shall not be significantly damaged.

104 The chain locker shall have adequate capacity and a suitable form to provide a proper stowage of the chain cable, and an easy direct lead for the cable into the chain pipes, when the cable is fully stowed. The chain locker boundaries and access openings shall be watertight. Provisions shall be made to minimise the probability of chain locker being flooded in bad weather. Drainage facilities of the chain locker shall be adopted.

105 Under normal operation of the mooring line provisions shall be made for securing the inboard end. The arrangement shall be such that the mooring line can be easily disconnected in case of emergency. A weak link

can be arranged at the inboard end to secure disconnection in case of emergency.

106 Mooring systems with all-wire rope or chain and wire rope anchor lines shall have provisions for securing the inboard ends of the wire rope to the storage drum. This attachment shall be designed in such a way that when including the frictional force being applied through the turns of rope always to remain on the drum it is able to withstand a force of not less than the minimum wire rope breaking strength.

107 The fastening of the wire rope to the storage drum shall be made in such a way that in case of emergency when the anchor and chain or wire rope have to be sacrificed, the wire rope can be readily made to slip from an accessible position. The storage drum shall have adequate capacity to provide a proper stowage of the wire rope.

108 Fairleads fitted between windlass or winch and anchor shall be of the roller type.

109 The windlass or winch, chain stopper and fairlead shall be efficiently supported to the main structure. The nominal equivalent stress, σ_e in the supporting structures is normally not to exceed $0.8 \sigma_f$ when subjected to a load equal to the breaking strength of the unit's anchor line. The strength analysis shall be made for the most unfavourable direction of the anchor line, i.e. angle of attack to structure. Detailed information regarding design of supporting structure is given in DNV-RP-C103.

110 Fatigue (FLS) shall be documented for winch/windlass foundation. Load spectrum developed according to Sec.2 F300 shall be applied. Stress concentration factors and S-N curves can be found in DNV-RP-C203. A DFF of 3 applies. The design fatigue life for the structural components shall be based on the specified service life of the structure, with service life minimum 20 years.

P. Arrangement and Devices for Towing of Mobile Units

P 100 General

101 The unit shall have a permanent arrangement for towing. Bridle(s) and/or pennant(s) for towing shall have clear way from the fastening devices to the fairlead. For column-stabilised units a bridle shall normally be used.

102 Normally the towing arrangement shall be designed for use of a single tug of sufficient capacity. If the size of the unit necessitates the use of two or more tugs pulling in the same direction, this can be allowed for in the design as specified in 303.

103 There shall be arrangements for hang-off and retrieval of the unit's towing bridle(s) and towing pennant(s).

104 In addition to the permanent towing arrangement, there shall be a possibility of using an emergency arrangement of equivalent strength. Application of the unit's mooring arrangement may be considered for this purpose.

105 The design load for the towing arrangement shall be clearly stated, e.g. for classed units, in the Appendix to the classification certificate.

106 The permanent towing arrangement can be omitted for column stabilised units with **DYNPOS AUTRO** notation provided the thrust capacity is able to maintain position during an environmental condition as specified in 302. The emergency towing arrangement shall have the same capacity as a permanent towing arrangement as required in 104 and 300.

107 The required towing design load as specified in 303 can be reduced for column stabilised units with the class notions **DYNPOS AUTR** and **AUTRO**, when the main towing equipment is used in combination with the available thrust capacity. The emergency towing arrangement shall have the same capacity as a permanent towing arrangement as required in 104 and 300. A reduction in the towing design load is not accepted for this system.

P 200 Material

201 Plate materials in towline fastening devices and their supporting structures shall be as given in Table D3 in DNV-OS-C101, Ch.1 Sec.4.

202 The termination of towing bridle(s) and/or pennant(s) where connected to the unit should be chain cable of sufficient length to ensure that steel wire rope segments of the towing arrangement will not be subject to chafing against the unit for towline pull sector between 90° port and 90°starboard. Alternatively the full length of bridle(s) and pennant(s) can be chain cable.

203 Chain cables and shackles to be used in the towing arrangement shall be of offshore quality (R3, R3S,R4, R4S or R5) or ship chain quality K3. Green pin shackles of polar type may be accepted provided they are certified by DNV.

204 Towing bridles and pennants of steel wire rope shall be in accordance with the requirements given in H and I.

205 All eyes in towing arrangement connections shall be fitted with hard thimbles or spelter sockets in accordance with M.

P 300 Strength analysis

301 The design load for the towing arrangement shall be based on the force, F_T , required for towing the unit when floating in its normal transit condition. For the purpose of determining the required towing force, thrust provided by the unit's own propulsion machinery should normally not be taken into account. The unit under tow shall be able to maintain position against a specified sea state, wind and current velocity acting simultaneously, without the static force in the towing arrangement exceeding its towing design load.

302 As a minimum the following weather conditions shall be used for calculation of environmental drift forces, F_T , for world-wide towing:

- sustained wind velocity: $U_{1 \text{ min}, 10} = 20 \text{ m/s}$ (10 m above sea level)
- current velocity: $V_C = 1 \text{ m/s}$
- significant wave height: $H_S = 5 \text{ m}$
- zero up-crossing wave period in second: $6 \leq T_z \leq 9$.

Guidance note:

Environmental forces may be calculated according to DNV-RP-C205.

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303 The towing design load, F_D , to be used in the strength analysis for each towing bridle or pennant is a function of the required towing force and the number of tugs comprised in the design and given by:

$$F_D = f_{\text{tow}} F_T \text{ (kN)}$$

f_{tow} = Design load factor
= 1.0, if $N_{\text{TUG}} = 1$
= $1.5/N_{\text{TUG}}$, if $N_{\text{TUG}} > 1$

N_{TUG} = number of tugs comprised in the design of the towing arrangement.

Guidance note:

It is advised that the towing design load for each towing bridle or pennant not to be taken less than 1000 kN and that the towing arrangement is designed for use of a single tug.

---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

304 The minimum breaking strength, S_{mbs} of the unit's towing bridle(s) and/or towing pennant(s), shall not be less than 3 times the towing design load, F_D .

305 The nominal equivalent stress, σ_e in the flounder plate is normally not to exceed σ_f when subjected to a load equal to the breaking strength of the unit's towline, S_{mbs} . The strength analysis shall be made for the most unfavourable direction of the towline.

306 Towing fastening devices, including fairleads, and their supporting structures shall be designed for a load equal to the minimum breaking strength of the weakest link in the unit's towing bridle and/or towing pennants, S_{mbs} . Strength analyses shall be made for the most unfavourable direction of the towline pull, i.e. angle of attack to device or structure. The nominal equivalent stress, σ_e , in the towing devices and their supporting structures shall not exceed $0.9 \sigma_f$ and $0.8 \sigma_f$, respectively.

Q. Tension Measuring Equipment

Q 100 General

101 Moored flotation units shall be equipped with a calibrated system for measuring mooring line tensions. The line tensions shall be continuously displayed for each mooring line. A recorded of the line tension for the last 24 hours shall be logged with a sampling interval of 1 s.

102 Winches and windlasses shall be equipped with two load cells. The accuracy of the load measurement shall be verified against a certified reference. The accuracy shall be within $\pm 5\%$

103 Units with thruster assistance shall have monitoring, simulation and logging systems which comply with Ch.2 Sec.3 D800, D1000 and D1100.

104 For tension measurement equipment the instrumentation shall comply with relevant standards such as DNV-OS-D202 in addition to requirements in Sec.3 D800.

105 Measuring ranges shall be between 0 to 70% of MBL.

Guidance note:

For special applications e.g. loading buoys this can be replaced by angle measurements during installation to verify the pretension, when continuous monitoring of anchor line tensions is not required.

Note that the use angle measurement instead of tension measurement poses a problem for polyester mooring where the line lengths will change with loading condition.

Other mooring system such as submerged turret systems (buoys docked in a cone in a ship's hull) tension measuring can be carried out by calculations. This requires that the position of the anchors and anchor line lengths are known within acceptable tolerances, and the unit's position is known and continuously monitored.

---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

R. Mooring Line Buoyancy Elements

R 100 General

101 The function of a mooring line buoyancy element (MLBE) is to improve configuration of the mooring line. Loss of MLBE shall not cause mooring line failure ref. Ch.2 Sec.2 B601. If loss occurs, buoy shall be replaced within short time.

102 Structural strength of MLBE shall be in accordance with DNV-OS-C101 “Design of Offshore steel structures, General (LRFD method)”.

103 The MLBE shall be able to withstand the worst combination of partial pressure and loads from mooring line. The MLBE shall be checked to withstand both ALS (line broken) and ULS condition. The MLBE shall be checked for excessive yielding and buckling. The mooring loads shall be calculated according to Ch.2 Sec.2 D401.

104 If MLBE is consisting of several chambers, calculations shall be carried out to see that the MLBE have enough buoyancy when one chamber is flooded.

Guidance note:

If MLBE is consisting of one chamber only, the maximum utilisation ratio shall not exceed 85% of permissible stress and all welds securing water tightness of the MLBE shall be considered special structure.

Pressure test connections /nozzles are considered as weak points. Long weld neck type is recommended to decrease probability of failure at these points.

---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

R 200 Permanent mooring

201 If MLBE is positioned in same location for more than 5 years fatigue calculations shall be carried out by use of site specific environmental data. Fatigue calculations shall be carried out in accordance with DNV-RP-C203, “Fatigue design of offshore steel structures”.

202 If no corrosion protection is provided for, corrosion allowance in accordance with Ch.2 Sec2 E204 shall be applied to the structure.

R 300 Materials for MLBE

301 Plate material grade shall be chosen based on principles of DNV-OS-C101, Ch.1 Sec.4.

The structural category shall be taken as primary. The NDE shall be concentrated on welds were cracks can cause loss of water tightness. The pad eye and load bearing parts shall be inspected according to inspection category 1.

302 Fabrication and testing shall be according to DNV-OS-C401 “Fabrication and testing of offshore structures”.

303 Forged and cast material for MLBE shall be in accordance with DNV-OS-B101 or equivalent.

R 400 Design of elements between mooring line and MLBE

401 Connection elements between the mooring line and the MLBE shall be in accordance with requirements of Ch.2 Sec.4 H.

402 The mooring line shall be designed in such a way that rotation of the mooring line will not cause rotation in neither MLBE nor connection elements.

403 The design of the connection elements shall ensure that out of plane bending due to friction between the various elements are taken into account in the design.

SECTION 5 TESTS

A. Testing of Mooring Chain and Accessories

A 100 General

101 All chain and accessories, except anchor shackles for mobile mooring which are not of R-quality, shall be tested according to requirements given in DNV-OS-E302.

102 Anchor shackles for or mobile mooring which are not of R-quality shall be tested according to requirements given in DNV-OS-E302 with the following exceptions:

- break load test may be omitted
- proof load test to 50% of MBL
- mechanical testing on test coupons is accepted, provided that the results are representative.

B. Test of Steel Wire Ropes

B 100 Tests of finished wire ropes

101 Steel wire ropes shall be tested according to requirements given in DNV-OS-E304.

C. Test of Windlass and Winch and Chain Stoppers

C 100 Tests of windlass and winch

101 Before assembly the following parts shall be pressure tested:

- housings with covers for hydraulic motors and pumps
- hydraulic pipes
- valves and fittings
- pressure vessels.

The tests shall be carried out in accordance with relevant parts of DNV-OS-D101.

102 After completion, at least one windlass or winch of a delivery to one unit shall be shop tested. Testing shall be performed according to Table C1.

103 After installation onboard, functional tests of the windlasses/winches are to be carried out. The tests are to demonstrate that the windlass with brakes etc. functions satisfactorily. For windlasses dedicated for emergency mooring the mean speed on the chain cable when hoisting the anchor and cable is not to be less than 9 m/minute and is to be measured over two shots (55 m) of chain cable during the trial. The trial should be commenced with 3 shots (82.5 m) of chain cable fully submerged. Where the depth of water in trial areas is inadequate, consideration will be given to acceptance of equivalent simulated conditions. The hoisting speed for windlasses intended for position mooring shall be according to design ref. Table C1.

Table C1 Test requirements						
Equipment	Test type	Shop Test		Commissioning	Sea Trial	Supplementary documentation.
		Component	Equipment			
Cable Lifter Unit	Static Braking. 50% of MBL applied to one brake at a time. (2 tests)		X**			FEM-analyses Calculations
Transmission	Function		X			
	Stalling		X**			Calculations
Load	Calibration	X				Calculations/Data sheet

Hydraulic Power Unit	Pressure		X			Calculations/Data sheets
	Function		X	X*		
Control system	Function		X			Data sheets Interfaces including field equipment may be simulated
Mooring System	Function			X		
	Stalling			X**		Calculations
	Pulling speed				X**	
	Haul in / pay out				X**	
	Emergency rel.				X**	
	Dynamic brake				X**	
X* = verification X** = one unit only						

104 For windlasses or winches designed for long term mooring systems where deviations from requirements in Sec.4 K500. are accepted, deviations in the test requirements given in 103 can be accepted.

C 200 Test of chain stopper

After completion the chain stoppers shall be function tested.

D. Test of Manual and Automatic Remote Thruster Systems

D 100 General

101 Tests of thrusters assisted mooring shall be carried out in a realistic mooring situation.

102 All control, monitoring, alarm and simulation functions of thruster control system shall be tested.

103 In addition to 102, tests of simulated failures shall be carried out to verify redundant system (if required) in thruster and power installations. Alternative means of demonstrating these functions can be accepted.

E. Testing of Synthetic Fibre Ropes

E 100 General

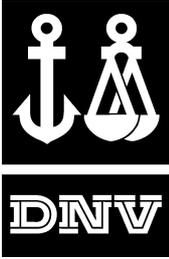
101 It is the rope manufacturer's responsibility to take sufficient number of samples of the completed fibre rope in order to complete the necessary test to document the fibre rope properties. Requirements regarding testing are given in DNV-OS-E303.

The change in length testing of the fibre rope should be defined based on the actual requirements of the mooring design such that accurate ULS and FLS may be determined.

F. Testing of Mooring Line Buoyancy Element

F 100 General

101 The tank shall be tested for tightness according to DNV-OS-C401, Ch.2 Sec.4 B: Testing of Tightness.



CHAPTER 3

CERTIFICATION AND CLASSIFICATION

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SECTION 1 CERTIFICATION AND CLASSIFICATION

A. General

A 100 Introduction

101 As well as representing DNV's recommendations of safe engineering practice for general use by the offshore industry, the offshore standards also provide the technical basis for DNV classification, certification and verification services.

102 A complete description of principles, procedures, applicable class notations and technical basis for offshore classification is given by the DNV offshore service specifications documents for classification, see Table A1.

Table A1 DNV offshore service specifications	
<i>No.</i>	<i>Title</i>
DNV-OSS-101	Rules for Classification of Offshore Drilling and Support Units
DNV-OSS-102	Rules for Classification of Floating Production, Storage and Loading Units

103 Mooring aspects subject to classification covered by this standard include:

- temporary mooring
- towing arrangements
- mobile mooring
- long term mooring.

104 For the purpose of temporary mooring the unit shall be equipped with at least two of each of the following items:

- anchors
- chain cables
- windlass (one winch may contain two cable lifters)
- chain stoppers or static brakes
- separate spaces in the chain lockers.

Details regarding structural arrangements are given in Ch.2 Sec.4 O. Specification of equipment is given in Sec.2.

B. Main Class for Offshore Units (1A1)

B 100 General

101 Depending on type of unit, the main class (**1A1**) for offshore units covers requirements for:

- temporary mooring
- towing.

102 For units with the additional class notation **POSMOOR**, the requirements for temporary mooring are normally covered.

103 For units with the additional class notations **DYNPOS-AUTS**, **DYNPOS-AUT**, the requirements for temporary mooring shall be complied with.

104 For units with the additional class notations **DYNPOS-AUTR**, **DYNPOS-AUTRO**, temporary mooring arrangement is not required as condition for classification.

105 If required by flag administrations, DNV can perform certification of the complete mooring equipment according to the **POSMOOR** notation or the relevant national regulations.

106 Ship-shaped units shall have an arrangement for temporary mooring complying with the Rules for Classification of Ships Pt.3 Ch.3 Sec.3.

107 For floating production and/or storage units with main class 1A1, the additional class notation **POSMOOR** is mandatory. The **POSMOOR** class notation is optional for mobile offshore units.

108 Equipment for drilling barges will be considered in each case.

109 Column-stabilised units shall have an arrangement for temporary mooring complying with Sec.2 A, except for units with the additional class notions **DYNPOS-AUTR** or **DYNPOS-AUTRO**, see 104.

- 110** Self-elevating, tension-leg and deep-draught units are not required to have temporary mooring.
- 111** Column stabilised units shall have arrangement and devices for towing complying with Ch.2 Sec.4 P.
- 112** Ship-shaped units with propulsion shall have arrangement and devices for towing complying with DNV Rules for Classification of Ships Pt.3 Ch.3 Sec.5 C.
- 113** Ship shaped production and storage units, with or without propulsion, shall have arrangement and devices for towing complying with DNV Rules for Classification of Ships Pt.5 Ch.3 Sec.2 C500.
- 114** When a unit is equipped with thruster assistance, the thrusters and thruster systems shall comply with Ch.2 Sec.3.

B 200 Documentation requirements

201 Documentation requirements shall be in accordance with the NPS DocReq (DNV Nauticus Production System for documentation requirements) and DNV-RP-A201, See Appendix A.

C. Main Class for Offshore Installations (OI)

C 100 General

- 101** Main class **OI** does not have requirements for temporary mooring.
- 102** For installations with main class **OI**, the additional class notation **POSMOOR** is mandatory.
- 103** Main class **OI** does not have requirements to a permanent towing arrangement. Towing operations are subject to acceptance by a marine warranty surveyor on a case to case basis.

D. Class Notation POSMOOR

D 100 General

- 101** Units with mooring system and equipment complying with this standard may be assigned the class notation **POSMOOR** or **POSMOOR V**.
- 102** The additional letter **V** refers to a mooring system, which is designed for positioning of a unit in vicinity of other structures.

Guidance note:

For column-stabilised units with conventional mooring systems, the class notation **POSMOOR V** applies when the distance between the unit and other structures is less than 300 m. The safety factors of the anchor lines are dependant of the collision hazard and consequences of failure, see Ch.2 Sec.2 D.

For units with an unconventional anchoring system and for all types of moored ship-shape units, the limiting distance between the unit and other structures to avoid collision hazard is given in Ch.2 Sec.2 D500.

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- 103** If the unit's mooring system is designed for thruster assistance, the system notation letters **TA** or **ATA** can be added to the **POSMOOR** notation.

TA The unit is provided with thruster assisted mooring system which is dependent on a manual remote thrust control system

ATA The unit is provided with thruster assisted mooring system which is dependent on an automatic remote thrust control system.

Guidance note:

Classification according to **TA** and **ATA** does not imply specific requirements regarding number of thrusters or capacity of these. The effect of thrusters will be determined and incorporated in the mooring analysis.

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D 200 Documentation required for the POSMOOR class notation - Mobile offshore units

201 The **POSMOOR** class notation shall prove that the unit has a mooring system which is documented to be able to operate safely within a range of water depths and environmental conditions according to the requirements in Ch.2 Sec.1 and Sec.2. DNV will not require new mooring analyses carried out as long as the unit is operating within the limits which form the basis for the approval.

202 To be assigned the **POSMOOR** class notation a mooring analysis shall be submitted, which shall cover a range of water depths for given environmental conditions. Typically three water depths shall be included. Both the water depths and the environmental conditions are to be decided by the operator. The analysis shall cover both survival (Consequence Class 1) and operation conditions (Consequence Class 2). The documentation shall include the following:

- Detailed description of the mooring system with mooring line type, quality, diameter, total length and minimum breaking capacity
- Anchor type and weight
- Mooring pattern and line length from fairlead to anchor for each water depth
- Pretension and/or /horizontal distance between fairlead and anchor for each water depth, both for survival and operation condition
- The environmental condition chosen for survival shall in principle represent a 100 year return period. For operation condition the environmental condition shall represent the condition when riser or gangway is connected
- The analysis shall include both ULS (intact system) and ALS (single failure)
- FLS (fatigue) shall be documented for fairleads and winch/windlass foundation
- For units with the additional class notation **TA** or **ATA** the thruster capacity, and how this capacity is utilized in the analyses, shall be documented.

203 Mooring lines, windlasses/winch and fairleads shall be certified by DNV

D 300 Requirements regarding maintaining the POSMOOR class notation in service

301 Site specific mooring analysis shall be submitted to DNV if the unit shall operate on a location where one or several of the following items is not according to the documentation submitted when the **POSMOOR** notation was granted:

- Water depth outside the original range
- Environmental condition is more severe
- Different mooring pattern and pretension
- New inserts in the mooring system and or change in mooring line length
- Introduction of MLBE or clump weights
- New inserts in the mooring system such as chain, steel wire rope and fibre ropes shall be certified by DNV according to DNV-OS-E302, DNV-OS-E304 and DNV-OS-E303 respectively. The certificates shall be submitted together with the mooring analysis
- Wind and current coefficients, RAOs and wave drift coefficients to be updated if the unit has gone through a major reconstruction.

D 400 Documentation required for the POSMOOR class notation - Long Term Mooring

401 The **POSMOOR** class notation shall prove that the unit has a mooring system which is documented to be able to operate safely at a specific location.

402 The mooring system shall be designed according to the technical requirements given in this standard and the mooring equipment shall be certified by DNV according to requirements given in Sec.2.

The design of the mooring system shall include ULS (intact system), ALS (single failure) and FLS (fatigue). FLS shall be included for fairleads and winch/windlass foundation.

The environmental condition chosen for survival shall in principle represent a 100-year return period. For the operational condition, the environmental condition shall represent a condition when a riser or a gangway is connected. If mooring forces are transmitted from an off-loading vessel, then such operational conditions shall also be considered.

403 Alternatively the mooring system can be designed according to other recognized standards, see D600. However, the mooring equipment shall be certified by DNV according to requirements given in Sec.2 B.

D 500 Scope and application

501 Deviations from the requirements of this standard are only acceptable upon agreement with DNV.

D 600 Use of alternative recognised standards

601 For mobile offshore units like for instance drilling and accommodation units, **POSMOOR** notations shall only be granted if the mooring system is designed and components certified according to this standard.

602 For floating production and/or storage units and installations, **POSMOOR** notations may be based on that the technical part of this standard is replaced by for instance API RP2SK or ISO 19901-7 subject to agreement between DNV and client. Regardless of the technical standard applied in designing of the mooring system all the mooring equipment shall be certified by DNV according to requirements given in Sec.2.

Note that API RP2SK is not accepted by DNV as a recognised standard regarding requirements to design and installation of fluke anchors.

603 A note will be included in the Appendix to the class certificate for floating production units or installations with **POSMOOR** class notations, where the mooring system is designed according to another recognised standard.

D 700 Basic assumptions

701 For mobile offshore units it is the intention to prove that the unit has a mooring system which is documented to be able to operate safely within a range of water depths and environmental conditions, see D200.

702 For long term moored units, site specific environmental data shall be applied.

703 The classification is based on the condition that an up to date anchor line record is kept available for presentation to DNV's surveyor upon request.

D 800 Documentation requirements

801 Documentation requirements shall be in accordance with the NPS DocReq (DNV Nauticus Production System for documentation requirements) and DNV-RP-A201.

D 900 Survey of towing and mooring equipment

901 Requirements regarding survey of towing, temporary and position mooring equipment for mobile offshore units are given in DNV-OSS-101 Ch.3 Sec.4 L.

902 Requirements regarding survey of towing, temporary and position mooring equipment of floating production and/or storage units are given in DNV-OSS-102 Ch.3 Sec.4 L and Ch.3 Sec.6.

SECTION 2 EQUIPMENT SELECTION AND CERTIFICATION

A. Specification of Equipment

A 100 General

101 Equipment for temporary mooring shall in general be selected in accordance with the requirements given in Table A1.

A 200 Equipment number

201 The equipment number is given by the formula:

$$EN = \Delta^{2/3} + A$$

Δ = Moulded displacement (t) in salt waters (density 1.025 t/m³) on maximum transit draught

A = projected area in m² of all the wind exposed surfaces above the unit's light transit draught, in an upright condition, taken as the projection of the unit in a plane normal to the wind direction. The most unfavourable orientation relative to the wind shall be used taking into account the arrangement of the mooring system.

202 The shielding effect of members located behind each other shall normally not be taken into account. However, upon special consideration a reduced exposed area of the leeward members may be accepted. The shape of the wind-exposed members shall normally not be taken into account.

203 The solidification effect shall normally not be taken into account.

204 To each group of equipment numbers, as they appear in Table A1, there is associated an equipment letter which will be entered in the Appendix to the classification certificate. If the unit is equipped with heavier equipment than required by classification, the letter, which corresponds to the lowermost satisfied group of equipment numbers, will replace the class requirement letter.

Table A1 Equipment table									
<i>Equipment number Exceeding – not exceeding</i>	<i>Equipment letter</i>	<i>Stockless anchors</i>		<i>Chain cables</i>					
		<i>Number</i>	<i>Mass per anchor (kg)</i>	<i>Total length (m)²</i>	<i>Diameter and grade</i>				
					<i>NV R3 or K3¹⁾</i>	<i>NV R3S</i>	<i>NV R4</i>	<i>NV R4S</i>	<i>NV R5</i>
720 – 780	S	2	2 280	467.5	36				
780 – 840	T	2	2 460	467.5	38				
840 – 910	U	2	2 640	467.5	40				
910 – 980	V	2	2 850	495	42				
980 – 1 060	W	2	3 060	495	44				
1 060 – 1 140	X	2	3 300	495	46				
1 140 – 1 220	Y	2	3 540	522.5	46				
1 220 – 1 300	Z	2	3 780	522.5	48				
1 300 – 1 390	A	2	4 050	522.5	50				
1 390 – 1 480	B	2	4 320	550	50				
1 480 – 1 570	C	2	4 590	550	52				
1 570 – 1 670	D	2	4 890	550	54				
1 670 – 1 790	E	2	5 250	577.5	56	54	50		
1 790 – 1 930	F	2	5 610	577.5	58	54	52		
1 930 – 2 080	G	2	6 000	577.5	60	56	54		
2 080 – 2 230	H	2	6 450	605	62	58	54		
2 230 – 2 380	I	2	6 900	605	64	60	56		
2 380 – 2 530	J	2	7 350	605	66	62	58		
2 530 – 2 700	K	2	7 800	632.5	68	64	60		
2 700 – 2 870	L	2	8 300	632.5	70	66	62		
2 870 – 3 040	M	2	8 700	632.5	73	68	64		
3 040 – 3 210	N	2	9 300	660	76	70	66	63	61
3 210 – 3 400	O	2	9 900	660	78	73	68	65	63
3 400 – 3 600	P	2	10 500	660	78	73	68	65	63
3 600 – 3 800	Q	2	11 100	687.5	81	76	70	67	65
3 800 – 4 000	R	2	11 700	687.5	84	78	73	69	67
4 000 – 4 200	S	2	12 300	687.5	87	81	76	72	70

Equipment number Exceeding – not exceeding	Equipment letter	Stockless anchors		Chain cables					
		Number	Mass per anchor (kg)	Total length (m) ²⁾	Diameter and grade				
					NV R3 or K3 ¹⁾	NV R3S	NV R4	NV R4S	NV R5
4 200 – 4 400	T	2	12 900	715	87	81	76	72	70
4 400 – 4 600	U	2	13 500	715	90	84	78	74	72
4 600 – 4 800	V	2	14 100	715	92	87	81	77	75
4 800 – 5 000	W	2	14 700	742.5	95	90	84	80	78
5 000 – 5 200	X	2	15 400	742.5	97	90	84	80	78
5 200 – 5 500	Y	2	16 100	742.5	97	90	84	80	78
5 500 – 5 800	Z	2	16 900	742.5	100	92	87	82	80
5 800 – 6 100	A*	2	17 800	742.5	102	95	90	85	83
6 100 – 6 500	B*	2	18 800	742.5	107	100	95	90	88
6 500 – 6 900	C*	2	20 000	770	111	105	97	92	89
6 900 – 7 400	D*	2	21 500	770	114	107	100	95	92
7 400 – 7 900	E*	2	23 000	770	117	111	102	97	94
7 900 – 8 400	F*	2	24 500	770	122	114	105	99	96
8 400 – 8 900	G*	2	26 000	770	127	120	111	105	102
8 900 – 9 400	H*	2	27 500	770	132	124	114	109	105
9 400 – 10 000	I*	2	29 000	770	132	124	114	109	105
10 000 – 10 700	J*	2	31 000	770	137	130	120	114	110
10 700 – 11 500	K*	2	33 000	770	142	132	124	117	114
11 500 – 12 400	L*	2	35 500	770	147	137	127	120	117
12 400 – 13 400	M*	2	38 500	770	152	142	130	123	119
13 400 – 14 600	N*	2	42 000	770	157	147	137	129	125
14 600 – 16 000	O*	2	46 000	770	162	152	142	134	130

1) K3 can be applied for units where the temporary mooring is not a part of the position mooring system such as DP units
2) The total length of chain cable required shall be equally divided between the two anchors.

B. Certification of Equipment

B 100 General

101 Equipment shall be certified consistent with its functions and importance for safety. The principles of categorisation of equipment subject to certification are given in the respective offshore service specifications, see Table B1.

B 200 Categorisation of equipment

201 Categorisation of equipment that is normally installed as part of the areas covered by this offshore standard is given in Table B1.

Component	Certificate
Anchor	NV
Windlass or winch	NV
Fairlead	NV
Anchor chain cable and accessories	NV
Steel wire rope	NV
Fibre rope segments and termination hardware	NV
Chain stopper	NV
Towing equipment	NV
Mooring Line Buoyancy Element (MLBE)	NV

B 300 Certification of material

301 For the items given in Table B2 the following material certificates are required:

Materials for:	
Anchor	NV
Mooring chain and accessories	NV

Steel wire Ropes	NV
Steel wire rope end attachment	NV
Fibre rope segments and termination hardware	NV
Windlass cable lifter	NV
Winch drum and drum flanges	NV
Windlass/winch framework	NV
Shafts for cable lifter and/or drum	NV
Couplings	NV
Gear shafts and gear wheels	NV
Brake components (pawl wheel/stopper)	NV
Chain stopper	NV
Mooring Line Buoyancy Element (MLBE)	NV
Fairlead (cable lifter/sheaves, shafts, housing and support)	NV
Towing equipment (Shackles, flounder plate, steel wire rope and chain)	NV

C. Classification Requirements for Anchors

C 100 Fluke anchors for temporary moorings

101 Anchor types relevant for classification are:

- ordinary stockless anchor
- ordinary stocked anchor
- HHP (High Holding Power) anchor.

102 The mass of ordinary stockless anchors shall not be less than given in A. The mass of individual anchors may vary by $\pm 7\%$ of the table value, provided that the total mass of anchors is not less than would have been required for anchors of equal mass.

103 The mass of the head shall not to be less than 60% of the table value.

104 For anchors approved as HHP anchors, the mass shall not be less than 75% of the requirements given in A. In such cases the letter r will be added to the equipment letter.

105 The total mass of the anchors corresponding to a certain equipment number may be divided between 3 or 4 instead of 2 anchors. The mass of one anchor will then be 1/3 or 1/4 respectively of the total mass required.

106 If steel wire rope is accepted instead of stud link chain cable, the mass of the anchors shall be at least 25% in excess of the requirement given in Table A1 and E203.

107 Ordinary anchors and H.H.P. anchors are to be subjected to proof testing in a machine specially approved for this purpose.

108 The proof test loads are to be as given in Table C1 dependent on the mass of equivalent anchor, defined as follows:

- total mass of ordinary stockless anchors
- mass of ordinary stocked anchors excluding the stock
- 4/3 of the total mass of H.H.P. anchors.

For intermediate values of mass the test load is to be determined by linear interpolation.

<i>Mass of anchor (kg)</i>	<i>Proof test load (kN)</i>	<i>Mass of anchor (kg)</i>	<i>Proof test load (kN)</i>	<i>Mass of anchor (kg)</i>	<i>Proof test load (kN)</i>
2 200	376	5 700	713	13 500	1 180
2 300	388	5 800	721	14 000	1 210
2 400	401	5 900	728	14 500	1 230
2 500	414	6 000	735	15 000	1 260
2 600	427	6 100	740	15 500	1 270
2 700	438	6 200	747	16 000	1 300
2 800	450	6 300	754	16 500	1 330
2 900	462	6 400	760	17 000	1 360
3 000	474	6 500	767	17 500	1 390
3 100	484	6 600	773	18 000	1 410
3 200	495	6 700	779	18 500	1 440
3 300	506	6 800	786	19 000	1 470
3 400	517	6 900	795	19 500	1 490
3 500	528	7 000	804	20 000	1 520
3 600	537	7 200	818	21 000	1 570
3 700	547	7 400	832	22 000	1 620
3 800	557	7 600	845	23 000	1 670
3 900	567	7 800	861	24 000	1 720
4 000	577	8 000	877	25 000	1 770
4 100	586	8 200	892	26 000	1 800
4 200	595	8 400	908	27 000	1 850
4 300	604	8 600	922	28 000	1 900
4 400	613	8 800	936	29 000	1 940
4 500	622	9 000	949	30 000	1 990
4 600	631	9 200	961	31 000	2 030
4 700	638	9 400	975	32 000	2 070
4 800	645	9 600	987	34 000	2 160
4 900	653	9 800	999	36 000	2 250
5 000	661	10 000	1 010	38 000	2 330
5 100	669	10 500	1 040	40 000	2 410
5 200	677	11 000	1 070	42 000	2 490
5 300	685	11 500	1 090	44 000	2 570
5 400	691	12 000	1 110	46 000	2 650
5 500	699	12 500	1 130	48 000	2 730
5 600	706	13 000	1 160		

C 200 Additional requirements for HHP (High Holding Power) anchors for temporary mooring

201 Anchors shall be designed for effective hold irrespective of the angle or position at which they first settle on the sea bed after dropping from the anchor's stowage. In case of doubt a demonstration of these abilities may be required.

202 The design approval of HHP anchors is normally given as a type approval, and the anchors are listed in the Register of Approved Manufacturers or Register of Type Approved Products.

203 HHP anchors for which approval is sought shall be tested on sea bed to show that they have a holding power per unit of mass at least twice that of an ordinary stockless anchor.

204 If approval is sought for a range of anchor sizes, at least two sizes shall be tested. The mass of the larger anchor to be tested shall not be less than 1/10 of that of the largest anchor for which approval is sought. The smaller of the two anchors to be tested shall have a mass not less than 1/10 of that of the larger.

205 Each test shall comprise a comparison between at least two anchors, one ordinary stockless anchor and one HHP anchor. The mass of the anchors shall be as equal as possible.

206 The tests shall be conducted on at least 3 different types of bottom, which normally shall be: soft mud or silt, sand or gravel, and hard clay or similar compacted material.

207 The tests shall normally be carried out by means of a tug. The pull shall be measured by dynamometer or determined from recently verified curves of the tug's bollard pull as function of propeller r.p.m. Provided the pull is measured by verified curves of the tug's bollard pull the minimum water depth for the tests shall be 20 m.

208 The diameter of the chain cables connected to the anchors shall be as required for the equipment letter in question. During the test the length of the chain cable on each anchor shall be sufficient to obtain an approximately horizontal pull on the anchor. Normally, a horizontal distance between anchor and tug equal to 10 times the water depth will be sufficient.

C 300 Identification marking for anchors for temporary and mobile mooring

301 The following marks shall be stamped on one side of the anchor:

- a) mass of anchor (excluding possible stock)
- b) HHP, when approved as high holding power anchor
- c) certificate no.
- d) date of test
- e) DNV's stamp.

C 400 Requirements for anchors used in mobile mooring

401 Proof testing of anchor strength is only applicable for ordinary fluke anchors.

402 These anchors are to be subjected to proof testing in a machine specially designed for this purpose or the structural strength of the anchor has to be documented by calculations, see 405.

403 The proof load of anchors to be used for mobile mooring is not to be less than 50% of the minimum breaking strength of the anchor line.

404 The anchors are to withstand the specified proof load without showing signs of defects.

405 Proof load testing of anchors can be omitted if the capacity can be documented by calculations, ref. Ch.2 Sec.4, B100.

D. Classification Requirements for anchors used in long term mooring system

D 100 General

101 Anchors to be used in long term mooring system shall be designed according to requirements given in Ch.2 Sec.4. Proof load testing is not required.

102 The Anchor design and the specified anchor installation tension shall be verified and subject to independent analysis/assessment before approval.

E. Classification Requirements for Mooring Chain

E 100 General

101 Mooring chain and accessories shall be made by manufacturers approved by DNV for the pertinent type of anchor chain, size and method of manufacture.

102 Chain links, shackles and accessories, except anchor shackles for mobile mooring, to be installed on DNV classed units shall be designed, manufactured and tested according to DNV-OS-E302. Tailor made connection elements shall be approved by DNV with respect to structural strength and fatigue.

103 The anchor shackles for mobile mooring of other qualities than R quality shall be proof load tested together with the anchor. NDT shall be according to DNV-OS-E302. Shackle shall be included in the anchor certificate.

E 200 Temporary mooring

201 The diameter and total length of stud link chain shall not be less than given in Table A1.

202 Upon special consideration by DNV steel wire ropes and an increased mass of anchor may substitute the main part of the chain. A minimum length of chain towards the anchor is required. The length and strength of the steel wire rope, chain and the mass of anchors shall be as given in F201 and C106.

203 If the total mass of anchors is divided between 3 or 4 instead of 2 anchor lines instead of 2, the reduced diameter of the anchor chain shall be based on a mass corresponding to 1/3 or 1/4 respectively of the total mass of the anchors required within Table A1 for the relevant equipment number of the unit.

204 The total length of such anchor chain shall be at least 50% or 100% respectively in excess of the requirement given in Table A1 for the corresponding reduced diameter of the chain.

E 300 Position mooring

301 The chain cable anchor lines used in the position mooring system can be of stud or studless type. Chain grades shall be NV R3, NV R3S, NV R4 or NV R5. The chain cable can be substituted partly or completely by steel wire rope or by synthetic fibre rope.

Guidance note:

For units with dynamic positioning system (DYNPOS) without a position mooring system installed the chain grade K3 may be accepted for temporary mooring.

---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

302 All chain and accessories shall meet the requirements for materials, design, manufacture and testing in DNV-OS-E302.

303 The materials for mooring chain of grades NV R3, NV R3S, NV R4 and NV R5 shall be delivered with DNV material certificates and the chain cable shall be certified by DNV according to DNV-OS-E302.

F. Classification Requirements for Steel Wire Ropes

F 100 General

101 Steel wire ropes shall be manufactured by works approved by DNV.

F 200 Temporary mooring

201 If steel wire rope is accepted instead of stud link chain cable.

The following shall be fulfilled:

- The steel wire rope shall have at least the same breaking strength as the chain.
- A length of chain cable shall be fitted between the anchor and the steel wire rope. The length shall be taken as the smaller of 12.5 m and the distance between the anchor in stowed position and the winch.
- The anchor weight shall be increased by 25%.
- The length of the steel wire rope shall at least be 50% above the value for the chain cable given in Table A1.

202 Technical requirements for steel wire ropes are given in Ch.2 Sec.4 I and DNV-OS-E304.

F 300 Position mooring

301 Requirements concerning materials, manufacture and testing of steel wire ropes are given in DNV-OS-E304. Steel wire ropes shall be certified by DNV according to DNV-OS-E304.

302 If steel wire rope is used in line with fibre ropes then rotation on the steel wire rope shall be duly considered. Rotation can be caused by variation in torque response to tension between the two types of ropes.

G. Classification Requirements for Synthetic Fibre Ropes

G 100 General

101 Fibre ropes used in positioning systems shall be certified by DNV according to DNV-OS-E303.

102 Detail requirements are given in DNV-OS-E303.

It shall be ensured that the design loads submitted for design review of mooring analysis are commensurate for those used or determined in the testing of response to maximum tension and cyclic loading for determination of ULS and FLS of the whole mooring line including hardware.

G 200 In-service condition assessment

201 It is a requirement of this standard that the condition of the fibre-rope assemblies shall be assessed during service, to ensure sufficient margin towards relevant failure modes. Reference is made to Ch.2 Sec.2 concerning stress rupture and creep failure.

202 The in-service condition assessment scheme shall state how this is done in practice.

203 Detailed requirements to In-service condition assessment programmes can be found in DNV-OS-E303.

H. Classification Requirements for Windlass, Winches and Chain Stoppers

H 100 General

101 Windlasses, winches and chain stoppers shall be certified by DNV.

102 Detailed requirements regarding design, material and testing are given in Ch.2 Sec.4 K and Ch.2 Sec.5 C.

103 Requirements for structural strength of supporting structure is given in Ch.2 Sec.4 O.

I. Classification Requirements for Fairleads

I 100 General

- 101** Fairleads shall be certified by DNV.
- 102** Requirements regarding design and material are given in Ch.2 Sec.4 M.
- 103** Requirements for structural strength of supporting structure is given in Ch.2 Sec.4 O.

J. Classification Requirements for Mooring Line Buoyancy Element

J 100 General

- 101** Mooring Line Buoyancy Elements shall be certified by DNV.
- 102** Requirements regarding design and material are given in Ch.2 Sec.4 R.

K. Classification Requirements for Arrangement and Devices for Towing

K 100 General

- 101** Bridle(s) or pennants for towing shall have clear way from the fastening devices to the fairlead.
- 102** There shall be an arrangement for retrieval of the unit's towline in case the connection to the towing vessel should break.
- 103** In addition to the permanent towing arrangement, there shall be the possibility of using an emergency arrangement of equivalent strength. Application of the unit's mooring arrangement may be considered for this purpose.
- 104** The design load for the towing arrangement will be stated in the unit's Appendix to the classification certificate.
- 105** Requirements regarding material and structural strength are given in Ch.2 Sec.4 P.
- 106** It will be stated in the Appendix to the class certificate that main towing arrangement is not installed since the column stabilised unit with class notation **DYNPOS AUTRO** will use the DP system during transit, ref. P106.
- 107** The reduction in the towing design load will be included in the Appendix to the class certificate when Column stabilised units with **DYNPOS AUTR** or **AUTRO** class notation are using the DP system in combination with the main towing arrangement, ref. P107.

L. Classification Requirements for Tension Measuring Equipment

L 100 General

- 101** Tension measuring equipment shall normally be installed on classed units.
- 102** Requirements regarding tension-measuring equipment are given in Ch.2 Sec.4 Q.

M. Classification Requirements for Thrusters and Thruster Systems

M 100 General

- 101** Manual and automatic installed thrusters and thruster systems shall comply with requirements in Ch.2 Sec.3 and the Rules for Classification of Ships Pt.6 Ch.7.

N. Survey during Installation

N 100 General

- 101** For floating production and/or storage units and CALM buoys a surveyor shall be present during installation of anchors and during hook-up and pre-tensioning of the mooring lines.

APPENDIX A REQUIRED DOCUMENTATION

A. Required Documentation

A 100 General Design documentation

101 The following general design documentation of the mooring system is required:

- a) number of lines
- b) type of line segments
- c) dimensions
- d) material specifications
- e) weight in air and seawater
- f) line length from fairlead to anchor point of individual segments
- g) additional line length kept onboard
- h) characteristic strength
- i) anchor pattern
- j) anchor type
- k) horizontal distance between fairleads and anchor point and/or initial pretensions
- l) position of buoyancy elements, and net buoyancy
- m) position of weight elements, and weight in air and seawater
- n) position and type of connection elements, such as Kenter shackles, D-shackles, and triplates
- o) windlass, winch and stopper design
- p) anchor design including anchor size, weight and material specifications.

A 200 Metocean data

201 Environmental conditions used as basis for the design shall be according to Ch.2 Sec.1:

- a) Combinations of significant wave heights and peak periods along the 100-year contour line for a specified location. Directionality may be considered if sufficient data exist to develop contour lines for from 0° to 360° with a maximum spacing of 30°.
- b) 1 hour mean wind speed with a return period of 100 year, and wind gust spectrum Directionality may be considered if sufficient data exist to develop wind speeds with 100 year return periods for directions from 0° to 360° with a maximum spacing of 30°.
- c) Surface and subsurface current speed with a return period of 10 years. Directionality may be considered if sufficient data exist to develop current speeds with 10 year return periods for directions from 0° to 360°, with a maximum spacing of 30°.
- d) Current profile.
- e) Water depths.
- f) Soil conditions.
- g) Marine growth, thickness and specific weight.
- h) Wave spectrum.
- i) Wave energy distribution: Long crested sea. Wind generated waves may be considered short crested described by a cosine to the power 4 wave directionality function.

A 300 Design Documentation - details

301 The design documentation shall include the following:

- a) Design Analyses, motion transfer functions and wavedrift coefficients.
- b) External environment: Calculation report: wind and current coefficients.
- c) Design analyses, ultimate, accidental and limit states.
- d) Test procedure for quay and sea trial.
- e) The accuracy of computer program applied for calculation of the unit's response shall be quantified by comparison with relevant model test results.

- f) The accuracy of the model test results applied in the design shall be quantified.
- g) Wind and current loads based on coefficients from wind tunnel tests, model basin tests or theoretical calculations according to recognised theories, see Ch.2 Sec.1.
- h) Transfer functions (RAOs) of motion in six degree of freedom.
- i) Wave drift force coefficients, see Ch.2 Sec.1 C400. Viscous effect shall be considered together with the current effect on the wave drift forces.
- j) Wave frequency motions for selected sea states, see Ch.2 Sec.1 B.
- k) Wind and wave induced low frequency motions, see Ch.2 Sec.2 B300.
- l) Mean offset caused by wind, current and waves.
- m) Mooring line tensions in ULS and ALS limit states, see Ch.2 Sec.2 B, C and D.
- n) Fatigue calculations of mooring line segments and accessories, see Ch.2 Sec.2 F.
- o) Mechanical component documentation for anchor chain.
- p) Mechanical component documentation for buoyancy elements.
- q) Mechanical component documentation for anchor joining shackle.
- r) Windlass or Winch:
- s) Windlass and winch lifting capacity, static and dynamic braking capacity, see Ch.2 Sec.4 K.
 - design criteria for anchor winch or windlass
 - assembly or arrangement drawing of winch or windlass
 - design analysis winch or windlass
 - non-destructive testing plan - winch or windlass
 - detail drawing of components for winch or windlass, such as break, clutch, frame, gear, hoisting device, shaft
 - structural strength calculation and of main components of windlass or winch such as cable lifter or drum, couplings, shafts, brakes, gears and frame bases.
- t) Design criteria - anchor.
- u) Detail drawings - anchor.
- v) Design analysis of anchors except for type approved drag anchors.
- w) Anchor resistance.
- x) Necessary installation tension for drag embedment anchors.
- y) Detail drawings and structural strength calculations of fairlead, see Ch.2 Sec.4 M.

302 Control systems

- a) Control and monitoring system documentation for anchoring and monitoring systems.
- b) Control and monitoring system documentation for main automatic dynamic positioning control system.
- c) Test procedure for quay and sea trial for main automatic dynamic positioning control system.
- d) Documentation for thruster assisted mooring control system.
- e) Control system functional description, test procedure at manufacturer, test procedure for quay and sea trial for thruster assisted mooring simulation system.
- f) Control and monitoring system documentation for position reference system.
- g) Control and monitoring system documentation for vertical reference system.
- h) Control and monitoring system documentation for vertical reference measurement system.
- i) Control system functional description and control and monitoring system documentation for thruster control mode selection system.
- j) Reliability and availability analysis for fuel oil system.
- k) Reliability and availability analysis for lubrication oil system.
- l) Reliability and availability analysis for seawater cooling arrangement.
- m) Reliability and availability analysis for fresh water cooling arrangement.

303 Additional documentation required if fibre ropes are used in mooring systems:

- a) User specification as detailed in DNV-OS-E303. It is the responsibility of the purchasing company to define the operating conditions to which the rope performance shall be engineered.
- b) Items of particular importance are:

- stress-rupture / creep-failure performance
- change-in-length performance
- torque and rotation behaviour with respect to connecting components.

304 Additional documentation required for thruster assisted mooring systems:

- a) System schematics for remote thrust control system.
- b) System schematics for automatic thrust control system.
- c) Power distribution schematics for thrust system.
- d) Test program for sea trials regarding thruster assistance.
- e) Net available thrust output showing which effects have been considered to derive the net thrust relative to nominal thrust output.

305 If the thruster assistance is subject to redundancy requirements, the redundancy is to be documented by one of the following methods:

- a) Failure mode and effect analysis (FMEA), covering all relevant sub-systems. Special attention should be taken in case emergency shut down systems are installed.
- b) A test program covering failure situations and thereby demonstrating redundancy. The test program has to be carried out during thruster assistance sea trials.

306 Additional documentation required for long term mooring:

- a) Fatigue calculation of mooring lines and connecting elements using site specific data.
- b) Line tensions with and without marine growth shall be considered.
- c) Corrosion allowance shall be included in design.
- d) When fluke anchors or plate anchors are used calculations of anchor resistance for ULS and ALS, see guidance in DNV-RP-E301 and DNV-RP-E302.