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Introduction

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

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

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 Please indicate if you are aware of any reason why this draft standard should not be published as a British Standard.

Submission of Comments

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Template for comments and secretariat observations

Date: xx/xx/20xx	Document: ISO/DIS xxxx
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1	2	(3)	4	5	(6)	7
MB	Clause No./ Subclause No./Annex (e.g. 3.1)	Paragraph/Figure/ Table/Note	Type of comment	Commend (justification for change) by the MB	Proposed change by the MB	Secretariat observations on each comment submitted
	3.1	Definition 1	ed	Definition is ambiguous and needs clarifying.	Amend to read '...so that the mains connector to which no connection...'	
	6.4	Paragraph 2	te	The use of the UV photometer as an alternative cannot be supported as serious problems have been encountered in its use in the UK.	Delete reference to UV photometer.	

PROJECT NUMBER: IEC 61400-3-2 ED1	
DATE OF CIRCULATION: 2021-10-15	CLOSING DATE FOR COMMENTS: 2022-01-07
SUPERSEDES DOCUMENTS: 88/788/RR	

IEC TC 88 : WIND ENERGY GENERATION SYSTEMS			
SECRETARIAT: Denmark		SECRETARY: Mrs Christine Weibøl Bertelsen	
OF INTEREST TO THE FOLLOWING COMMITTEES: TC 114		PROPOSED HORIZONTAL STANDARD: ☐ Other TC/SCs are requested to indicate their interest, if any, in this CD to the secretary.	
FUNCTIONS CONCERNED: ☐ EMC ☒ ENVIRONMENT ☒ QUALITY ASSURANCE ☒ SAFETY			

This document is still under study and subject to change. It should not be used for reference purposes.

Recipients of this document are invited to submit, with their comments, notification of any relevant patent rights of which they are aware and to provide supporting documentation.

TITLE:

Wind energy generation systems – Part 3-2: Design requirements for floating offshore wind turbines

NOTE FROM TC/SC OFFICERS:

In order to assist MT 3-2 when sorting and compiling the given comments on the CD document, it is of great importance that all comments given in the comments form refer to both clause and line numbers in the CD document.

CONTENTS

CONTENTS	2
FOREWORD	8
INTRODUCTION	10
1 Scope	11
2 Normative references	11
3 Terms and definitions	13
4 Symbols and abbreviated terms	22
4.1 Symbols and units	22
4.2 Abbreviations	24
5 Principal elements	25
5.1 General	25
5.2 Design methods	25
5.3 Safety level for FOWT	26
5.4 Safety classes for RNA	26
5.5 Quality assurance	27
5.6 Rotor–nacelle assembly markings	27
5.6 Support structure markings	27
6 External conditions – definition and assessment	27
6.1 General	27
6.2 Wind turbine classes	28
6.3 Definition of external conditions at a FOWT site	28
6.3.1 General	28
6.3.2 Wind conditions	29
6.3.3 Marine conditions	29
6.3.4 Electrical power network conditions	36
6.3.5 Other environmental conditions	36
6.4 Assessment of external conditions at a FOWT site	37
6.4.1 General	37
6.4.2 The metocean database	37
6.4.3 Assessment of wind conditions	38
6.4.4 Assessment of marine conditions	40
6.4.5 Assessment of other environmental conditions	44
6.4.6 Assessment of electrical network conditions	45
6.4.7 Assessment of soil conditions	45
7 Structural design	46
7.1 General	46
7.2 Design methodology	47
7.3 Loads	47
7.3.1 General	47
7.3.2 Gravitational and inertial loads	47
7.3.3 Aerodynamic loads	47
7.3.4 Actuation loads	47
7.3.5 Hydrodynamic loads	47
7.3.6 Sea/lake ice loads	48
7.3.7 Other loads	48

7.4	Design situations and load cases	49
7.4.1	General	49
7.4.2	Power production (DLC 1.1 to 1.6)	56
7.4.3	Power production plus occurrence of fault or loss of electrical network connection (DLC 2.1 – 2.6)	57
7.4.4	Start up (DLC 3.1 to 3.3)	60
7.4.5	Normal shutdown (DLC 4.1 to 4.3)	60
7.4.6	Emergency stop (DLC 5.1)	61
7.4.7	Parked (standstill or idling) (DLC 6.1 to 6.4)	61
7.4.8	Parked plus fault conditions (DLC 7.1 to 7.2)	63
7.4.9	Transport, assembly, maintenance and repair (DLC 8.1 to 8.4)	64
7.4.10	Redundancy check and damage stability (DLC F1.1 to F2.3)	67
7.5	Load and load effect calculations	68
7.5.1	General	68
7.5.2	Relevance of hydrodynamic loads	68
7.5.3	Calculation of hydrodynamic loads	68
7.5.4	Calculation of sea/lake ice loads	70
7.5.5	Overall damping assessment for support structure response evaluations	70
7.5.6	Simulation requirements	71
7.5.7	Other requirements	74
7.6	Ultimate limit state analysis	75
7.6.1	Method	75
7.6.2	Ultimate strength analysis	77
7.6.3	Fatigue failure	78
7.6.4	Special partial safety factors	79
7.6.5	Working stress design method	79
7.6.6	Serviceability analysis	80
8	Control system	80
9	Mechanical systems	82
10	Electrical system	82
11	Anchor design	83
12	Assembly, transport and installation	83
12.1	General	83
12.2	Planning	84
12.3	Environmental conditions	84
12.4	Documentation	84
12.5	Transport, receiving, handling and storage	84
13	Commissioning, operation and maintenance	84
13.1	General	84
13.2	Design requirements for safe operation, inspection and maintenance	85
13.3	Commissioning	86
13.3.1	General	86
13.3.2	Energization	86
13.3.3	Commissioning tests	86
13.3.4	Records	86
13.3.5	Post commissioning activities	86
13.4	Operator's instruction manual	87
13.4.1	General	87

13.4.2	Instructions for operations and maintenance record	87
13.4.3	Instructions for unscheduled automatic shutdown	87
13.4.4	Instructions for diminished reliability	88
13.4.5	Work procedures plan	88
13.4.6	Emergency procedures plan	88
13.5	Maintenance manual	89
14	Stationkeeping systems	89
14.1	General	89
14.2	Tendon systems	90
14.3	Synthetic mooring	90
14.4	Mooring accessories	90
14.5	Dynamic power cable	90
15	Floating stability	91
15.1	General	91
15.2	Intact static stability criteria	92
15.3	Quasi static evaluation	92
15.4	Dynamic response evaluation	93
15.5	Damage stability criteria	93
16	Materials	93
17	Marine support systems	94
17.1	General	94
17.2	Bilge system	94
17.3	Ballast system	94
Annex A (informative)	Key design parameters for a floating offshore wind turbine (FOWT)	95
A.1	Floating offshore wind turbine (FOWT) identifiers	95
A.1.1	General	95
A.1.2	Rotor nacelle assembly (machine) parameters	95
A.1.3	Support structure parameters	95
A.1.4	Wind conditions (based on a 10-min reference period and including wind farm wake effects where relevant)	96
A.1.5	Marine conditions (based on a 3-hour reference period where relevant)	97
A.1.6	Electrical network conditions at turbine	97
A.2	Other environmental conditions	98
A.3	Limiting conditions for transport, installation and maintenance	98
Annex B (informative)	Shallow water hydrodynamics and breaking waves	100
B.1	Selection of suitable wave theories	100
B.2	Modelling of irregular wave trains	101
B.3	Wave height distributions	101
B.3.1	General	101
B.3.2	The Goda model for maximum wave height	101
B.3.3	The Battjes and Groenendijk wave height distribution	104
B.3.4	The Forristall wave and crest height distributions	107
B.4	Breaking waves	109
B.5	Reference documents	112
Annex C (informative)	Guidance on calculation of hydrodynamic loads	113
C.1	General	113
C.2	Morison's equation	113

C.3	Diffraction and radiation theory	113
C.4	Slam loading	113
C.5	Vortex-induced vibrations and motions	114
C.6	Appurtenances and marine growth	114
C.7	Global analysis and fatigue analysis methods	115
C.8	Breaking wave loads	116
C.9	Air gap	116
Annex D (informative)	Floating offshore wind turbine (FOWT) anchor design	117
Annex E (informative)	Statistical extrapolation of operational metocean parameters for ultimate strength analysis	118
E.1	General	118
E.2	Use of IFORM to determine 50-yr significant wave height conditional on mean wind speed	118
E.3	Examples of joint distributions of V and H_S and approximations to the environmental contour	120
E.4	Choice of sea state duration	122
E.5	Determination of the extreme individual wave height to be embedded in SSS	123
E.6	Reference documents	123
Annex F (informative)	Corrosion protection	124
F.1	General	124
F.2	The marine environment	124
F.3	Corrosion protection considerations	125
F.4	Corrosion protection systems – Support structures	125
F.5	Corrosion protection in the rotor–nacelle assembly	126
F.6	Reference documents	127
Annex G (informative)	Prediction of extreme wave heights during tropical cyclones	128
G.1	General	128
G.2	Wind field estimation for tropical cyclones	128
G.3	Wave estimation for tropical cyclones	129
G.4	Reference documents	129
G.5	Databases for tropical storms conditions	130
Annex H (informative)	Recommendations for alignment of safety levels in tropical cyclone regions	131
H.1	General	131
H.2	Global robustness level criteria	131
H.3	Design load cases	132
Annex I (informative)	Earthquakes	134
Annex J (informative)	Model tests	135
Annex K (informative)	Tsunamis	137
K.1	General	137
K.2	Numerical model of tsunami [3],[4]	137
K.3	Evaluation of variance of water surface elevation and current velocity [5]	139
K.4	Reference documents	140
Annex L (informative)	Stationkeeping system	141
L.1	Redundancy of stationkeeping system	141
L.2	Mooring system accessories	141
Annex M (informative)	Differing limit state methods in IEC and ISO standards	142
Annex N (informative)	Application of non-standard duration extreme operating gusts	144

Annex O (informative) Application of load and load effect logic to floating substructure design	145
O.1 Typical load computation setups	145
O.2 Applied example	146
Annex P (informative) Guidance on simulation length and associated parameters.....	147
P.1 General considerations	147
P.1.1 Initial transient time	147
P.1.2 Low-frequency dynamics sampling	147
P.1.3 Reference period	147
P.2 Simulations for fatigue limit state analysis.....	148
P.2.1 Response variance and reference period	148
P.2.2 Statistical convergence of damage	148
P.3 Simulations for extreme limit state analysis.....	148
P.3.1 CE consistency with the reference period	149
P.3.2 Characteristic value variability	149
Annex Q (informative) Guidance on estimation of wave directional spreading by long wave method / single point measurement	150
Q.1 Background.....	150
Q.2 Linear free-wave extraction.....	150
Q.3 Second-order calculation	151
Q.4 References	152
Annex R (informative) Direction spreading function.....	153
Annex S (Informative) Concrete structures design	155
S.1 Design Load Cases.....	155
S.1.1 Limit States in Reinforced Concrete Design	155
S.1.2 ULS, ALS and FLS Load Cases	156
S.1.3 SLS Load Cases.....	156
S.1.4 Load factors	156
S.2 Design criteria	157
S.2.1 Material factors.....	157
S.2.2 ULS, ALS, FLS Verifications	157
S.2.3 SLS : Watertightness Verification.....	157
S.2.4 SLS: Crack-Opening Verification.....	157
S.2.5 SLS : Limitation of stresses	158
Annex T (informative) Relationship between peak wave period and significant wave height in the sea areas affected by swell	159
T.1 General.....	159
T.2 Relationship between wave height and wave period in the sea areas affected by swell	159
T.3 References	159
Annex U (informative) Application of damage stability criteria	160
U.1 Objective	160
U.2 Scenario of loss of floating stability.....	160
U.3 Flow of application of new damage stability criteria.....	160
U.4 Definition of target probability of failure (PS).....	161
U.5 Definition of collision probability (P1)	162
U.6 Definition of total loss probability by ship collision (P2)	164
U.6.1 Concept of estimation of P2 and PT	164
U.6.2 Simplification of FEM analysis	164

U.6.3	Estimation of P2 by limit curve.....	166
U.7	Additional countermeasure to reduce P2.....	167
U.8	References	167
Bibliography.....		168
Figure 1	– Parts of a floating offshore wind turbine (FOWT).....	15
Figure 2	– Rigid-body motion degrees of freedom of a floating substructure.....	22
Figure 3	– Design process for a floating offshore wind turbine (FOWT).....	26
Figure 4	– Definition of water levels	34
Figure 5	– Top-down view of nacelle yaw and nacelle yaw misalignment in a simulation	56
Figure 6	– The two approaches to calculate the design load effect.....	76
Figure B.1	– Regular wave theory selection diagram.....	101
Figure B.2	– Comparison of wave height distribution results	109
Figure E.1	– Example of the construction of the 50-year environmental contour for a 3-hour sea state duration.	119
Figure K.1	– The calculated result of Equation (K.8)	139
Figure O.1	– Example of load and load effect workflow for a hybrid “beams” and “nodes” floating substructure model setup.....	146
Figure Q.1	– A typical 20-min time history spectrum recorded at the Draupner platform. [1]	150
Figure T.1	– The relationship between significant wave height and significant wave period based on the measurement at Fukushima offshore site [2].	159
Figure U.1	– Concept flow of application of new damage stability criteria.....	161
Figure U.2	– Concept image of the approaching frequency.	163
Figure U.3	– Concept of estimation of P2 and PT in a strict way.	164
Figure U.4	– Concept of a limit curve.	166
Figure U.5	– Concept of the probability of total loss probability by ship collision.	166
Table 1	– Conversion between extreme wind speeds of different averaging periods.....	39
Table 2	– Design load cases	51
Table 3	– Safety factor for yield stress	80
Table B.1	– Constants h_1 and h_2 and normalised wave heights h_x % as a function of H_{tr}	105
Table B.2	– Breaking wave type.....	111
Table H.1	– Additional load cases for tropical cyclone affected regions.....	133
Table M.1	– Mapping of limit states and load cases in ISO 19904-1 Table 4 and load cases from IEC 61400-3-2	143
Table S.1	– Partial factors γ_F for actions for different limit states.....	156
Table S.2	– Material factors γ_m for different limit states and materials	157
Table S.3	– Allowable crack-width for different exposure zones	157
Table U.1	– Annual reliability of offshore structures	161

INTERNATIONAL ELECTROTECHNICAL COMMISSION

WIND ENERGY GENERATION SYSTEMS –

Part 3-2: Design requirements for floating offshore wind turbines

FOREWORD

- 1) The International Electrotechnical Commission (IEC) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, IEC publishes International Standards, Technical Specifications, Technical Reports, Publicly Available Specifications (PAS) and Guides (hereafter referred to as “IEC Publication(s)”). Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
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International Standard IEC 61400-3-2 has been prepared by IEC technical committee 88: Wind energy generation systems.

This edition cancels and replaces IEC TS 61400-3-2 published in 2019. This edition constitutes a technical revision.

This edition includes the following significant technical changes with respect to the first edition of IEC 61400-3-2:

- a) The relevant contents of IEC 61400-3-1 have been migrated into IEC 61400-3-2, making this revised IEC 61400-3-2 a self-standing document that does not have to be read directly in conjunction with IEC 61400-3-1;
- b) Several modifications have been made regarding metocean conditions in Clause 6 considering the nature of FOWT and the sea area where FOWT may be constructed, including: (1) the importance of wave directional spreading has been highlighted as it may result in larger loads for FOWT, including the addition of two new informative annexes and (2) the characteristic of swell has been explained, which may be relevant for some FOWT projects, including the addition of one new informative annex regarding the characteristic of swell;

- c) Clauses 7.1 to 7.5 have been changed to include a revised DLC table and its related descriptions, including amongst others updated requirements on directionality, wave conditions and redundancy check and damage stability cases; further updates are made related to guidance and necessities provided on load calculations and simulation requirements;
- d) Clause 7.6 has been updated with guidance on fatigue assessment along with clarifications on serviceability analysis and the applicable material for WSD; related Annex M has been updated and a new Annex O has been added for clarification of the safety factors and load and load effect approach for floating substructures;
- e) The concept of floating structural control that will interact with the wind turbine controller has been introduced in Clause 8;
- f) Clause 11 has been renamed from “Foundation and substructure design” to “Anchor design” and requirements for the transient conditions have been added;
- g) A more detailed clause regarding concrete design has been added to Clause 16 together with an informative Annex S;
- h) Clause 15 has been updated with the aim to improve ease of use, using experience from O&G and considering wind turbine peculiarities; updates included guidance for TLPs, damage stability, dynamic stability, testing and the addition for Annex U regarding how to analyse collision probability.

This part is to be read in conjunction with IEC 61400-1, *Wind turbines – Part 1: Design requirements*.

The text of this International Standard is based on the following documents:

FDIS	Report on voting
88/708/FDIS	88/712/RVD

Full information on the voting for the approval of this International Standard can be found in the report on voting indicated in the above table.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

A list of all parts of the IEC 61400 series, published under the general title *Wind energy generation systems*, can be found on the IEC website.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under "<http://webstore.iec.ch>" in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

A bilingual version of this publication may be issued at a later date.

IMPORTANT – The 'colour inside' logo on the cover page of this publication indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this document using a colour printer.

INTRODUCTION

This part of IEC 61400 outlines the minimum design requirements for floating offshore wind turbines (FOWT) and is not intended for use as a complete design specification or instruction manual.

Several different parties may be responsible for undertaking the various elements of the design, manufacture, assembly, installation, erection, commissioning, operation and maintenance of a FOWT and for ensuring that the requirements of this document are met. The division of responsibility between these parties is a contractual matter and is outside the scope of this document.

Any of the requirements of this document may be altered if it can be suitably demonstrated that the safety of the system is not compromised. Compliance with this document does not relieve any person, organization, or corporation from the responsibility of observing other applicable regulations.

WIND ENERGY GENERATION SYSTEMS –

Part 3-2: Design requirements for floating offshore wind turbines

1 Scope

This part of IEC 61400 specifies requirements for assessment of the external conditions at a floating offshore wind turbine (FOWT) site and specifies essential design requirements to ensure the engineering integrity of FOWTs. Its purpose is to provide an appropriate level of protection against damage from all anticipated hazards during the planned lifetime.

This document focuses on the engineering integrity of the structural components of a FOWT but is also concerned with subsystems such as control and protection mechanisms, internal electrical systems and mechanical systems.

A wind turbine shall be considered as a FOWT if the floating substructure is subject to hydrodynamic loading and supported by buoyancy and a stationkeeping system. A FOWT encompasses five principal subsystems: the RNA, the tower, the floating substructure, the stationkeeping system and the onboard machinery, equipment and systems that are not part of the RNA.

The following types of floating substructures are explicitly considered within the context of this document:

- i) ship-shaped structures and barges,
- j) semi-submersibles (Semi),
- k) spar buoys (Spar),
- l) tension-leg platforms/buoys (TLP / TLB).

This document can be utilized for structural types other than listed above, but special consideration may be needed to support novel features to achieve the same target safety level. These other structures can have a great range of variability in geometry, materials and structural forms and, therefore, can be only partly covered by the requirements of this document. In other cases, specific requirements stated in this document can be found not to apply to all or part of a structure under design. In all the above cases, conformity with this document will require that the design is based upon its underpinning principles and achieves a level of safety equivalent, or superior, to the level implicit in it.

This document is applicable to unmanned floating structures with one single horizontal axis turbine. While generally applicable, additional considerations may be needed, e.g., for multi-turbine units on a single floating substructure, vertical-axis wind turbines, FOWTs with shared moorings, spinning spars, or combined wind/wave energy systems.

This document should be used together with the appropriate IEC and ISO standards mentioned in Clause 2. In particular, this document is fully consistent with the requirements of IEC 61400-1. The safety level of the FOWT designed according to this document shall be at or exceed the level inherent in IEC 61400-1.

2 Normative references

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

- 59 For undated references, the latest edition of the referenced document (including any
60 amendments) applies.
- 61 API RP 2SM: 2014, *Design, Manufacture, Installation and Maintenance of Synthetic Fiber*
62 *Ropes for Offshore Mooring*
- 63 API RP 2T (R2015): 2010, *Recommended Practice for Planning, Designing, and Constructing*
64 *Tension Leg Platforms*
- 65 IEC 60721 (all parts), *Classification of environmental conditions*
- 66 IEC 61400-1:2019, *Wind energy generation systems – Part 1: Design requirements*
- 67 IEC 61400-3-1:2019, *Wind energy generation systems – Part 3-1: Design requirements for fixed*
68 *offshore wind turbines*
- 69 IEC 61400-15-1:202X, *Wind energy generation systems – Part 15-1: Site suitability input*
70 *conditions for wind power plants*
- 71 IMO, *International Code on Intact Stability*, 2008 (2008 IS CODE), 2020 Edition
- 72 IMO SOLAS Consolidated Edition 2020
- 73 IMO 2009 MODU CODE (2020 Edition)
- 74 ISO 2394:2015, *General principles on reliability for structures*
- 75 ISO 2533:1975, *Standard Atmosphere*
- 76 ISO 19900:2016, *Petroleum and natural gas industries – General requirements for offshore*
77 *structures*
- 78 ISO 19901-1:2015, *Petroleum and natural gas industries – Specific requirements for offshore*
79 *structures – Part 1: Metocean design and operating conditions*
- 80 ISO 19901-4:2016, *Petroleum and natural gas industries – Specific requirements for offshore*
81 *structures – Part 4: Geotechnical and foundation design considerations*
- 82 ISO 19901-6:2009 (/Cor.1:2011), *Petroleum and natural gas industries – Specific requirements*
83 *for offshore structures – Part 6: Marine operations*
- 84 ISO 19901-7:2013, *Petroleum and natural gas industries – Specific requirements for offshore*
85 *structures – Part 7: Stationkeeping systems for floating offshore structures and mobile offshore*
86 *units*
- 87 ISO 19902:2020, *Petroleum and natural gas industries – Fixed steel offshore structures*
- 88 ISO 19903:2019, *Petroleum and natural gas industries – Concrete offshore structures*
- 89 ISO 19904-1:2019, *Petroleum and natural gas industries — Floating offshore structures — Part 1:*
90 *Ship-shaped, semi-submersible, spar and shallow-draught cylindrical structures*
- 91 ISO 19906:2019, *Petroleum and natural gas industries – Arctic offshore structures*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 61400-1 and the following apply.

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

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

3.1

air gap

clearance between the highest water surface that occurs during the extreme environmental conditions and the lowest exposed part not designed to withstand wave impingement

3.2

anchor

device attached to the end of the mooring line or tendon and partially or fully buried in the seabed to limit the movement of the mooring line or tendon and to transfer loads to the seabed

Note 1 to entry: Available options for anchoring floating structures include drag anchors, anchor piles (driven, jetted, suction, torpedo/gravity-embedded and drilled and grouted), and other anchor types such as gravity anchors and plate anchors.

3.3

co-directional

acting in the same direction

3.4

control system

system implementing the turbine and FOWT support structure control functions, including sensors, logic elements, actuators, communication networks, and power supplies

The intent of the control system is to control operation of the turbine and FOWT support structure by active and passive means to optimize the power yielding and keep the operating parameters within the limits assumed in the structural design of the whole FOWT. The control system is likely to include control loops for normal operation as well as alarms and shutdown mechanisms to ensure that limits are not exceeded.

3.5

current

flow of water past a fixed location usually described in terms of a current speed and direction

3.6

diffraction

phenomenon that describes the bending of waves around obstacles and spreading of waves past openings

3.7

design wave

deterministic wave with a defined height, period and direction, used for the design of an offshore structure

Note 1 to entry: A design wave may be accompanied by a requirement for the use of a particular periodic wave theory.

3.8

designer

party or parties responsible for the design of a FOWT

3.9**dynamic power cable**

dynamic and submerged electrical cable feeding or collecting power from a floating substructure; the dynamic part is located from the hang-off of the floating substructure to either the touch-down point or to another floating substructure

3.10**environmental conditions**

characteristics of the environment (wind, waves, sea currents, water level, sea/lake ice, marine growth, scour and overall seabed movement, etc.) which may affect the behaviour of a FOWT.

3.11**external conditions**

external factors affecting operation of a FOWT, including the environmental conditions, the electrical network conditions, and other climatic factors (temperature, snow, ice, etc.)

3.12**extreme significant wave height**

significant wave height of the sea state over the reference period with an annual probability of exceedance of $1/N$ ("return period": N years), extrapolated from the extreme distribution of significant wave height at the site

3.13**extreme wave height**

individual wave height (generally the zero up-crossing wave height) with an annual probability of exceedance of $1/N$ ("return period": N years)

3.14**fast ice cover**

rigid continuous cover of ice not in motion

3.15**fetch**

distance over which the wind blows over the sea with approximately constant wind speed and direction

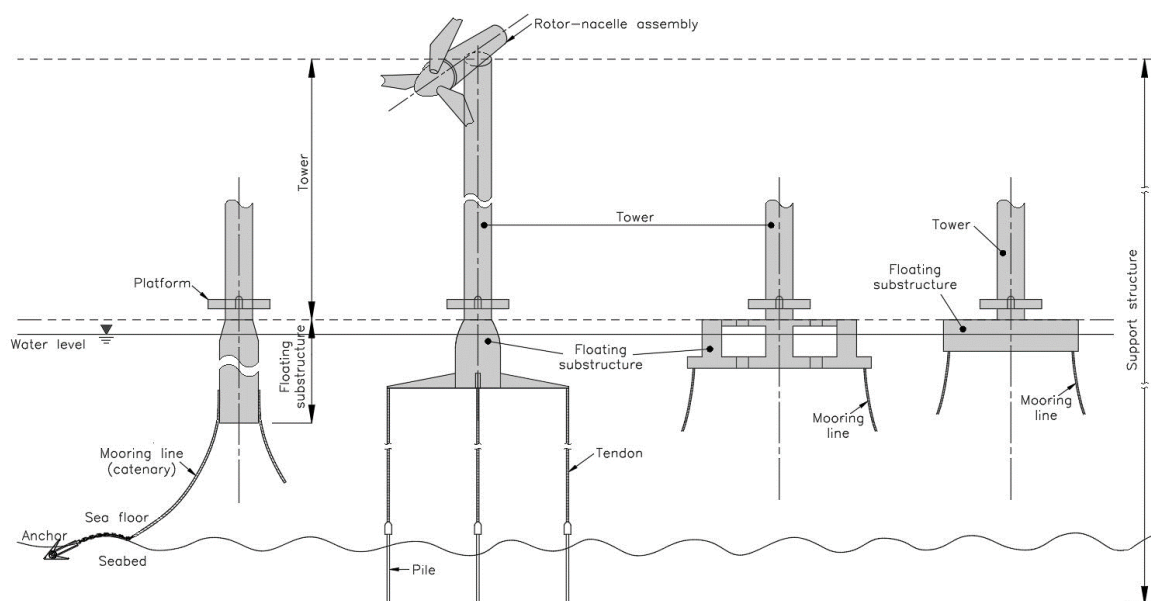
3.16**fixed offshore wind turbine**

wind turbine with a substructure that is subject to hydrodynamic loading and is founded on the seabed

3.17**floating offshore wind turbine**

wind turbine with a floating substructure that is subject to hydrodynamic loading and is supported by buoyancy and a station-keeping system

Note 1 to entry: Different FOWT support structure concepts are shown in Figure 1 together with the other parts of a FOWT support structure.



From left to right: Spar, TLP, Semisubmersible and Barge.

Figure 1 – Parts of a floating offshore wind turbine (FOWT)

3.18

floating offshore wind turbine site

location or intended location of an individual FOWT either alone or within a wind farm

3.19

floating stability

ability of a floating substructure to generate restoring moment after deviation from an equilibrium floating position

Note 1 to entry: Generally, verification of floating stability applies to both intact and damage conditions.

3.20

floating substructure

part of a FOWT support structure that floats above the sea floor, connects to the tower and stationkeeping system, and consists of a buoyant structure for supporting operational loads.

Note 1 to entry: A floating substructure can also be referred to as a hull. Different floating substructure concepts are shown in Figure 1 together with the other parts of a FOWT.

3.21

highest astronomical tide

highest still water level that can be expected to occur under any combination of astronomical conditions and under average meteorological conditions

Note 1 to entry: Storm surges, which are meteorologically generated and essentially irregular, are superimposed on the tidal variations, so that a total still water level above highest astronomical tide may occur.

3.22

hindcasting

method of simulating historical (metocean) data for a region through numerical modelling

3.23

hub height

height of the centre of the swept area of the wind turbine rotor above the mean sea level

3.24**hummocked ice**

crushed ice and ice floes piled up into ridges when large ice floes meet with each other or with a rigid obstacle, for example a floating substructure.

3.25**ice floe**

sheet of ice in size from metres to several kilometres, not rigidly frozen to a shore, still or in motion

3.26**icing**

build-up of a cover of ice or frost on parts of a FOWT that can result in added loads and/or changed properties

3.27**land-locked waters**

waters almost or entirely surrounded by land

3.28**load effect**

effect of a single load or combination of loads on a structural component or system, for example internal force, stress, strain, motion, etc.

3.29**lowest astronomical tide**

lowest still water level that can be expected to occur under any combination of astronomical conditions and under average meteorological conditions

Note 1 to entry: Storm surges, which are meteorologically generated and essentially irregular, are superimposed on the tidal variations, so that a total still water level below lowest astronomical tide may occur.

3.30**manufacturer**

party or parties responsible for the manufacture and construction of a FOWT.

3.31**marine conditions**

characteristics of the marine environment (waves, sea currents, water level, sea/lake ice, marine growth, seabed movement and scour, etc.) which may affect the behaviour of a FOWT.

3.32**marine growth**

surface coating on structural components caused by plants, animals and bacteria

3.33**mean sea level**

average level of the sea over a period of time long enough to remove variations due to waves, tides and storm surges

3.34**mean zero crossing period**

average period of the zero-crossing (up or down) waves in a sea state

Note 1 to entry: Relations exist between mean zero crossing period and peak period.

3.35**metocean**

abbreviation of meteorological and oceanographic

3.36**misaligned (for wind and waves)**

acting from different directions

3.37**mooring system**

passive type of stationkeeping system that typically comprises mooring lines, anchors, connectors and hardware and may include other components such as buoys, clamped weights, turrets, disconnecting system, etc.

3.38**moving ice**

portions of sea/lake ice that move under the action of wind and/or currents

3.39**multi-directional (for wind and waves)**

acting in multiple directions

3.40**nacelle yaw**

for turbines with an active or passive nacelle-yaw control mechanism, degree of freedom determining the orientation of the RNA with respect to the tower (and by extension the floating substructure)

3.41**operational limit**

value of a certain physical parameter defined in the design basis such as acceleration, inclination, displacement, excursion, frequency, rpm, voltage, strain, pressure, wind speed, wave height, etc. that satisfies the most demanding of the prescribed operating criteria for a specified FOWT to ensure its operation within acceptable Reliability and Safety criteria

3.42**peak wave period**

period of the peak energy in the wave spectrum

3.43**power collection system**

electrical system that collects the power from one or more FOWTs

Note 1 to entry: The power collection system includes all electrical equipment connected between the wind turbine terminals and the network connection point. For offshore wind farms, the power collection system may include the connection to shore.

3.44**recognized classification society**

member of the International Association of Classification Societies (IACS), with recognized and relevant competence and experience in floating structures

3.45**redundancy (for stationkeeping system)**

A FOWT stationkeeping system can be defined as redundant when following a loss of one mooring line or tendon, the FOWT will be kept within a confined area by the damaged stationkeeping system and will not interfere with other structures, such that no further consequences of the loss of the mooring line or tendon will take place. Dynamic infield power

296 cable rupture and power shutdown due to FOWT drift-off may be an accepted solution based
297 on owner/developer approval

298 **3.46**

299 **reference period**

300 period during which stationarity is assumed for a given stochastic process, for example wind
301 speed, sea elevation or response

302 **3.47**

303 **refraction**

304 process by which wave energy is redistributed as a result of changes in the wave propagation
305 velocity due to variations in water depth and/or current velocity

306 **3.48**

307 **rotor–nacelle assembly**

308 part of a FOWT carried by the support structure

309 **3.49**

310 **scantling**

311 sizing of plates, girders and stiffeners of floating substructures

312 **3.50**

313 **sea floor**

314 interface between the sea and the seabed

315 **3.51**

316 **sea floor slope**

317 local gradient of the sea floor, for example associated with a beach

318 **3.52**

319 **sea/lake ice**

320 frozen seawater or lake freshwater

321 **3.53**

322 **sea state**

323 condition of the sea in which its statistics remain stationary

324 **3.54**

325 **seabed**

326 materials below the sea floor in which a support structure is founded

327 **3.55**

328 **seabed movement**

329 movement of the seabed due to natural geological processes

330 **3.56**

331 **scour**

332 removal of seabed soils by currents and waves or caused by structural elements interrupting
333 the natural flow regime above the sea floor

334 **3.57**

335 **semisubmersible**

336 floating substructure normally consisting of a top structure with a number of widely spaced,
337 large cross-section, supporting columns connected to submerged pontoons or heave plates

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

3.58**shallow water**

depth in which the presence of the seabed has a pronounced effect on the wave hydrodynamics

Note 1 to entry: The distinction between shallow water and non-shallow water is defined in Figure B.1. For extreme sea states a site may have to be considered as shallow while for normal conditions it can be considered deep.

3.59**significant wave height**

statistical measure of the height of waves in a sea state, defined as either the average height of the highest one third of the zero up-crossing waves or as $4 \times \sigma_\eta$ where σ_η is the standard deviation of the sea surface elevation

Note 1 to entry: The former height is called the statistical significant wave height (usually denoted $H_{1/3}$ ¹, while the latter height is called the spectral significant wave height (denoted by H_s or H_{m0}).

3.60**significant wave period**

statistical measure of the period of waves in a sea state, defined as the average period of the highest one third of the zero up-crossing waves, denoted $T_{1/3}$

Note 1 to entry: Relations exist between the peak period T_p and $T_{1/3}$.

3.61**spar**

deep-draught, small water-plane area cylindrical floating substructure

3.62**splash zone**

external region of the FOWT support structure that is frequently wetted due to wave, tidal variations and floating substructure motions

Note 1 to entry: To define upper and lower limit of the splash zone, the following parameters shall be superimposed where applicable to the specific FOWT support structure type:

- the highest still water level with a return period of 1 year increased by the crest height of a wave with height equal to the significant wave height with a return period of 1 year,
- the lowest still water level with a return period of 1 year reduced by the trough depth of a wave with height equal to the significant wave height with a return period of 1 year,
- draft variation, and
- vertical motions (heave, roll, pitch) of the floating substructure.

3.63**stationkeeping system**

system capable of limiting the excursions and/or accelerations of the FOWT within prescribed limits and maintaining the intended orientation

Note 1 to entry: A stationkeeping system may differ from a mooring system in the case of active thrusters, tendons, etc.

3.64**still water level**

abstract water level calculated by including the effects of tides and storm surge but excluding variations due to waves

Note 1 to entry: Still water level can be above, at, or below mean sea level.

¹ In deep water, $H_{1/3} \approx 0,956H_s$ regardless of wave spectral form (ISO 21650:2007).

3.65**storm surge**

change in water level caused by atmospheric change and/or wind associated with a storm

3.66**support structure**

part of FOWT consisting of the tower, floating substructure, and stationkeeping system

Note 1 to entry: Refer to Figure 1.

3.67**swell**

sea state in which waves generated by winds remote from the site have travelled to the site, rather than being locally generated

3.68**tendon**

collection of components of a stationkeeping system that forms a tensioned vertical or near-vertical link between the TLP-type floating substructure and the anchor on and beneath the sea floor for the purpose of providing stationkeeping and floating stability to FOWTs

3.69**tension leg platform**

vertically moored, buoyant, compliant structural system wherein excess buoyancy of the floating substructure (in excess of weight and tendon loads) maintains tension in the mooring system

3.70**tidal current**

current resulting from tides

3.71**tidal range**

vertical distance between the highest astronomical tide and the lowest astronomical tide

3.72**tides**

regular and predictable movements of the sea generated by astronomical forces

3.73**tower**

part of a FOWT support structure which connects the floating substructure to the rotor-nacelle assembly

3.74**tsunami**

long period sea waves caused by rapid vertical movements of the sea floor

3.75**uni-directional (for wind and waves)**

acting in a single direction

3.76**water depth**

vertical distance between the sea floor and the still water level

Note 1 to entry: As there are several definitions for the still water level (see 3.64) there can be several water depth values.

3.77**wave crest elevation**

vertical distance between the crest of a wave and the still water level

3.78**wave direction**

mean direction from which the wave is travelling

3.79**wave height**

vertical distance between the highest and lowest points on the water surface of an individual zero up-crossing wave

3.80**wave period**

time interval between the two zero up-crossings which bound a zero up-crossing wave

3.81**wave spectral peak frequency**

frequency of the peak energy in the wave spectrum, the inverse of the wave peak period

3.82**wave spectrum**

frequency domain description of the sea surface elevation in a sea state

3.83**wave steepness**

ratio of the wave height to the wave length

3.84**weather downtime**

one or more intervals of time during which the environmental conditions are too severe to allow for execution of a specified marine operation

3.85**weather window**

interval of time during which the environmental conditions allow for execution of a specified marine operation

3.86**wind profile – wind shear law**

mathematical expression for assumed wind speed variation with height above still water level

Note 1 to entry: Commonly used profiles are the logarithmic profile (equation (1)) and the power law profile (equation (2)).

$$V(z) = V(z_r) \cdot \frac{\ln(z/z_0)}{\ln(z_r/z_0)} \quad (1)$$

$$V(z) = V(z_r) \cdot \left(\frac{z}{z_r} \right)^\alpha \quad (2)$$

where

$V(z)$ is the wind speed at height z ;

z is the height above the still water level;

z_r is a reference height above the still water level used for fitting the profile;

z_0 is the roughness length;

α is the wind shear (or power law) exponent.

3.87

wind sea

sea state being generated by local winds

3.88

yaw

floating substructure nautical motion degree of freedom

Note 1 to entry: The six rigid-body motion degrees of freedom of a floating substructure—surge, sway, heave, roll, pitch and yaw—are illustrated in Figure 2.

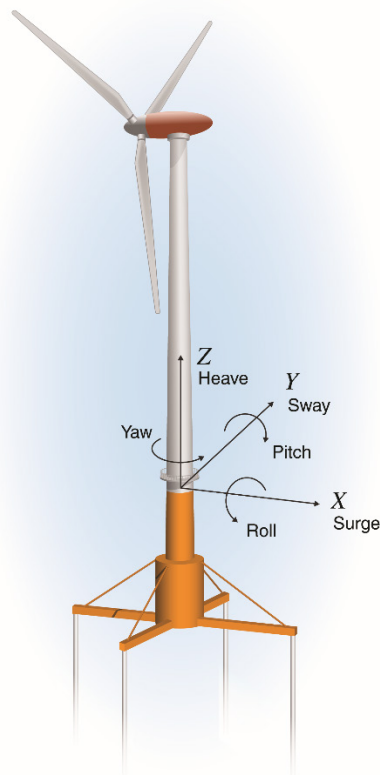


Figure 2 – Rigid-body motion degrees of freedom of a floating substructure

3.89

zero up-crossing wave

portion of a time history of wave elevation between zero up-crossings

Note 1 to entry: A zero up-crossing occurs when the sea surface rises (rather than falls) through the still water level.

4 Symbols and abbreviated terms

For the purposes of this document, the symbols and abbreviated terms given in IEC 61400-1 and the following apply:

4.1 Symbols and units

A_C Charnock's constant

[-]

d water depth

[m]

$f_{\text{low frequency}}$ upper end of low-frequency range

AVA [Hz]

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491	f_p	wave spectral peak frequency	[Hz]
492	g	acceleration due to gravity	[m/s ²]
493	H	individual wave height	[m]
494	H_B	breaking wave height	[m]
495	H_N	individual wave height with a return period of N years	[m]
496	H_s	spectral significant wave height	[m]
497	H_{sN}	spectral significant wave height with a return period of N years	[m]
498	$H_{1/3}$	statistical significant wave height	[m]
499	k	wave number	[-]
500	$K_{\max}$	accumulated freezing degree-days	[°C]
501	L_k	velocity component integral scale parameter	[m]
502	$p(V_{\text{hub}})$	probability density function of hub height wind speed	[-]
503	R_d	design value for component resistance	[-]
504	R_k	characteristic value for component resistance	[-]
505	s	sea floor slope	[°]
506	S_d	design value for load effect	[-]
507	$S.F.$	safety factor	[-]
508	S_k	characteristic value for load effect	[-]
509	S_η	single sided wave spectrum	[m ² /Hz]
510	t	time	[s]
511	T	wave period	[s]
512	T_p	peak spectral period	[s]
513	T_z	mean zero-crossing wave period	[s]
514	U_N	current velocity, with a return period of N years	[m/s]
515	U_{ss}	sub surface current velocity	[m/s]
516	U_w	wind-generated current velocity	[m/s]
517	V_N	expected extreme wind speed (averaged over 10 min), with a return period of N years	[m/s]
519	V_{eN}	expected extreme wind speed (averaged over 3 s), with a return period of N years	[m/s]
521	z	vertical distance above SWL	[m]
522	α	sea floor slope in radians	[rad]
523	η	sea surface elevation relative to SWL	[m]
524	κ	von Karman's constant	[-]
525	λ	wave length	[m]
526	θ_c	current direction	[°]
527	θ_w	wave direction	[°]
528	θ_{wm}	mean wave direction	[°]
529	$\sigma_{\text{allowable}}$	allowable stress	[N/m ² or Pa]

530	σ_{buckling}	allowable buckling stress	[N/m ² or Pa]
531	σ_y	specified minimum yield strength	[N/m ² or Pa]
532	σ_{cr}	critical compressive buckling stress or shear buckling stress	[N/m ² or Pa]
533	σ_η	sea surface elevation standard deviation	[m]
534	τ	temperature	[°C]

535 **4.2 Abbreviations**

536	COD	co-directional
537	CPT	cone penetration test
538	DLC	design load case
539	ECD	extreme coherent gust with direction change
540	ECM	extreme current model
541	EDC	extreme direction change
542	EOG	extreme operating gust
543	ESS	extreme sea state
544	EWLR	extreme water level range
545	EWM	extreme wind speed model
546	EWS	extreme wind shear
547	FMEA	failure modes and effects analysis
548	FOWT	floating offshore wind turbine
549	HAT	highest astronomical tide
550	IACS	international association of classification societies
551	IMO	international maritime organization
552	LAT	lowest astronomical tide
553	MIC	microbiologically influenced corrosion
554	MIS	misaligned
555	MSL	mean sea level
556	MUL	multi-directional
557	NCM	normal current model
558	NSS	normal sea state
559	NTM	normal turbulence model
560	NWLR	normal water level range
561	NWP	normal wind profile model
562	RCS	recognized classification society
563	RNA	rotor-nacelle assembly
564	SSS	severe sea state
565	SWL	still water level
566	TLB	tension-leg buoy
567	TLP	tension-leg platform
568	UNI	uni-directional
569	WSD	working stress design

5 Principal elements

5.1 General

The engineering and technical requirements to ensure the safety of the structural, mechanical, electrical and control systems of a FOWT are given in this document. This specification of requirements applies to the design, manufacture, transport (including towing), assembly, installation and manuals for operation and maintenance of a FOWT and the associated quality management process. In addition, safety procedures, which have been established in the various practices that are used in the transport, assembly, installation, operation and maintenance of a FOWT, are taken into account.

5.2 Design methods

This document requires the use of a structural dynamics model to predict design load effects. Such a model shall be used to determine the load effects for all relevant combinations of external conditions and design situations as defined in Clause 6 and Clause 7 respectively. A minimum set of such combinations has been defined as load cases in this document.

The design of the support structure of a FOWT shall be based on site-specific external conditions. These shall therefore be determined in accordance with the requirements stated in Clause 6. The conditions shall be summarized in the design basis.

The design of the FOWT support structure shall include the design of the stationkeeping system per Clause 14 and consider floating stability per Clause 15. The offset requirements, metocean conditions and corresponding loads on the floating substructure induced by the dynamic power cable system and the potential for clashing with the stationkeeping system shall be taken into account. Consideration shall be given to the submerged weight, mechanical response characteristics and hang-off location.

In the case of the rotor–nacelle assembly, which may have been designed initially on the basis of a standard wind turbine class as defined in IEC 61400-1, 6.2, it shall be demonstrated that the FOWT support structure and the site-specific offshore conditions do not compromise the RNA structural integrity. The demonstration shall comprise a comparison of loads and deflections in the RNA calculated for the specific FOWT support-structure and the specific site conditions with those calculated during initial design.

The design of the control and protection system (see Clause 8), mechanical systems (see Clause 9) and electrical system (Clause 10) shall be verified taking account of the dynamic response of the FOWT.

The design process for a FOWT is illustrated in Figure 3. The figure indicates the key elements of the design process and identifies the corresponding relevant clauses of this standard. The process is iterative and shall incorporate load and load effect calculations for the complete wind turbine comprising the integrated support structure and rotor–nacelle assembly. The structural design of a FOWT may be regarded as completed when its structural integrity has been verified based on the limit state analyses defined in 7.6.

Data from full-scale testing of the RNA shall be used to increase confidence in predicted design values and to verify structural dynamics models and design situations. Data from full-scale testing of the FOWT support structure may similarly be used, if available. Guidance relating to the measurement of mechanical loads for full-scale wind turbine testing is available in IEC 61400-13. Data from model-scale testing should be used to determine the response of a particular FOWT configuration, to verify structural dynamics models and design situations, and to confirm that no extraordinary or unexpected behaviour of the tested configuration occurs (see Annex J).

Verification of the adequacy of the design shall be made by calculation and should be supported by testing. For guidance regarding how model tests can be utilized in the design process, see Annex J.

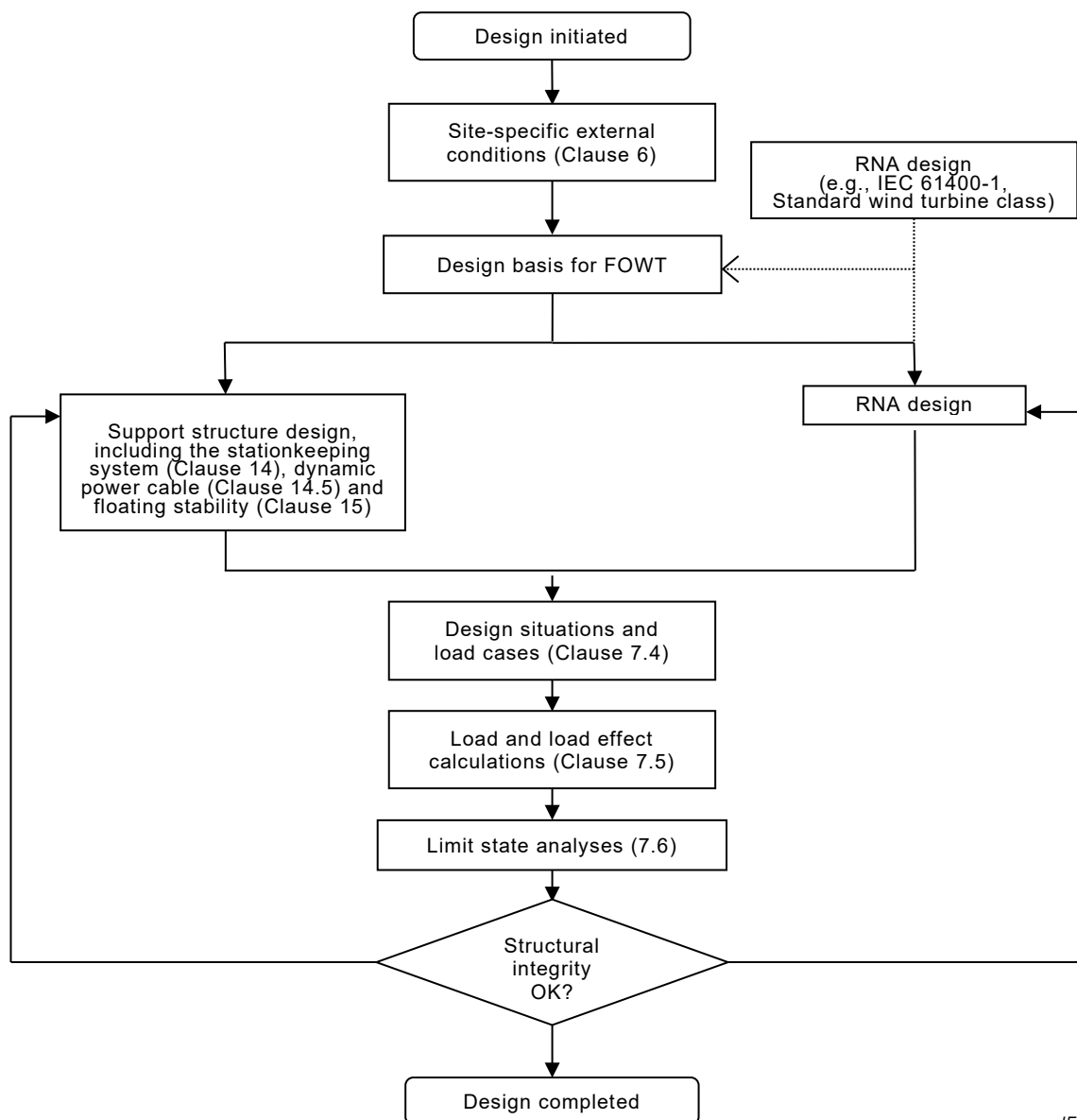


Figure 3 – Design process for a floating offshore wind turbine (FOWT)

5.3 Safety level for FOWT

The FOWT is typically unmanned and considered as having moderate consequences of failure, so, the FOWT support structure should, in general, be designed to have a safety level equivalent to the medium (L2) exposure level as defined in ISO 19904-1.

5.4 Safety classes for RNA

An RNA shall be designed according to one of the following two safety classes:

- a normal safety class that applies when a failure results in risk of personal injury or other social or economic consequence;

- a special safety class that applies when the safety requirements are determined by local regulations and/or the safety requirements are agreed between the manufacturer and the customer.

Partial safety factors for normal safety class RNAs are specified in IEC 61400-1.

Partial safety factors for special safety class RNAs shall be agreed upon between the manufacturer and the customer. An RNA designed according to the special safety class is a class S turbine as defined in IEC 61400-1.

5.5 Quality assurance

Quality assurance shall be an integral part of the design, procurement, manufacture, installation, commissioning, operation and maintenance, and decommissioning of FOWTs and all their components.

5.6 Rotor–nacelle assembly markings

The following information, as a minimum, shall be prominently and legibly displayed on the indelibly marked rotor–nacelle assembly nameplate:

- RNA manufacturer and country;
- model and serial number;
- production year;
- rated power;
- reference wind speed, V_{ref} ;
- hub height operating wind speed range, $V_{\text{in}} - V_{\text{out}}$;
- operating ambient temperature range;
- IEC wind turbine class (see IEC 61400-1);
- rated voltage at the wind turbine terminals;
- frequency at the wind turbine terminals or frequency range in the case that the nominal variation is greater than 2 %.

5.6 Support structure markings

The following information, as a minimum, shall be prominently and legibly displayed on the indelibly marked FOWT support structure (including floating substructure) nameplate:

- draft marking (combined load line markings for operating in sea operation);
- unit identification;
- company and registered owner identification;
- markings required by local authorities.

6 External conditions – definition and assessment

6.1 General

FOWTs are subjected to environmental and electrical conditions, including the influence of nearby turbines, that may affect their loading, durability and operation. To ensure the appropriate level of safety and reliability, environmental, electrical and soil parameters shall be taken into account in the design and shall be explicitly stated in the design documentation.

The environmental conditions are divided into wind conditions, marine conditions (waves, sea currents, water level, sea/lake ice, marine growth, seabed movement and scour) and other

environmental conditions. The electrical conditions refer to the electrical power network conditions. Soil properties are relevant to the design of the FOWT anchor and stationkeeping system.

The structural integrity shall be demonstrated taking proper account of the marine conditions at each specific site at which the FOWT will be subsequently installed.

The design process for a FOWT is shown in Figure 3. The assessment of site-specific external conditions is the first step in the design process and forms the basis for the design. This clause therefore specifies both the definition and assessment of the external conditions.

The external conditions are subdivided into normal and extreme categories. The normal external conditions generally concern recurrent structural loading conditions, while the extreme external conditions represent rare external design conditions. The design load cases shall consist of critical combinations of these external conditions for specified joint return periods with wind turbine operational modes and other design situations.

The definition and assessment of the normal and extreme external conditions to be considered in design are specified in 6.2 to 6.4.

The abbreviations added in parentheses in the subclause headings in the remainder of this clause are used for describing the external conditions for the design load cases defined in 7.4.

6.2 Wind turbine classes

The external conditions to be considered in design are dependent on the intended site or site type for a FOWT installation. In IEC 61400-1 wind turbine classes are defined in terms of wind speed and turbulence parameters. The intention of the classes is to cover most onshore applications. IEC 61400-1 includes a specific class for tropical cyclone conditions ("T class"). Additional guidance on tropical cyclone conditions is available in Annex H of this document.

There are some principal differences between offshore and onshore wind conditions. However, for a FOWT the definition of classes in terms of wind speed and turbulence parameters remains appropriate as the basis of design of the rotor–nacelle assembly (RNA). As stated in 5.2 it shall be demonstrated subsequently that site-specific external conditions do not compromise the structural integrity of the rotor-nacelle assembly.

The manufacturer shall in the design documentation describe the models used and values of essential design parameters. Where the models described in Clause 6 are adopted, a statement of the values of the parameters will suffice. The design documentation should contain the information listed for guidance in Annex A.

6.3 Definition of external conditions at a FOWT site

6.3.1 General

A FOWT shall be designed to safely withstand the wind conditions and marine conditions adopted as the basis of design.

The wind regime and marine conditions for load and safety considerations are divided into the normal conditions which occur frequently during normal operation of a FOWT, and the extreme conditions which are defined as having a 1-year or 50-year return period².

The extreme conditions are intended to produce N -year ($N = 1$ or 50) return period load effects (cross-sectional loads, deformations, etc.). Combining marginal N -year events directly will in

² The normal range of water levels is, however, defined in this document as the variation in water level with a return period of 1 year, refer to 6.3.3.4.2.

general produce load effects of longer return period than N years. The more environmental parameters that are combined in this way, the more conservative the design potentially becomes. For the assessment of the combined wind and marine environment, several parameters are relevant for the load effects of offshore turbines. Thus for FOWT design, the assessment of joint environmental conditions by specifying associated conditions instead of direct combinations of marginal conditions of equal return period is appropriate. FOWTs can exhibit significant dynamic response. This shall be accounted for when establishing joint environmental conditions.

To determine joint environmental conditions for design, the approach of environmental contours can be used. The joint environmental conditions to be designed for are then defined as those among all conditions on the environmental contour that cause the most extreme response. The possible dynamic response shall be considered in the assessment. By this approach joint wind speeds, wave heights, wave periods, water levels, directional relations etc. may be established.

The application of the method of environmental contours, or other probabilistic methods, generally requires information defining the long-term joint probability distributions of wind and marine conditions. In practice not all environmental conditions are typically measured simultaneously. Environmental contours are instead developed for subsets of parameters – e.g. wave heights and water level, wave height and wave period, etc.

The following clauses define the predominant marginal extreme conditions to consider as a minimum, e.g. N -year return wind and marine conditions. Conditions to associate with these shall be established. In the absence of sufficient information to develop site-specific environmental contours, conservative alternatives are provided.

6.3.2 Wind conditions

The wind parameters defined in IEC 61400-1 are appropriate for the offshore environment. Site-specific conditions representative of the FOWT site shall be assessed in accordance with the requirements stated in 6.4.3.

It should be ensured that the representation of the power spectrum of the turbulence and the sampling of turbulence by the rotor in the low-frequency range is adequate.

Discrete event durations for EOG, EDC, ECD defined in IEC 61400-1 Clause 6.3.2 should take into consideration possible FOWT motion natural frequencies that are considerably lower than for fixed systems and should be evaluated, if relevant. For methods to address longer EOG periods, see Annex N.

6.3.3 Marine conditions

The loading and response of the floating substructure is typically more driven by waves than by wind; care should be taken when the combined wind and wave input to the load simulations is defined in order not to disregard important sea states.³

Swells can be of importance in conjunction with low-frequency responses of FOWTs. Wind-wave misalignment cases leading to bi-directional wave loading may require specific attention for FOWTs and shall be taken into account. This may be particularly important for load cases driving tower-base fatigue-

³ For fixed offshore wind turbines, the waves are often taken dependent on the wind speed; this may be insufficient for FOWTs.

6.3.3.1 General

The marine conditions described in this subclause include waves, sea currents, water level, sea ice, marine growth, scour and seabed movement. Other external conditions relevant to the offshore environment are defined in 6.3.5.

6.3.3.2 Waves

6.3.3.2.1 General

Waves are irregular in shape, vary in height, length and speed of propagation, and may approach a FOWT from one or more directions simultaneously. The features of a real sea are best reflected by describing a sea state by means of a stochastic wave model.

The stochastic wave model represents the sea state as the superposition of many small individual frequency components, each of which is a periodic wave with its own amplitude, frequency and direction of propagation; the components have random phase relationships to each other. A design sea state shall be described by a wave spectrum, S_{η} , together with the significant wave height, H_s , a peak spectral period, T_p , and a mean wave direction, θ_{wm} , or a peak wave direction, θ_{wp} . Where appropriate, the wave spectrum may be supplemented with a directional spreading function. Standard wave spectrum formulations are provided in ISO 19901-1.

In some applications, periodic or regular waves can be used as an abstraction of a real sea for design purposes. A deterministic design wave shall be specified by its height, period and direction.

The correlation of wind conditions and waves shall be taken into account for the design of a FOWT. This correlation shall be considered in terms of the long-term joint probability distribution of relevant parameters, e.g.:

- mean wind speed, V ;
- significant wave height, H_s ;
- peak spectral period, T_p ; and
- water depth, d .

The joint probability distribution of these parameters is affected by local site conditions such as fetch, water depth, bathymetry, etc. The distribution shall therefore be determined from suitable long-term measurements and/or by the use of numerical hindcasting techniques whichever is appropriate, refer to 6.4.4.

The correlation of normal wind conditions and waves shall also consider wind-wave misalignment, i.e. consideration of mean wind and wave directions (separation of wind sea and swell may also be considered). The multi-directional distributions of wind and wave directions can have an important influence on the loads acting on the support structure. The importance of this influence will depend on the nature of the wind and wave directionality and on properties of the support structure such as eigenfrequencies, modal damping, mode shapes and geometrical symmetry. The designer may, in some cases, demonstrate by appropriate analysis that it is conservative and therefore acceptable to assume that the wind and waves are aligned (co-directional) and acting from a single, worst case direction (uni-directional).

Alternatively, the designer may demonstrate by appropriate analysis that it is conservative and therefore acceptable to assume that the wind and waves are misaligned and acting from two, worst case directions (for example, 90° misalignment may be the worst case because of the consequential lack of aerodynamic damping). The assumptions regarding wind and wave directions are considered for each design load case in 7.4.

When taking account of the wind and wave misalignment, particular care shall be taken to ensure that the directional data and wind turbine modelling techniques are reliable, refer to 7.5.

The combined extreme event of wind, waves, water level, and other relevant parameters shall ensure that global extreme environmental actions with return periods of 1 year and 50 years are considered. The geometric and dynamic properties of the support structure may imply that several combined events shall be specified.

Wave models are defined in 6.3.3.2.2 to 6.3.3.2.5 in terms of sea state representations including stochastic linear wave models and regular non-linear design waves. The stochastic wave models shall be based on a wave spectrum appropriate to the site anticipated for the FOWT.

By definition H_s and T_p are independent of reference period. In order to determine the joint probability distribution of V_{hub} , H_s , and T_p , a one hour averaging period shall be used to define the mean wind speed against which to correlate the significant wave height and peak spectral period.

In any cases, the spreading of the wave may be important for the load calculation of FOWT and should be considered. Neglection of the spreading may cause less conservative results, e.g., the underestimation of fluctuating yaw motion of the floating substructure, which is different from fixed wind turbines. See Annex Q, Annex R and ISO19901-1:2015 for more detail information of wave spreading.

6.3.3.2.2 Normal sea state (NSS)

The significant wave height, peak spectral period and direction for each normal sea state shall be selected, together with the associated mean wind speed, based on the long-term joint probability distribution of metocean parameters appropriate to the anticipated site.

For fatigue load calculations, the designer shall ensure that the number and resolution of the normal sea states considered are sufficient to account for the fatigue damage associated with the full long-term distribution of metocean parameters.

For ultimate load calculations, the normal sea states considered shall be those sea states characterised by the expected value of the significant wave height, H_s , and peak spectral period, T_p , conditioned on a given value of mean wind speed. The designer shall take account of the range of peak spectral period, T_p , appropriate to each significant wave height. Design calculations shall be based on values of peak spectral period which result in the highest loads acting on the FOWT.

6.3.3.2.3 Severe sea state (SSS)

The severe sea state model shall be considered in combination with normal wind conditions for calculation of the ultimate loading of a FOWT during power production. The severe sea state model associates a severe sea state with each mean wind speed in the range corresponding to power production. The significant wave height, $H_{s,SSS}(V)$, for each severe sea state shall in general be determined by extrapolation of appropriate site-specific metocean data such that the combination of the significant wave height and the mean wind speed has a return period of 50 years⁴. The severe sea state shall include the extreme individual wave height that, in combination with the associated wave period and the mean wind speed, has a return of 50 years. The designer shall take account of the range of wave period, T , appropriate to each extreme wave height. In the absence of a more sophisticated probabilistic assessment, design

⁴ It is recommended that the extrapolation of metocean data be undertaken using the so-called Inverse First Order Reliability Method (IFORM). This method is described in Annex E which also gives guidance on how to determine $H_{s,SSS}(V)$ from site-specific environmental conditions. Alternative methods for environmental contours are also introduced in Annex E.

calculations shall assume values of wave periods within this range that result in the highest loads acting on a FOWT.

For all mean wind speeds, the unconditional extreme significant wave height, H_{s50} , with a return period of 50 years may be used as a conservative value for $H_{s,SSS}(V)$. Similarly, it is conservative to adopt the extreme individual wave height H_{50} for the extreme individual wave height in the severe sea state. This approach may be used in the absence of information defining the long-term joint probability distribution of wind and waves.

6.3.3.2.4 Extreme sea state (ESS)

The extreme sea state model shall be considered for combined global environmental actions with return periods of 1 year and 50 years. The designer may need to investigate a number of extreme sea states combined with, for example, different water levels to determine the appropriate extreme sea state(s) for design, refer 6.3.3.4.3 and 6.3.3.3.5. Both the extreme significant wave height (H_{s50} or H_{s1}) and the extreme individual wave height (H_{50} or H_1) shall be included in the sea state. The designer shall take account of the range of wave period, T , appropriate to each extreme wave height. Design calculations shall assume values of wave periods within this range that result in the highest loads acting on a FOWT.

The extreme sea state(s) shall be determined from analysis of appropriate site-specific metocean data (i.e. measurements and/or hindcast data) for the FOWT site, refer to 6.4.4.

In the absence of information defining the long-term joint probability distribution of extreme wind and waves, it shall be assumed that the extreme 10-min mean wind speed with a 50-year return period occurs during the extreme 3-hour sea state with a 50-year return period. The same assumption shall apply with regard to the combination of the extreme 10-min wind speed and the extreme 3-hour sea state each with a 1-year return period. The extreme individual wave height shall be assumed to occur at a random time during the simulation of the extreme sea state.

6.3.3.2.5 Breaking waves

The influence of breaking waves shall be assessed during the design of a FOWT. Breaking waves are classified as spilling, plunging or surging, the first two types being relevant to sites suitable for FOWTs. The water depth, sea floor slope and wave period determine whether the form of the breaking wave is expected to be spilling or plunging.

Annex B provides guidance relating to shallow water hydrodynamics and the influence of site characteristics on the nature and dimensions of breaking waves. Guidance is provided in Annex C relating to the calculation of the loading applied by a breaking wave to a FOWT support structure.

6.3.3.3 Sea currents

6.3.3.3.1 General

Although sea currents may, in principle, vary in space and time, they are generally considered as a horizontally uniform flow field of constant velocity and direction, varying only as a function of depth. The following components of sea current velocity shall be taken into account:

- sub-surface currents generated by tides, storm surge and atmospheric pressure variations, etc.;
- wind-generated, near-surface currents.

The total current velocity is the vector sum of these components. Wave induced water particle velocities and current velocities shall similarly be added vectorially. The influence of sea currents on the relationship between wave length and wave period is generally small and may be neglected, refer to ISO 19901-1:2015, A.8.4.3 for further guidance. Other site specific

current components may exist, such as near shore, wave induced surf currents running parallel to the coast.

The influence of sea currents on the fatigue loading of a FOWT may be insignificant in cases where the total current velocity is small compared to the wave induced water particle velocity in the wave crest and where vibrations of the support structure are unlikely to occur due to vortex shedding or moving ice floes. The designer shall determine whether sea currents may be neglected for calculation of fatigue loads by means of an appropriate assessment of site-specific data.

6.3.3.3.2 Sub-surface currents

The sub-surface current profile may be characterised by a simple power law over the water depth d , where the current velocity $U_{ss}(z)$ is defined as a function of height z above SWL:

$$U_{ss}(z) = U_{ss}(0) [(z + d)/d]^{1/7} \quad (3)$$

The 1-year and 50-year return period values of the sea surface velocity $U_{ss}(0)$ may be determined from analysis of appropriate measurements at the FOWT site, refer to 6.4.4.3.

In general, it is conservative to assume that the sub-surface currents are aligned with the wave direction.

6.3.3.3.3 Wind-generated, near-surface currents

The wind-generated current may be characterised as a linear distribution of velocity $U_w(z)$ reducing from the surface velocity $U_w(0)$ to zero at a depth of 20 m below SWL:

$$U_w(z) = U_w(0) (1 + z/20) \quad (4)$$

At sites where the water depth is less than 20 m, the wind-generated current velocity at the sea floor will be non-zero.

The wind-generated sea surface current velocity may be assumed to be aligned with the wind direction, and may be estimated from

$$U_w(0) = 0,01 V_{1\text{-hour}}(z = 10 \text{ m}) \quad (5)$$

where $V_{1\text{-hour}}(z = 10 \text{ m})$ is defined as the 1-hour mean value of wind speed at 10 m height above SWL.

The 1-year and 50-year return period values of $V_{1\text{-hour}}(z = 10 \text{ m})$ may be determined from analysis of appropriate measurements at the FOWT site. These wind speeds may then be used with equation (5) to estimate the 1-year and 50-year return values of wind-generated sea surface current velocity.

6.3.3.3.4 Normal current model (NCM)

The normal current model is defined as the appropriate site-specific combination of wind-generated currents and tidal currents. The normal current model excludes storm-generated sub-surface currents. Normal tidal currents shall be accounted for as the mean of tidal current speeds.

The normal current model shall be assumed for those load cases involving normal and severe wave conditions (NSS, SSS) and for each load case the velocity of the wind-generated currents may be estimated from the relevant mean wind speed, refer to 6.3.3.3.3.

6.3.3.3.5 Extreme current model (ECM)

The extreme current model shall be considered for those ultimate load cases associated with extreme wave conditions (ESS). Currents associated with ESS shall result in combined global environmental actions with return periods of 1 year and 50 years and are denoted by U_1 and U_{50} , respectively. Load calculations shall be undertaken based on the currents which result in the highest loads acting on a FOWT.

These extreme values shall be determined from analysis of appropriate site-specific metocean data (i.e. measurements and/or hindcast data) for the FOWT site, refer to 6.4.4.

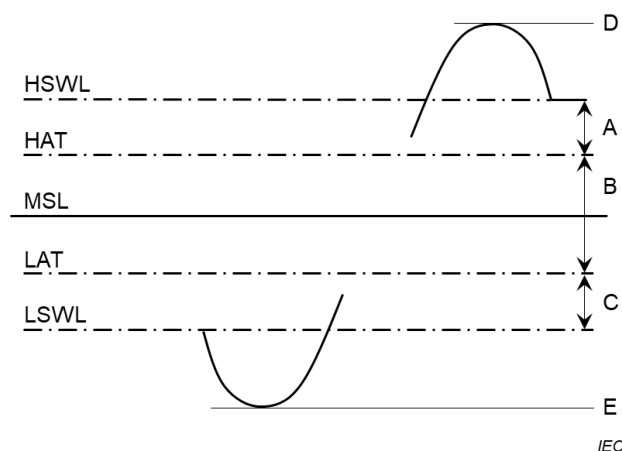
In the absence of information defining the long-term joint probability distribution of extremes it is conservative to apply currents with return period of 1 year and 50 years and to assume the current to be co-directional with the waves.

6.3.3.4 Water level

6.3.3.4.1 General

The water depth range shall be determined where relevant for FOWT design.

Different water levels are illustrated in Figure 4.



Key

HSWL	highest still water level	A	positive storm surge
HAT	highest astronomical tide	B	tidal range (equal to NWLR, see clause 6.3.3.4.2)
MSL	mean sea level	C	negative storm surge
LAT	lowest astronomical tide	D	maximum crest elevation
LSWL	lowest still water level	E	minimum trough elevation

Figure 4 – Definition of water levels

6.3.3.4.2 Normal water level range (NWLR)

The normal water level range shall be assumed equal to the long-term difference between highest astronomical tide (HAT) and lowest astronomical tide (LAT).

The NWLR shall be assumed for those fatigue and ultimate load cases involving the normal sea state model (NSS) based on the joint probability distribution of sea state conditions and wind speed (H_s , T_p , V_{hub}). The NWLR range shall also be assumed for ultimate load cases associated with

- severe sea state (SSS);
- wave conditions with a return period of 1 year.

Ultimate load calculations shall be undertaken based on either the water level within the NWLR that results in the highest loads, or by appropriate consideration of the probability distribution of water levels within the NWLR.

For ultimate load cases associated with the severe stochastic sea state (SSS) model, the water levels corresponding to NWLR may cause the wave heights to be depth-limited. If this is the case, and in order to avoid the wave heights being depth-limited, a higher water level within the extreme water level range (EWLR) shall then be assumed.

For the calculation of the hydrodynamic fatigue loads the designer may in some cases demonstrate by means of an appropriate analysis that the influence of water level variation on fatigue loads is negligible or can be accounted for in a conservative manner by assuming a constant water level greater than or equal to the mean sea level.

6.3.3.4.3 Extreme water level range (EWLR)

The extreme water level range shall be assumed for ultimate load cases associated with wave conditions with a return period of 50 years (ESS). Combination with ESS shall result in combined global environmental actions with a return period of 50 years. The designer may need to investigate a number of representations of the ESS combined with different water levels. Load calculations shall be undertaken based on the water levels which result in the highest loads acting on a FOWT. The relevant design driving water levels shall be determined for calculation of the hydrodynamic loading, ice loading and the buoyancy of the floating substructure.

In the absence of the long-term joint probability distribution of metocean parameters including water level, the designer shall at least undertake calculations based on the following water levels:

- highest still water level with a return period of 50 years, based on an appropriate combination of highest astronomical tide and positive storm surge;
- lowest still water level with a return period of 50 years, based on an appropriate combination of lowest astronomical tide and negative storm surge;
- water level associated with the highest breaking wave load.

6.3.3.5 Sea/lake ice

At some locations, loading of the floating substructure of a FOWT due to sea/lake ice can be critical. The ice loads may be associated with static loading from a fast ice cover, or dynamic loading caused by wind and current induced motion of ice floes. Moving ice floes impacting the floating substructure over a considerable period of time may result in significant fatigue loading. A site-specific assessment of the occurrence and properties of the sea/lake ice shall be undertaken as stated in 6.4.4.5.

6.3.3.6 Marine growth

Marine growth influences the mass, the geometry, and the surface roughness of the floating substructure and the stationkeeping and dynamic cable systems of a FOWT. Consequently, marine growth may influence hydrodynamic loads, dynamic response, accessibility and the rate of corrosion of the structure.

Marine growth may be considerable at some locations and shall be taken into account in the design of the FOWT support structure.

Marine growth is broadly divided into “hard” (generally animal such as mussels and barnacles) and “soft” (seaweeds and kelps), where hard growth is generally thinner but rougher than soft growth. Marine organisms generally colonize a structure soon after installation but the growth rate tapers off after a few years.

The nature and thickness of marine growth depends on the structural member’s position relative to the sea level, orientation relative to dominant current, age and maintenance strategy; but also on other site conditions such as salinity, oxygen content, pH value, current, and temperature.

The corrosion environment is normally modified by marine growth in the upper submerged zone and the lower part of the splash zone of the FOWT support structure. Depending on the type of marine growth and other local conditions, the net effect may be either to enhance or retard corrosion attack. Enhancement of corrosion processes by marine growth (e.g. through corrosive metabolites) is commonly referred to as Microbiologically Influenced Corrosion (MIC). Marine growth may further interfere with systems for corrosion control, including coatings/linings and cathodic protection.

Due to the uncertainties involved in assumptions regarding marine growth, a strategy for inspection and possible removal of marine growth should be planned as part of the FOWT design. The frequency, inspection method and growth removal criteria shall be based on the impact of marine growth on the structural reliability of a FOWT, and the extent of experience with marine growth under the specific conditions prevailing at the site.

6.3.3.7 Seabed movement and scour

The anchors of a FOWT shall be designed taking account of the influence of seabed movement and scour. The analysis of seabed movement and scour, and the design of appropriate protection shall conform to the requirements of ISO 19901-4 and ISO 19901-7. Requirements regarding the assessment of seabed conditions are stated in 6.4.4.7.

6.3.4 Electrical power network conditions

The conditions at the FOWT terminals are to be determined for the specific installation as described in 6.4.6.

6.3.5 Other environmental conditions

Environmental (climatic) conditions other than wind and marine conditions can affect the integrity and safety of a FOWT, by thermal, photochemical, corrosive, mechanical, electrical or other physical action. Moreover, combinations of the climatic parameters may increase their effects.

The following other environmental conditions shall at least be taken into account and the action taken stated in the design documentation:

- air temperature;
- humidity;
- air density;
- solar radiation;
- rain, hail, snow and ice;
- ice and snow accumulation;
- chemically active substances;

- 1038 • mechanically active particles;
- 1039 • salinity causing corrosion;
- 1040 • lightning;
- 1041 • seismicity causing earthquakes and/or tsunamis;
- 1042 • water density;
- 1043 • water temperature.

1044 The climatic conditions taken into account shall be defined in terms of either representative
1045 values or limits of the variable conditions. The probability of simultaneous occurrence of climatic
1046 conditions shall be taken into account when the design values are selected.

1047 Variations in the climatic conditions within the normal limits which correspond to a 1-year return
1048 period, or more often, shall not interfere with the designed normal operation of a FOWT.

1049 Unless correlation exists, other extreme environmental conditions according to 6.4.5.3 shall be
1050 combined with the normal wind conditions according to IEC 61400-1 and normal marine
1051 conditions according to 6.3.3.

1052 Specific attention should be paid to the assessment of the seismic analysis in the case of
1053 TLP/TLB-type floating substructures, see Annex I.

1054 **6.4 Assessment of external conditions at a FOWT site**

1055 **6.4.1 General**

1056 The external conditions at a FOWT site shall be assessed as the basis of design and/or design
1057 verification in accordance with the requirements of the following subclauses.

1058 The partial safety factors for loads referenced in 7.6.2.2 assume that the site assessment of
1059 the normal and extreme metocean conditions has been carried out according to the minimum
1060 requirements of this Clause 6.4.

1061 **6.4.2 The metocean database**

1062 A site-specific metocean database shall be established containing information on

- 1063 • wind speeds and directions;
- 1064 • significant wave heights, wave periods and directions;
- 1065 • correlation of wind and wave statistics;
- 1066 • current speeds and directions;
- 1067 • water levels;
- 1068 • occurrence and properties of sea/lake ice and occurrence of their drift directions and drift
1069 speeds;
- 1070 • occurrence of icing of the turbine and its FOWT support structure;
- 1071 • other relevant metocean parameters such as air and water temperatures and densities,
1072 water salinity, site bathymetry, marine growth, etc.

1073 The database may be established from site-specific measurements supported, where
1074 appropriate, by numerical simulations (hindcasts). If site-specific measurements are used, the
1075 results shall generally be correlated with data from a nearby location for which long-term
1076 measurements exist, unless the results can otherwise be shown to be conservative. The
1077 monitoring period for the site-specific measurements shall be sufficient to ensure reliable
1078 statistics for the individual parameters as well as the joint probability distribution of these

parameters⁵. Long-term site-specific measurements shall not generally be required when correlation with suitable long-term data from a nearby location is undertaken or when numerical tools can be reliably applied for transposing the long-term data to the wind turbine site.

Time series measurements may be of particular importance in order to characterise wave heights, periods and wave spectra at shallow water sites.

When assessing the quality and quantity of data, special attention should be given to the adequacy of the data with respect to extrapolation to very infrequent events.

6.4.3 Assessment of wind conditions

6.4.3.1 General

The site wind parameters shall be either measured and extrapolated, or calculated using appropriate methods (e.g. monitoring measurements made at the site, long-term records from local meteorological stations, simulation models or local codes and standards). The methods described in 11.3 of IEC 61400-1 and IEC 61400-15-1 apply with the deviations specified below.

Values of the following parameters shall be estimated at the wind turbine site in addition to those specified in IEC 61400-1:

- extreme 10-min average wind speed $V_{1, \text{hub}}$ at hub height with a return period of 1 year;
- wind speed standard deviation $\hat{\sigma}$ from the ambient turbulence (estimated as the mean value of the standard deviation of the longitudinal component) and the standard deviation $\hat{\sigma}_\sigma$ of $\hat{\sigma}$ at V_{hub} between V_{in} and V_{out} and V_{hub} equal to V_{ref} .

High values of wind shear have been reported for extended periods of time for certain areas in connection with highly stratified flow or severe roughness changes. However, for the gust models which employ the mean wind profile (i.e. EOG, ECD, EWS as defined in IEC 61400-1) the shear may be assumed equal to the mean wind shear. This is justified because these models are concerned with gusts generated by turbulence, which implies that shear values associated with high turbulence levels are appropriate.

The interval of any wind speed bin used in the above shall be 2 m/s or less, and the wind direction sectors shall be 30° or less. IEC 61400-1 requires that all parameters, except for air density, be available as functions of wind direction and given as 10-min averages. Because the offshore environment generally exhibits less directional variation than the onshore environment, providing omnidirectional information for parameters such as shear and turbulence is acceptable unless precluded by coastal effects for near-shore sites or nearby obstacles.

The site extreme wind parameters shall be either:

- measured in the range of 0,2 V_{ref} to 0,4 V_{ref} and extrapolated, or
- derived from a correlation analysis of short-term monitoring measurements made at the site and long-term records from local meteorological stations, or from local codes or standards, or
- based on experience of nearby sites. In this case the assumption of similarity between the sites is to be justified.

⁵ If only correlation analysis of measured data is to be undertaken, the location of the long-term measurements should be less than 50 km from the prospective FOWT site and the water depth, the fetch and the bathymetry should be similar at the two locations. When correlating the long-term data with the wind turbine site-specific short term data, care should be taken that the correlation is adequate and that the uncertainty of the correlation analysis can be estimated. Should the location of the long-term measurements be more than 50 km from the prospective wind turbine site, it is advisable also to undertake numerical simulations (hindcasts) to estimate the site's metocean statistics.

Where site-specific extreme average wind speeds are available only for averaging periods longer than 10 min, the conversion factors stated in Table 1 may be used to estimate the extreme 10-min average wind speed. The factors in this table give the ratio between the extreme wind speed for a given averaging period and the extreme 10-min average wind speed.

Table 1 – Conversion between extreme wind speeds of different averaging periods

Averaging period	10 min	1 h	3 h
Correction factor relative to extreme 10-min average wind speed	1,00	0,95	0,90

1123

The long-term probability distribution of mean wind speed, V_{hub} , may be assumed to be independent of averaging period for periods in the range between 10 min and 3 h⁶.

6.4.3.2 IEC 61400-1 wind conditions applied to rotor-nacelle assembly design

In the case that the wind conditions specified in IEC 61400-1 are used as the basis of design of the rotor–nacelle assembly, the following variations to the parameter values may be assumed:

- the inclination of the mean flow with respect to a horizontal plane is zero;
- the wind profile, $V(z)$, denotes the average wind speed as a function of height, z , above the still water level. In the case of standard wind turbine classes, the normal wind speed profile is given by the power law:

$$V(z) = V_{\text{hub}} (z/z_{\text{hub}})^{\alpha} \quad (6)$$

1133

where, for normal wind conditions, the power law exponent, α , is 0,14.

6.4.3.3 Assessment of ambient free stream turbulence

The value of the ambient free stream turbulence standard deviation shall be determined using appropriate statistical techniques applied to measured and preferably de-trended data. Where topographical (shore line) or other local effects may influence the turbulence intensity, these effects shall be represented in the data. The characteristics of the anemometer, sampling rate and averaging time used to obtain measured data shall be taken into account when evaluating the turbulence intensity.

Where no site data for turbulence is available, the turbulence standard deviation σ_1 may be estimated using the surface roughness parameter z_0 derived from the Charnock expression for atmospheric conditions that are near-neutral:

$$z_0 = \frac{A_C}{g} \left[\frac{\kappa \cdot V_{\text{hub}}}{\ln(z_{\text{hub}}/z_0)} \right]^2 \quad (7)$$

1145

where

g is the acceleration due to gravity;

κ 0,4 is von Karman's constant, and

A_C is Charnock's constant.

⁶ This assumption may not be valid at the tail of long-term probability distribution, for mean wind speeds exceeding V_{out} .

1150 A_C 0,011 is recommended for open sea and $A_C = 0,034$ may be used for near-coastal
1151 locations⁷.

1152 The roughness of the sea surface increases with wind speed and thus the turbulence intensity
1153 will increase as a function of wind speed in near-neutral conditions. At many offshore sites, it
1154 has been found that average turbulence intensity offshore is high at low wind speeds, decreases
1155 to a minimum at wind speeds of approximately 8 to 12 ms⁻¹ (at 10 m reference height) and then
1156 increases slowly with increasing wind speed.

1157 The roughness parameter is found by solving the above implicit equation and, in turn, the
1158 standard deviation of the longitudinal wind speed component may be calculated from

$$\sigma_1 = \frac{V_{\text{hub}}}{\ln(z_{\text{hub}}/z_0)} + 1,28 \times d \times I_{15} \quad d = 4 \text{ m/s} \quad (8)$$

1159

1160 where I_{15} is the average value of hub height turbulence intensity determined at $V_{\text{hub}} = 15 \text{ m/s}$.
1161 The use of the assumption of near-neutral conditions (as equation (7)) will, in general, give low
1162 average values for the standard deviation of the longitudinal wind speed component and is not
1163 valid for representing tropical cyclone conditions.⁸

1164 Models accounting for non-neutral atmospheric conditions offshore have been proposed. The
1165 models in "H. Wang, R. J. Barthelmie, S. C. Pryor and H. G. Kim, *A new turbulence model for*
1166 *offshore wind turbine standards*, Wind Energy, Volume 17, Issue 10, pages 1587–1604, October
1167 2014" may be applied if no other information is available. They represent three different levels
1168 of turbulence spanning the range from far offshore to very near-shore with complex terrain
1169 onshore. Care shall be taken when justifying the level to adopt.

1170 In the absence of suitable site-specific data to estimate the turbulence standard deviation with
1171 a 1-hour averaging period, this may be assumed to be related to the 10-min average turbulence
1172 standard deviation by

$$\sigma_{i,1\text{-hour}} = \sigma_{i,10\text{-min}} + b; \quad b = 0,2 \text{ m/s} \quad (9)$$

1173

1174 6.4.3.4 Assessment of wake effects from neighbouring wind turbines

1175 The assessment of wake effects from neighbouring wind turbines shall be undertaken in
1176 accordance with the requirements stated in IEC 61400-1. Guidance is provided in
1177 IEC 61400-1, Annex E, regarding site-specific conditions.

1178 6.4.4 Assessment of marine conditions

1179 6.4.4.1 Assessment of extreme wave conditions

1180 The following extreme sea state parameters shall be estimated:

⁷ The surface roughness parameter and resulting turbulence standard deviation calculated using the Charnock equation apply for open sea conditions. Care should be taken in cases where the influence of shore topology and onshore roughness may lead to higher values of turbulence standard deviation. Use of the higher value of the coefficient is recommended unless site specific data confirm otherwise.

⁸ The standard deviation $4\text{m/s} \times I_{15}$ in equation (8) differs from $1,44\text{m/s} \times I_{15}$ specified in IEC 61400-1 because significantly larger standard deviations have been recorded at some offshore locations. Hence, this parameter should be carefully evaluated for the specific site, accounting for available information from similar or neighbouring sites. Further, the specification of Weibull-distributed turbulence intensity in the IEC 61400-1 class definition is not generally valid offshore, which influences the assessment of ETM.

- 1181 • the significant wave height with a return period of 50 years assuming a 3-hour reference
1182 period, $H_{s,50}$;
- 1183 • the significant wave height with a return period of 1 year assuming a 3-hour reference period,
1184 $H_{s,1}$;
- 1185 • the extreme individual wave height with a return period of 50 years, H_{50} and the associated
1186 range of wave periods;
- 1187 • the extreme individual wave height with a return period of 1 year, H_1 and the associated
1188 range of wave periods;
- 1189 • the extreme crest height with a return period of 50 years.

1190 The extreme significant wave height and the extreme individual wave height may be determined
1191 in several ways. The most appropriate approach is based on statistical analysis of peak storm
1192 significant wave heights of the metocean database above a certain threshold. The extreme
1193 individual wave heights may be established by convolution of the long-term distribution of the
1194 significant wave height H_s and peak spectral period T_p , with the conditional short term
1195 distribution of individual wave height H given the significant wave height H_s . Reference is made
1196 to ISO 19901-1. The extreme wave heights may, however, be limited by water depth.

1197 Breaking waves may occur at the site of a FOWT depending on the water depth, sea floor slope,
1198 wave height, period and steepness. Based on an assessment of these parameters, the guidance
1199 provided in Annex B may be followed to determine the nature and dimensions of breaking waves
1200 based on site conditions. This informative annex also presents an empirical model of the
1201 distribution of wave heights in shallow water areas.

1202 Annex G provides guidance on assessment of extreme wave conditions during tropical cyclone
1203 conditions.

1204 In the case that the metocean data is insufficient to assess the extreme wave height and the
1205 range of associated wave periods, for deep water it may be assumed that:

$$H = 1,86 H_s \quad (10)$$

1206

1207 which is obtained as the most probable maximum wave in a 3-hour reference period sea-state
1208 with significant wave height H_s assuming a Rayleigh distribution of wave heights and
1209 1 000 waves, i.e. the 0,1 % exceedance quantile of the Rayleigh distribution. Associated with
1210 this wave height, the following wave period range can be applied

$$11,1 \sqrt{H_s/g} \leq T \leq 14,3 \sqrt{H_s/g} \quad (11)$$

1211

1212 It should be noted that the equation above is the relation for wind generated waves. A FOWT
1213 may be installed at sites where swell dominates. In such sites, longer periods than the value
1214 specified in equation (11) may be observed. For details, see Annex T.

1215 For a given wave height, the wave period has a depth-dependent lower limit which is determined
1216 from the breaking wave height limit, refer to Annex B. Note that in deep water the ratios H_{50}/H_{s50}
1217 and H_1/H_{s1} are usually in the range 1,9 to 2,0. For shallow water sites where measurements
1218 are not available, H_{50} and H_1 shall be assumed equal to the breaking wave height in cases
1219 where the latter is less than 2,0 times the value of the appropriate H_s .

1220 6.4.4.2 Assessment of normal wave conditions

1221 For the normal sea states, the site-specific metocean database shall be analysed in order to
1222 establish the long-term joint probability distribution of the following parameters:

- 1223 • mean wind speed at hub height, V_{hub} ;
- 1224 • significant wave height, H_s ;
- 1225 • peak spectral period, T_p .

1226 Note that this is a minimum requirement and in the case where the use of standard wave
1227 spectrum is not appropriate, more wave parameters or discrete wave spectrum including two
1228 dimensional spectrum of frequency and direction may be considered. For example, in case swell
1229 and wind-induced wave are both dominant and spectrum with two peak is used for design,
1230 additional parameters are needed.

1231 In 6.3.3.2.2 defining NSS a 1-hour averaging period is required for the establishment of the
1232 long-term joint probability distribution of V_{hub} , H_s , and T_p . If the available joint statistical data
1233 for V_{hub} , H_s , and T_p are based on a different averaging period, the data shall be converted to
1234 be based on a 1-hour averaging period for the wind speed. The correlation between V_{hub} , H_s ,
1235 and T_p may increase with a longer averaging period because the build-up of waves under the
1236 influence of wind happens over a period of hours. However, depending on the specific
1237 characteristics of the site, the correlation may not change significantly with the averaging period
1238 and therefore it may be reasonable to assume that the long-term joint probability distribution of
1239 V_{hub} , H_s and T_p is independent of averaging period.

1240 If necessary, the joint probability distribution shall be extended to include wind and wave
1241 directions although site-specific measurements allowing the derivation of the joint occurrence
1242 of these five parameters are often not available⁹. The resolution of the joint probability
1243 distribution shall be such that the interval of any wind speed bin shall be 2 m/s or less, the
1244 interval of any significant wave height bin shall be 0,5 m or less, and the interval of any wave
1245 period bin shall be 0,5 s or less. The intervals of significant wave height and wave period bins
1246 may be increased if the calculated fatigue loads are not less conservative; this may be
1247 demonstrated using appropriate representative values. If directional data are available, the
1248 widths of wind and wave direction sectors shall be 30° or less.

1249 There is no requirement for assessment of site-specific wave spectra and directional spreading
1250 and the standard formulations provided in ISO 19901-1 may be assumed. Where appropriate
1251 and reliable measurements exist, site-specific wave spectra and the directional spreading
1252 function may, however, be assessed as the basis of design and/or design verification of a FOWT.

1253 **6.4.4.3 Assessment of currents**

1254 In addition to their impact on the loading of the support structure of a FOWT, currents affect the
1255 location and orientation of boat landings and fenders and may create seabed scouring.

1256 Sea currents shall be assessed taking into account components associated with tidal, storm
1257 surge, wind-generated currents and ocean currents, where these are relevant to the wind
1258 turbine site. The velocity and directional characteristics of each significant component of sea
1259 current at the site shall be separately assessed.

1260 Extreme sea surface current velocities having 1 year and 50 year return periods shall be
1261 determined from analysis of the site-specific metocean database.

1262 There is no requirement for assessment of site-specific variation of current velocity with depth
1263 and the standard profiles provided in 6.3.3.3 may be assumed. Where appropriate and reliable
1264 measurements exist, site-specific current profiles may, however, be assessed as the basis of
1265 design and/or design verification of a FOWT.

⁹ It should be noted that an assumption of co-directionality of wind and waves may not be conservative for sites where large misalignment between wind and wave directions is common.

6.4.4.4 Assessment of water level, tides and storm surges

The mean and fluctuation in water level at the wind turbine site shall be assessed in order to determine the following parameters:

- mean sea level (MSL);
- highest astronomical tide (HAT) and lowest astronomical tide (LAT);
- highest still water level (HSWL) including positive storm surge;
- lowest still water level (LSWL) including negative storm surge.

These parameters shall be determined from the site-specific metocean database. Accurate estimates of storm surge require a long data set. Long-term measurements or hindcasts available from a nearby location may be used together with correlation techniques to derive the site-specific storm surge characteristics.

6.4.4.5 Assessment of sea/lake ice

At sites where ice is expected to occur, its physical properties shall be taken into consideration for the design of support structures of FOWT.

The site-specific properties of the ice should be described in the design documentation.

There are several parameters to be assessed, some of which can be measured, others calculated from empirical formulae and others determined from sources of historical data such as ice atlases.

The most relevant parameters are listed below:

- sheet ice thickness with a 50-year return period, h_{50} ;
- the dimensions of thick ice features of finite extent (such as ridges) entrained within the ice which may interact with the structure, including the consolidated layer thickness h_c , with a 50-year return period;
- ice strength coefficient C_R ;
- ice density;
- current speed at 1 m below ice lower surface;
- wind speed at 10 m above surface, acting on the ice sheets and ridges;
- water level fluctuation;
- water salinity;
- water density;
- air density;
- freezing degree-days;
- wind drag coefficient C_W ;
- current drag coefficient C_C ;
- frequency of ice concentrations.

6.4.4.6 Assessment of marine growth

The thickness of marine growth and its dependence on depth below sea level shall be assessed based on applicable recommendations, local experience and existing measurements. Site-

specific studies may be necessary to establish the nature, likely thickness and depth dependence of marine growth¹⁰.

6.4.4.7 Assessment of seabed movement and scour

The stability of the seabed shall be assessed. It shall be determined whether the bathymetry and soil configuration at the site require consideration of the possibility of slope failure, slides, cavity failure or erosion phenomena. Settlement and soil liquefaction shall in general be taken into account for the design of gravity base anchors.

Based on observations, sea floor variations can usually be characterised as a combination of the following:

- local scour characterised by steep sided scour pits around structural elements such as piles and pile groups when used as anchors;
- global scour characterised by shallow scoured basins of large extent around a structure, possibly caused by overall structure effects, multiple structure interaction, or wave-soil-structure interaction;
- overall seabed movement of sand waves, ridges and shoals which would occur in the absence of a structure. Such movements can result in the lowering or rising of the sea floor, or repeated cycles of these. The addition of man-made structures may change the local sediment transport regime which can aggravate erosion, cause accumulation, or have no effect.

Seabed movement and scour can result in removal of vertical and lateral support for anchors, causing undesirable settlements and displacements of shallow anchors, overstressing of anchor elements and change of the dynamic properties of the FOWT structure. Where scour is a possibility, it shall be taken into account in design and/or its mitigation shall be considered. In general, the assessments shall follow the procedures outlined in ISO 19901-4 Clauses 6.3.4 and 6.3.5.

The extent of scour and the required scour protection at the FOWT site shall be determined:

- on the basis of previous records from nearby sites or sites with similar sea floor characteristics;
- from model tests; or
- from calculations calibrated by prototype or model tests.

6.4.5 Assessment of other environmental conditions

6.4.5.1 General

The parameters specified in 6.3.5 shall be assessed.

6.4.5.2 Other normal environmental conditions

Normal values for the environmental parameters given below may be assumed as follows:

- ambient air temperature range of $-10\text{ }^{\circ}\text{C}$ to $+30\text{ }^{\circ}\text{C}$;
- relative humidity of up to 100 %;
- solar radiation intensity of $1\,000\text{ W/m}^2$;
- air density of $1,225\text{ kg/m}^3$;
- water density of $1\,025\text{ kg/m}^3$;

¹⁰ Information regarding marine growth is available for some areas (North Sea, Persian Gulf, West African coast, Gulf of Mexico, coast of California, East coast of Canada), refer to ISO 19901-1.

- 1344 • water temperature range of 0 °C to +30 °C.

1345 Where there are no site data for the air density, it shall be assumed that the air density is
1346 consistent with ISO 2533:1975, suitably corrected for annual average temperature.

1347 When additional external conditions are specified by the designer, the parameters and their
1348 values shall also be stated in the design documentation and shall conform to the requirements
1349 of IEC 60721-2-1.

1350 **6.4.5.3 Other extreme environmental conditions**

1351 **6.4.5.3.1 General**

1352 Other extreme environmental conditions that shall be considered for design of a FOWT include
1353 temperature, lightning, ice, and earthquakes.

1354 **6.4.5.3.2 Temperature**

1355 In the absence of site-specific data, the extreme ambient air temperature range for FOWTs may
1356 be assumed to be –15 °C to +40 °C.

1357 In the absence of site-specific data, the extreme water temperature range for FOWTs may be
1358 assumed to be –2 °C to +35 °C.

1359 **6.4.5.3.3 Lightning**

1360 Lightning strikes of FOWTs may be more frequent and more severe than onshore. The
1361 provisions for lightning protection required in IEC 61400-24 may be considered as adequate for
1362 FOWTs .

1363 **6.4.5.3.4 Icing**

1364 No minimum ice requirements are given for FOWTs in the standard wind turbine classes. Ice
1365 build-up on the wind turbine parts shall be considered from

- 1366 • moisture and debris at temperatures around and below 0 °C;
- 1367 • spray of the wave crest at temperatures below 0 °C.

1368 **6.4.5.3.5 Earthquakes**

1369 Where relevant, assessment of earthquake conditions shall be performed; see Annex I.

1370 **6.4.6 Assessment of electrical network conditions**

1371 For the assessment of electrical network conditions reference is made to Clause 11.7 of
1372 IEC 61400-1. In the absence of site data, a loss of electrical connection for a continuous period
1373 of 3 months shall be considered to be the extreme condition.

1374 **6.4.7 Assessment of soil conditions**

1375 Soil investigations shall be performed to provide adequate information to characterise soil
1376 properties throughout the depth and area that will affect or be affected by the anchor. The
1377 investigations shall in general include the following:

- 1378 • geological survey of the site;
- 1379 • bathymetric survey of the sea floor including registration of boulders, sand waves or
1380 obstructions on the sea floor;
- 1381 • geophysical investigation;
- 1382 • geotechnical investigations consisting of in-situ testing and laboratory tests.

1383 In order to develop the required anchor design parameters, data obtained during the
1384 investigations shall be considered in combination with an evaluation of the shallow geology of
1385 the region, if available. If practical, the soil sampling and testing program should be defined
1386 after reviewing the geophysical results.

1387 Soil investigations shall include one or more soil borings to provide soil samples for in-situ tests
1388 and laboratory tests to determine data suitable for definition of engineering properties. The
1389 number and depths of borings required shall depend on the number and location of wind turbine
1390 anchors in the offshore wind farm, the soil variability in the vicinity of the site, the type of anchor,
1391 and the results of any preliminary geophysical investigations. In a large offshore wind farm,
1392 sampling boreholes for at least 10% of the total anchor locations should be collected. Cone
1393 penetration tests (CPT) and shallow vibro-core borings may be used to supplement soil borings
1394 in the soil investigation. Site-specific soil data shall in principle be established for each anchor
1395 within the wind farm. CPTs may be used for this purpose at wind turbine locations where soil
1396 boring is not undertaken. For calibration of the CPTs, one CPT shall be performed in the vicinity
1397 of one of the soil borings.

1398 The soil investigation shall provide the following data as the basis of the anchor design:

- 1399 • data for soil classification and description of the soil;
- 1400 • shear strength parameters, including soil degradation effects if relevant for the anchor type;
- 1401 • deformation properties, including consolidation parameters if relevant for the anchor type;
- 1402 • permeability, if relevant for the anchor type;
- 1403 • stiffness and damping parameters for prediction of the dynamic properties of the FOWT, if
1404 relevant for the anchor type.

1405 For each soil layer, these engineering properties shall be thoroughly evaluated by means of
1406 appropriate in situ and laboratory testing.

1407 The assessment of soil conditions shall also consider the potential for soil liquefaction, long-
1408 term settlement and displacement of the anchor as well as the surrounding soil, hydraulic
1409 stability and soil stability characteristics.

1410 **7 Structural design**

1411 **7.1 General**

1412 The FOWT shall be designed in accordance with this clause. Additional requirements relevant
1413 to the design of floating substructures shall follow ISO 19904-1.

1414 The stationkeeping system shall be designed per Clause 14.

1415 The integrity of the load-carrying components of a FOWT structure shall be verified and an
1416 acceptable safety level shall be ascertained. The ultimate and fatigue strength of structural
1417 members shall be verified by calculations, tests or both to demonstrate the structural integrity
1418 of a FOWT with the appropriate safety level.

1419 Calculations shall be performed using appropriate methods. Descriptions of the calculation
1420 methods shall be provided in the design documentation. The descriptions shall include evidence
1421 of the validity of the calculation methods or references to suitable verification studies. The load
1422 level in any test for strength verification shall correspond with the safety factors appropriate for
1423 the characteristic loads according to 7.6.

1424 FOWT support structure, rotor, and drive train resonances shall be identified for the frequency
1425 range up to and including 2 times the blade passing frequency excitation. Possible resonances
1426 shall be investigated at turbulence levels of 30 % of the NTM class C design turbulence for DLC

1427 1.2. If high resonant loads are found at low turbulence, means shall be taken to avoid the
1428 resonances or they shall be included in the design loads.

1429 **7.2 Design methodology**

1430 It shall be verified that limit states are not exceeded for the FOWT design.

1431 The design calculations shall be based on validated methods and recognised codes.

1432 **7.3 Loads**

1433 **7.3.1 General**

1434 Loads described in 7.3.2 through 7.3.7, shall be considered for the design calculations.

1435 **7.3.2 Gravitational and inertial loads**

1436 Gravitational and inertial loads are static and dynamic loads resulting from gravity, vibration,
1437 rotation and seismic activity.

1438 Inertial loads, including gyroscopic loads, are of special importance to FOWTs due to their
1439 potentially additional compliance and increased dynamic response from aerodynamic and
1440 hydrodynamic loading.

1441 **7.3.3 Aerodynamic loads**

1442 Aerodynamic loads are static and dynamic loads that are caused by the airflow and its
1443 interaction with the stationary and moving parts of wind turbines.

1444 The airflow is dependent upon the average wind speed and turbulence across the rotor plane,
1445 the rotational speed of the rotor, the density of the air, and the aerodynamic shapes of the wind
1446 turbine components and their interactive effects, including aeroelastic effects.

1447 The aerodynamic interaction between the airflow and the FOWT is of special importance due
1448 to their additional compliance and increased dynamic response. The interaction of potentially
1449 large translational and rotational motions of the floating substructure with the aerodynamic
1450 loading of the RNA and tower shall be considered, including aeroelastic effects and the
1451 associated global and local dynamic and unsteady aerodynamic effects (e.g. dynamic inflow,
1452 oblique inflow, skewed wake, unsteady airfoil aerodynamics including dynamic stall, blade-
1453 vortex interaction). Wind loads on the floating substructure shall also be considered, where
1454 relevant.

1455 **7.3.4 Actuation loads**

1456 Actuation loads result from the operation and control of FOWTs. They are in several categories
1457 including torque control from a generator/inverter, nacelle yaw and blade pitch actuator loads
1458 and mechanical braking loads. In each case, it is important in the calculation of response and
1459 loading to consider the range of actuator forces available, including friction. In particular, for
1460 mechanical brakes, the range of friction, spring force or pressure as influenced by temperature
1461 and ageing shall be taken into account in checking the response and the loading during any
1462 braking event.

1463 **7.3.5 Hydrodynamic loads**

1464 Hydrodynamic loads are dynamic loads which are caused by the water flow and its interaction
1465 with the support structure of a FOWT.

1466 The hydrodynamic loads are dependent on the kinematics of the water flow, the density of the
1467 water, the depth of the water, the shape of the floating substructure and their interactive effects,
1468 including hydroelastic effects.

1469 When currents are included in design evaluations, the convective acceleration of the fluid with
1470 current can also affect the fluid-inertial loading of the floating substructure.

1471 Positive air gap shall be documented for the primary parts of a FOWT support structure that are
1472 not designed to be exposed to hydrodynamic loads. Sufficient air gap for the lowest point of the
1473 wind turbine blades shall also be evaluated. The air gap assessment shall capture the response
1474 with a 50-year return period. The motion of the floater shall be accounted for in the assessment
1475 in addition to the asymmetry of the wave, effect of diffraction/radiation and still water level.
1476 Recognized and calibrated methods for assessment of air gap is developed and can be used if
1477 proven valid (see Annex C). The selected methods should be supported by appropriate model
1478 tests. Air gap can alternatively be estimated directly based on the DLC load cases table (Table
1479 2). The air gap for the alternative method should be greater than or equal to $0,2 \times H_{s50}$, with a
1480 minimum value of 1,5 m. The following steps can be used to assess the air gap for the
1481 alternative method:

- 1482 • Find the maximum response (upwell) from the response time series for each realization
1483 (seed) of a given wave/wind/directionality condition
- 1484 • Calculate the mean value of all the maximum responses determined from using different
1485 realizations for the same wave/wind/directionality condition
- 1486 • Find the largest mean value across all the wind/wave/directionality conditions assessed
- 1487 • Assess the air gap based on the estimated upwell

1488 For sites where the extreme conditions are due to tropical cyclones, regional guidelines for
1489 determining the air gap shall be considered.

1490 Hydrodynamic loads arising from wave “run-up” should be considered, particularly for the
1491 design of external platforms and appurtenances. The wave run-up is principally affected by the
1492 geometry of the structure, wave height, and wave steepness and is typically determined through
1493 model tests.

1494 Additionally, strength for wave impact load including slamming and slapping (refer to Annex C
1495 for definitions), sloshing and green water in accordance with ISO 19904-1 should be assessed
1496 where relevant. For the sake of clarity, note that within ISO 19904-1 both the present “slam”
1497 and “slap” loads fall under the category of “slamming”.

1498 **7.3.6 Sea/lake ice loads**

1499 Sea/lake ice loading shall be considered, where relevant. See clause 7.5.4.

1500 **7.3.7 Other loads**

1501 Other loads such as wake loads, vessel impact loads, vortex-induced vibrations, etc., may occur
1502 and shall be included where appropriate. For other loads associated with cold climate, see
1503 IEC 61400-1, Clause 14 and Annex L.

1504 Wake effects from neighbouring FOWTs during power production shall be considered for all
1505 relevant ambient wind speeds and directions. The assessment of the suitability of a FOWT at a
1506 site in an offshore wind farm shall take into account the deterministic and turbulent flow
1507 characteristics associated with single or multiple wakes from upwind machines. The following
1508 effects should be considered on the structure, recovery, and geometric extent of upstream
1509 wakes:

- 1510 • variation in spacing between machines due to floating substructure motions;
- 1511 • static inclination and transient motions of the upwind machines in all degrees of freedom.

1512 The wake behind a wind turbine introduces a wind velocity deficit that tends to meander plus
1513 additional turbulence from what is present in the natural free stream. When wakes from one or